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Space Sustainability Policies: Analysis of the Current Economic Impact and Future Perspectives

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Abstract

In recent years, sustainability matters have gained increasing importance in several sectors. As evidenced by the increasing number of policy instruments lately implemented to address space sustainability, particularly concerning the space debris problem, the space industry is no exception. However, the effort invested in tackling space sustainability issues through regulatory instruments is not matched by an equivalent commitment to understanding the economic impact of these measures on the space industry. Furthermore, the current policy framework for space sustainability relies on vague and outdated hard laws and fragmented soft laws, resulting in weak enforceability and limited effectiveness.

This thesis evaluates the economic impact of the current policy framework for space sustainability on the space industry through three different case studies analyzing the financial effect on satellite manufacturers, in-space service providers, and space start-ups. Using a combination of literature reviews and online questionnaires, the economic impact is evaluated from the perspective of scholars, industry stakeholders, policy experts, and policy-makers, to ensure a comprehensive analysis of the topic. Furthermore, this work examines the current international and national policies, highlighting their major deficiencies in facing space sustainability issues. Subsequently, it presents the proposal for a new regulatory framework for space sustainability addressing these shortcomings. The new policy framework is constructed based on the establishment of a United Nations sub-agency that acts as a clarifying entity in charge of issuing international space hard laws for space sustainability. This new set of regulations comprises an official legal definition of space debris, policy mechanisms to address the liability problem, incentives for active debris removal activities, and instruments to sustain space companies in the sustainability transition.

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Acronyms

ADR

Active Debris Removal. 6, 10, 20, 22, 42–45, 58, 60–62, 65, 66

ASI

Italian Space Agency. 28, 31

COPUOS

Committee on the Peaceful Uses of Outer Space. 11, 13–15, 18–20, 56, 57

ESA

European Space Agency. 4, 6, 7, 17, 25, 27, 28, 31, 34, 63

ESA BIC

European Space Agency Business Incubation Center. 26, 31, 33

ESPI

European Space Policy Institute. 34

EU

European Union. 17, 34

FCC

Federal Communications Commission. 18

GEO

Geostationary Earth Orbit. 5, 13, 15–17, 37

IADC

Inter-Agency space Debris Committee. 13, 15, 16, 18, 19

ISO

International Organization for Standardization. 13, 15, 16

ITU

International Telecommunication Union. 16

LEO

Low Earth Orbit. 5, 9, 13, 15, 17, 18, 27, 37, 38, 40

NASA

National Aeronautics and Space Administration. 27, 28, 34

OST

Outer Space Treaty. 11

R&D

Research and Development. 15, 28, 30, 32, 33, 37–39, 41, 43, 44, 49, 51, 63, 65, 67, 68, 70, 71, 73, 74

UN

United Nations. 1, 11, 13–15, 18–20, 56, 57

UNOOSA

United Nations Office for Outer Space Affairs. 4, 57

US

United States. 6, 8, 17, 18, 22, 25, 34

Chapter 1

Introduction

Over the past few years, sustainability has gradually emerged as a key performance indicator in several industrial sectors, reflecting the growing global awareness that economic growth must come along with environmental responsibility and long-term viability. Indeed, from industrial production to transportation and from the services sector to agriculture, sustainable practices to reduce ecological footprint and protect the Earth's ecosystems are increasingly integrated with industrial routines, and the space industry is no exception to this trend[1]. With the ongoing expansion of space activities, the critical importance of sustainability in ensuring the long-term viability of space operations has become evident.

Space sustainability is a wide-ranging and complex topic that touches on various aspects of space access, exploration, and operation. It includes the sustainability of access to space, the long-term viability of Earth's orbits, and the preservation of extraterrestrial environments, such as the lunar or the Martian one. This variety of elements highlights the need for a comprehensive approach to sustainability in space. In other words, effective governance of outer space is urgent to work towards a sustainable future in space, as the United Nations (UN) Secretary-General António Guterres declared in May 2023[2].

Anyway, even though space sustainability can be approached from various angles, current efforts are primarily concentrated on ensuring the sustainability of Earth's orbits. This focus stems from the growing threat posed by space debris, also known as space junk, which endangers future space missions[3]. Space debris travels at extremely high velocities, making even small fragments capable of causing severe damage to operational spacecraft and satellites. If left unaddressed, the increasing accumulation of debris could lead to cascading collisions, known as the Kessler Syndrome, ultimately rendering certain orbits unusable[4]. Furthermore, the extensive international and national efforts to formulate guidelines and recommendations for mitigating space debris generation further highlight the significant attention given to this issue[5]. Together with the international treaties drafted in the 1960s and the 1970s, this set of laws constitutes the policy framework for space sustainability. However, this framework presents several shortcomings, including a lack of binding regulations, unclear liability provisions, and insufficient incentives for active debris removal[6][7]. These gaps hinder the development of a truly effective and comprehensive approach to this question, limiting the ability to address long-term challenges in space sustainability.

Furthermore, even if the commitment to developing policy instruments capable of safeguarding the orbital environment is considerable, there is a noticeably smaller effort dedicated to understanding the economic impacts such instruments may have on the space industry. Since the guidelines of the latest space debris mitigation instruments suggest the formulation of a stricter regulatory landscape in the future, it is essential to work for balance so that industry growth is not stifled, for example, by excessively increasing the amount of resources needed to develop the required space solutions[5]. Moreover, rigid guidelines will certainly modify the way of conducting business for space companies and, therefore, inevitably impact their financial statements. For example, since debris collisions with satellites are one of the major sources of space junk generation, satellite manufacturers are inevitably the target of guidelines and regulations, which aim to minimize debris creation during satellite operations[5]. Consequently, the economic impact on satellite manufacturers is significant. Furthermore, the in-space servicing sector is deeply affected by the regulatory framework for space sustainability as well. Indeed, ensuring space sustainability requires critical activities such as satellite maintenance, repair, refueling, and debris removal, and, thus, space sustainability policies are crucial to incentivize and sustain this sector[8][9]. Finally, also space start-ups face substantial consequences. The space sector is an extremely capital-intensive industry, given the innovativeness and expensiveness of its technologies, and this is already an important barrier to entry for new ventures[10]. In addition, regulations and guidelines requiring higher upfront investments to develop more efficient technologies, certainly worsen the situation. For all these reasons, a specific and exhaustive policy framework for space sustainability able to guide the transition towards a sustainable space without hindering the growth of the space industry is urgent[11].

Therefore, this thesis aims to contribute to closing this knowledge gap by examining the economic impact of the current policy framework for space sustainability and to help find a direction for effective framework development. This is carried out through a profound literature analysis and the analysis of three different case studies, as presented in Chapter 3. The bibliographic review is presented in Chapter 2, where the state-of-the-art policy instruments for space sustainability will be illustrated and analyzed, highlighting their major shortcomings, and considering all the major actors in this field. Moreover, the case study analyses combine the results of an interview conducted with industry players, with a specific literature review. The first case study explores in Chapter 4 the impact on a satellite value chain, investigating the design, production, and operation phases. The second case study analyzes in Chapter 5 the consequences on the emerging sector of in-space servicing. Lastly, in Chapter 6, the third case study examines the effect on the development and management of a start-up. Furthermore, to gain a balanced view on the topic, Chapter 7 investigates the perspective of policy experts and policy-makers. These analyses allow the formulation of a proposal to enhance the current sustainability regulations, considering framework gaps and interviewees' perspectives. Finally, the conclusion of this work on the current economic impact and the future perspectives of the policy framework for space sustainability will be shown in Chapter 9.

Chapter 2

Context

Following the global trend, sustainability of industrial activities has grown in relevance within the space sector lately[5]. Sustainability is now emerging as a critical priority in all development scenarios, as is easy to notice by observing the great number of recently developed policy instruments for space sustainability shown in Figure 2.1, such as the "Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space" by the United Nations Office for Outer Space Affairs (UNOOSA) in 2021 or the "Zero Debris Charter" by the European Space Agency (ESA) in 2023.

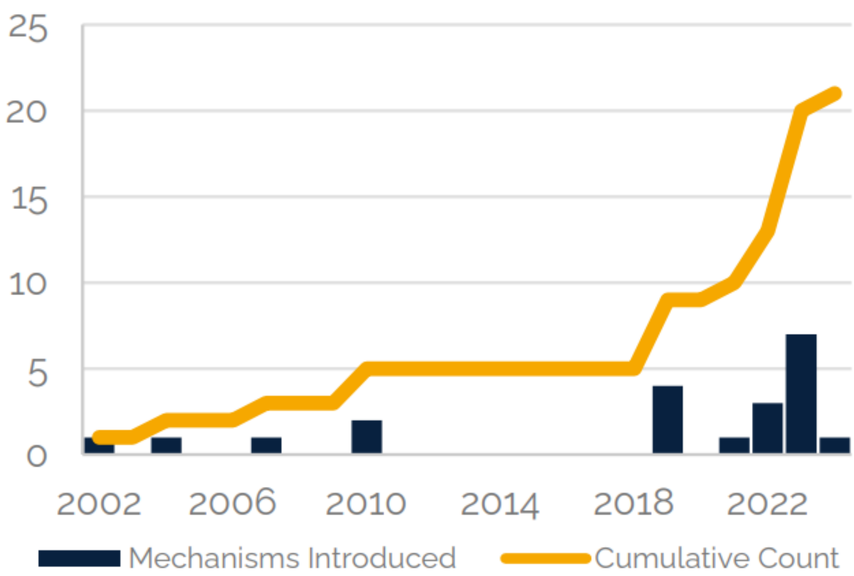


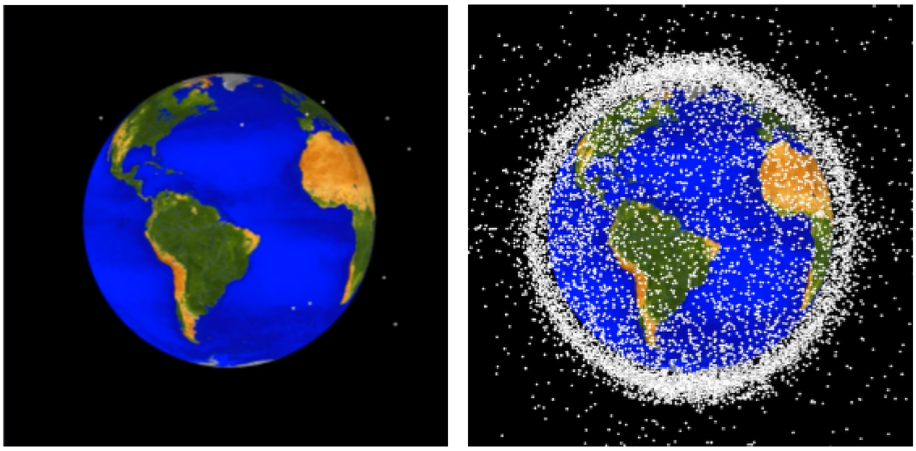
Figure 2.1: Evolution of international space debris mitigation instruments (excluding new releases of existing instruments)[5].

However, as of today, despite the different aspects of space sustainability, the majority of efforts have focused on the sustainability of Earth's orbits, especially the Low Earth Orbit (LEO) and the Geostationary Earth Orbit (GEO), because of the growing problem of space debris. Indeed, the accumulation of space debris, commonly defined as "all non-functional, human-made objects, including no longer functioning spacecraft or fragments of them, in orbit or reentering Earth's atmosphere"[12], poses a severe threat to future space operations. Due to the great increase in the number of satellites launched recently, the risk of collisions and the creation of new debris will become more and more significant in the next years, seriously endangering the orbital environment and everything in it. This undesirable future scenario would harm the entire global economy due to the essential role of the whole space infrastructure in every aspect of our lives, from communication and navigation to remote sensing and environmental control. For this reason, governments, international organizations, and private stakeholders are putting a lot of focus on drafting guidelines and creating policy tools for space debris mitigation[1].

The following sections illustrate why space junk is a significant issue and how space agencies, nations, and other industry players are more extensively dealing with this problem and other aspects of space sustainability.

2.1 The Space Debris Issue

As mentioned before, space debris is commonly defined as "all non-functional, human-made objects, including no longer functioning spacecraft or fragments of them, in orbit or reentering Earth's atmosphere"[12]. It can originate from several sources such as derelict spacecraft (non-functional spacecraft and abandoned launch vehicle stages), mission-related debris, and, particularly numerous in-Earth orbit, fragmentation debris from derelict rocket bodies and spacecraft breakup. In addition, space debris includes fragments from disintegration, erosion, or collisions, solidified liquids expelled from spacecraft, and unburned particles from solid rocket motors. Furthermore, thermal cycling and atomic oxygen corrosion acting on painted surfaces and thermal protective foils lead to the release of chips of coating material[13][14]. This space junk poses a significant threat to operational spacecraft, satellites, and the International Space Station, jeopardizing current and future missions due to the damage that a potential impact can cause to these spacecraft. As shown by Figure 2.2, since the start of the space age in 1957 the amount of space debris in Earth's orbit has deeply increased, as the number of satellite launches has continued to grow. Earth's space environment is now filled with millions of bits of fast-moving debris, threatening the future of humanity in space. In addition, more satellites have been launched in the last two years than in six decades of space



(a) (b)

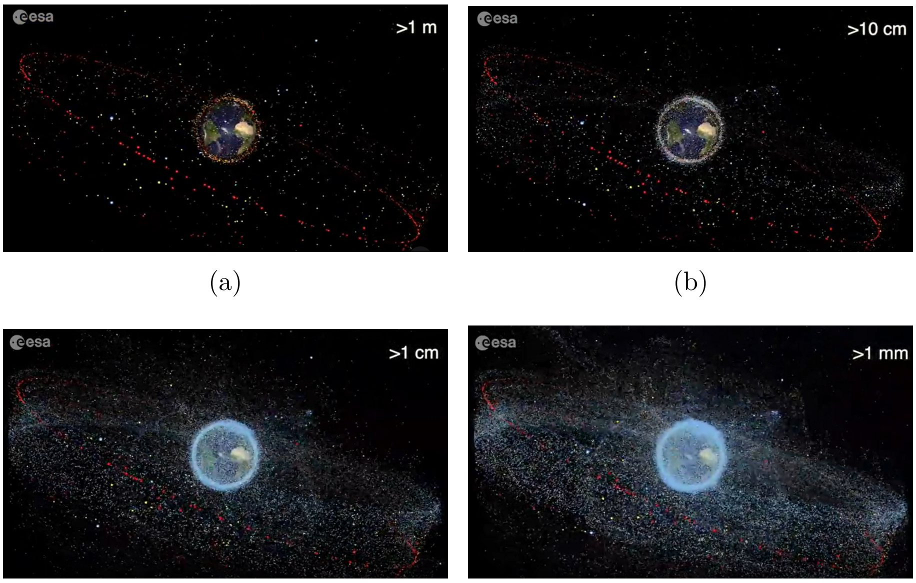
Figure 2.2: Difference between space debris bigger than 10 *cm* from 1960 (a) to 2019 (b)[15].

exploration, further worsening the situation. If current behaviors and trends in orbit continue, crucial orbital regions will become entirely unusable [12].

2.1.1 Space Debris in Numbers

Tracking space debris may not be so easy since some of them are extremely small. However, some institutions, like the United States (US) Space Command and ESA's Space Debris Office in Germany, are closely observing the situation. For example, the US Space Command recently measured the increase in space debris. Indeed, when it was established in 2019, the unit responsible for monitoring space traffic was tracking about 25,000 pieces of debris in orbit and, three years later, that number has risen to over 47,000[16].

In addition, as can be seen in Figure 2.3, ESA did some research, through the Space Debris Office, and determined the total mass of all space objects in Earth's orbits to be more than 13,000 tons. Furthermore, based on the statistical model MASTER-8, it estimated the presence of 40,500 space debris objects greater than 10 *cm*, 1,100,000 space debris objects from greater than 1 *cm* to 10 *cm*, and 130 million space debris objects from greater than 1 *mm* to 1 *cm*[18]. These numbers are already impressive but they are expected to grow significantly. According to several studies, the amount of space debris will increase considerably even if we stop launching objects in orbit today, causing a rise in the probability of collision and making mitigation guidelines and Active Debris Removal (ADR) techniques critically important[19][4].



(a) (b)

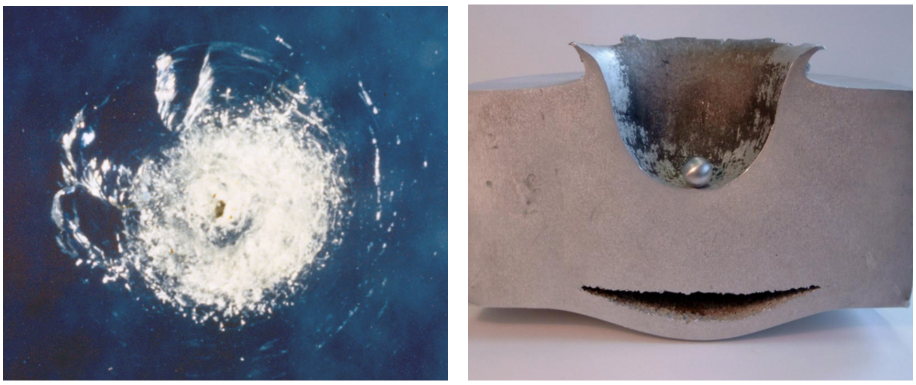
(c) (d)

Figure 2.3: Graphical representation of the distribution of space debris in orbit around Earth as 2019. Red: satellites (functional or dysfunctional); Yellow: rocket bodies: Green: mission-related objects (covers, caps, adapters, etc.); Blue: fragments[17].

2.1.2 The Danger of Orbital Collisions

The proliferation of space debris poses significant risks to space missions and the broader space environment. Indeed, space junk can represent a substantial operational hazard to spacecraft, such as satellites, space telescopes, and space stations, since even small fragments of debris can inflict severe damage through collision causing punctured spacecraft, disrupting operations, and, in extreme cases, complete mission failures. For instance, Figure 2.4 shows the possible consequences of an impact with space debris. Figure 2.4(a) illustrates a 4 mm pit found during the Space Transportation System program on the STS-7 window, resulting from the impact of a paint flake measuring approximately 200 μm in diameter[3]. In addition, Figure 2.4(b) depicts the outcome of a lab test impact, conducted by ESA, between an aluminum sphere with a diameter of 1.2 cm and a weight of about 1.7 g traveling at approximately 6.8 $\frac{km}{s}$ and a block of aluminum 18 cm thick. This test results in a crater with a diameter of 9 cm and a depth of 5.3 cm, and it simulates what can happen when a small space debris object hits a spacecraft[21].

Moreover, the impact of space debris extends to the space environment. When a spacecraft is hit, the collision can generate thousands of additional fragments,



(a) (b)

Figure 2.4: (a) Damage caused by a 200 μm paint flake to the window of STS-7[20]. (b) Damage caused by the collision of a 1.2 cm diameter sphere against a block, both made of aluminum[21].

exacerbating the existing problem. Two notable incidents highlight the environmental risk that space debris can represent: the 2007 Chinese Anti-Satellite Test and the 2009 Iridium-Cosmos Collision. The first happened on January 11, 2007, when China launched a ballistic missile from the Xichang Space Launch Center. The payload was a kinetic kill vehicle that collided with a non-operational Chinese weather satellite, the Fengyun-1C, at an altitude of 863 km, destroying the satellite. As figure 2.5 illustrates, the destruction created a cloud of more than 3,000 pieces

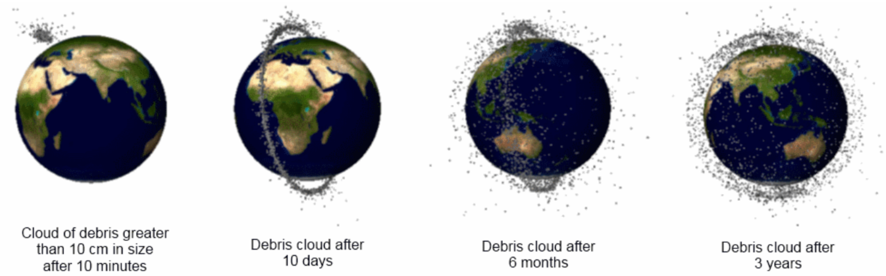


Figure 2.5: Evolution of the debris cloud from the 2007 Chinese Anti-Satellite Test[22].

of space debris and much of it will remain in orbit for decades[22]. The second incident happened on February 10, 2009, when an inactive Russian communications satellite, designated Cosmos 2251, collided with an active commercial communications satellite operated by US-based Iridium Satellite. The incident occurred approximately 800 km above Siberia. As figure 2.6 depicts, this collision produced

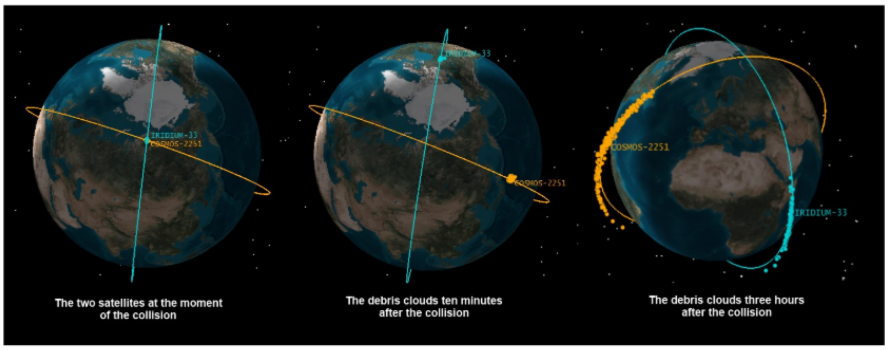


Figure 2.6: Evolution of the debris cloud from the 2009 Iridium-Cosmos Collision[23].

almost 2,000 pieces of debris, measuring at least 10 *cm* in diameter, and many thousands of smaller pieces[23].

These examples illustrate perfectly one of the reasons why it is so difficult to deal with space debris and why it is so important to act against this issue. Space junk is a type of pollution that can be called self-reinforcing pollution. In this case, pollution triggers a chain reaction or feedback loop, increasing the likelihood of further pollution. In other words, unlike standard terrestrial pollution, debris propagates additional pollution. Thus, for example, a collision between a satellite and a piece of debris, or even between two pieces of debris, creates additional debris which further increases the likelihood of other debris creating collisions[24].

Unfortunately, some numerical simulations of the evolution of orbital debris populations in LEO indicate that the debris population has reached a point where the environment is so unstable that population growth is inevitable[25][26]. The main conclusion from these analyses is that even if no further space launches were performed, the Earth's satellite population would remain relatively constant for only the next 50 years. Beyond that, the debris population would begin to increase noticeably due to the production of collisional debris. In reality, the satellite population growth in LEO will undoubtedly be worse than studies indicate, as spacecraft and their orbital stages will continue to be launched into space and unexpected major breakdowns may continue to occur[8]. If the forecasts are correct, and should the Kessler syndrome be realized, the space powers of the 2060s will begin to see a runaway growth in the number of collisions and debris in LEO[27]. Some studies analyzed the effectiveness of four scenarios ranging from no action taken to five, ten, and twenty objects removed per year from 2020. Removing as few as five troublesome debris objects every year from 2020 will mean that the large debris population at the dawn of the 23^{rd} century may be halved from approximately 60,000 to 30,000[8]. This further demonstrates the importance of

ADR technologies.

This information already illustrates why space debris is such a great concern and why it is fundamental to act quickly. Still, space debris is also an important problem for the global economy and human daily life. Nowadays, life on Earth is strongly dependent on the functioning of the thousands of satellites in orbit. Many essential fields, such as the financial industry, Global Navigation Satellite System services, the Internet of Things, mass media, communication, the aerospace industry, weather forecasts, response to natural disaster emergencies, the study of climate change, and agritech, rely heavily on satellites. Consequently, satellites malfunctioning due to debris collisions would lead to severe losses. A study shows that if no action against space debris is taken, in the long term space debris is projected to cause a negative impact equivalent to approximately 1.95% of the global Gross Domestic Product[28].

2.2 The Current Policy Framework for Space Sustainability

As previously discussed, sustainability in space is a vast topic, but international and national entities have concentrated mainly on the issue of space debris. For this reason, this study focuses the analysis of the policy framework on this topic, given the lack of policy instruments addressing other aspects. Despite the great attention paid to space debris, the regulatory framework is still vague and inadequate, especially regarding hard laws. Indeed, basically, all the hard laws regarding space were stipulated before 1980[29]. For this reason, the space law is outdated because it was thought to address completely different situations from the ones the space sector faces now. This is critical because, as of today, this gap is covered simply by soft law, a kind of "law" composed of instruments, such as the guidelines, that are defined as soft obligations, meaning they are non-binding. These include voluntary resolutions and codes of conduct widely accepted within the international community, that are not enforceable[30]. However, since space agencies draft a significant portion of soft law, this issue can be mitigated as long as space agencies continue to fund missions. Indeed, money can effectively leverage companies, such as satellite manufacturers, to comply with the guidelines, as failure to do so would result in losing contracts. Nonetheless, this can't be a permanent solution. Beyond the fact that this situation can lead to an uneven playing field between agencies with different guidelines and a flow of capital and competencies toward nations with less strict guidelines or with no guidelines at all, not encouraging further development of the regulations, the rise of private actors in the space sector can pose significant challenges for maintaining regulatory compliance[31]. Unlike government agencies, private companies may prioritize cost efficiency and rapid deployment to remain competitive, leading to inconsistent adherence to voluntary guidelines, especially when compliance entails additional costs or operational delays. A prominent example is SpaceX, which has transformed the space industry with cost-effective satellite launches and ambitious mega-constellation projects like Starlink. Although SpaceX uses debris mitigation technologies, no legally binding international regulations can force SpaceX to adhere to stringent sustainability practices[32].

2.2.1 The International Policy Framework: Hard Law

In general, the international hard space law does not address the threat of space debris because it was all drafted, as mentioned, before 1980, when space junk was not a problem. Indeed, the expression "space debris" is never mentioned in these treaties, but they use the more general concept of "space object". Nevertheless, some considerations can still be made by analyzing the laws that regulate outer space activity, especially the Outer Space Treaty (OST), the Convention on International Liability for Damage Caused, also known as the Liability Convention, and the Convention on Registration of Objects Launched into Outer Space, also known as Registration Convention. These are the most widely accepted treaties regarding space law, all drafted by the UN Committee on the Peaceful Uses of Outer Space (COPUOS), and the only ones where something applicable to space debris can be found, even if not specifically designed for it.

Outer Space Treaty

This is the most pertinent of the three and is the most important treaty in space law, also referred to as the "Constitution" of space law. Signed in 1967 by all the most important space-faring nations, it contains the fundamental principles governing outer space activities and it provides the basis for all the next treaties[6]. These principles are[33]:

- Space as a province of all mankind and therefore no national appropriation;
- Free and peaceful exploration and use of outer space and celestial bodies;
- Liability of states for damage caused by their space objects to other objects, outer space environment, or celestial bodies.

In these fundamentals, something useful in addressing the space debris issue can be found. For instance, uncontrolled space junk will limit access to Earth's orbit, breaching in this way both Article I, which states that outer space "shall be free for exploration and use by all States", and Article IX, declaring that states shall avoid outer space and celestial bodies contamination OST[34][35]. Furthermore, Article VI and Article VII expressed that launching states are responsible for national activities carried out by governmental agencies or non-governmental entities, and retain jurisdiction over an object launched and its component parts[35]. In addition, Article VII states that a launching state is internationally liable for damage caused to another state by its space objects or its component parts on the Earth, in air, or in outer space[35]. These articles provide the basis for the Liability Convention of 1972.

Liability Convention

This important treaty was approved in 1972 by all the leading space-faring nations. Firstly, the Liability Convention clarifies the meaning of damage, launching state, and space objects thanks to Article I. In this article, the term "damage" is identified as a "loss of life, personal injury or other impairment of health; or loss of or damage to property of States or of persons, natural or juridical, or property of international intergovernmental organizations"[36]. Furthermore, it declares that "launching state" includes both the "state which launches or procures the launching of a space object" and the "State from whose territory or facility a space object is launched"[36]. Finally, Article I defines "space object" to include "component parts of a space object as well as its launch vehicle and parts thereof"[36]. Subsequently, the document elaborates on liability in space, providing two different case studies depending on where damage occurs[37]. The first one, addressed by Article II, represents those situations when damage is caused by a space object within the Earth's environment, that is on Earth's surface or to an aircraft in flight[36]. In this case, the launching state is absolutely liable to pay compensation[36]. The other scenario is when the damage occurs elsewhere than on the surface of the earth, and in this situation, the launching state is subject to fault liability[36]. Finally, Article IV and Article V state that in cases where two or more states jointly launch a space object, they are liable based on the scenarios presented before[36].

Registration Convention

The Registration Convention, signed in 1974 by all the major space-faring nations, imposes, with Article II, the registration by the launching state of every object launched into space in an appropriate registry[38]. Furthermore, Article IV declares that every state of registry, i.e. a launching State that has registered an object, shall provide all the information regarding the space object to the Secretary-General of the United Nations, that, according to Article III, shall keep a register in which the information furnished shall be recorded[38].

2.2.2 The International Policy Framework: Soft Law

Unlike hard law, the international soft law for space sustainability is rather developed. The fundamental characteristic of soft laws is that they are not legally binding, thus nobody can be considered liable for not respecting these laws[30]. Nevertheless, soft law can be important in developing a policy framework. First, soft law can influence states' behaviors on diplomacy, technology, and even some political and legal aspects[7]. Furthermore, it can indicate the right direction to follow in the absence of hard law and subsequently evolve into a treaty or customary rules[29][7]. The main authors of the soft space law for space sustainability are the UN, the Inter-Agency space Debris Committee (IADC), and the International Organization for Standardization (ISO).

United Nations

As can be expected, the United Nations is one of the most important policy-making bodies in the international field. Their work on policy for space sustainability has concentrated on space junk and it has produced two main documents:

- The Space Debris Mitigation Guidelines of the UN COPUOS adopted in 2007.
- The UN COPUOS Guidelines for Long-Term Sustainability of Outer Space Activities adopted in 2019.

The Space Debris Mitigation Guidelines of the UN COPUOS are the result of more than a decade of work undertaken by the COPUOS and its Scientific and Technical Subcommittee. They explicitly stated that they are drafted based on the IADC Space Debris Mitigation Guidelines, but also that they take into consideration the UN treaties and principles on outer space. The document contains these recommendations[39]:

1. Limit debris released during normal operations;
2. Minimize the potential for break-ups during operational phases;
3. Limit the probability of accidental collision in orbit;
4. Avoid intentional destruction and other harmful activities;
5. Minimize the potential for post-mission break-ups resulting from stored energy;
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in the LEO region after the end of their mission;
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with the GEO region after the end of their mission.

The UN COPUOS Guidelines for Long-Term Sustainability of Outer Space Activities have a wider scope compared to the Space Debris Mitigation Guidelines mentioned before, also addressing issues such as space weather, spectrum, or link to national laws and regulations. They are composed in this way[40]:

1. Guidelines on policy and regulatory framework for space activities:

    - These guidelines focus on what member states of UN should do in their national policy. They ask states to adopt, revise, and amend national regulatory frameworks for outer space activities from the perspective of the long-term sustainability of outer space activities. Then, they require nations to ensure that national space activities comply with relevant national and international regulatory frameworks, requirements, policies, and processes related to space sustainability. Finally, they want states to ensure the equitable, rational, and efficient use of the radio frequency spectrum and the various orbital regions used by satellites and to enhance the practice of registering space objects.

2. Guidelines on the safety of space operations:

    - These guidelines concentrate on the safety of space operation, asking for the exchange of updated information on space objects, space debris, space weather data and forecasts, and orbital events between states and international intergovernmental organizations. Furthermore, they require the establishment of appropriate means to enable timely coordination to reduce the probability of and/or to facilitate effective responses to orbital collisions, and orbital break-ups. Finally, they encourage states to create models capable of assessing, tracking, and analyzing orbital and physical characteristics of space debris, improving the accuracy of space weather forecasts, and addressing risks linked to the uncontrolled re-entry of potentially dangerous space objects.

3. Guidelines on international cooperation, capacity-building, and awareness:

    - These guidelines focus on member states' actions to improve international cooperation, capacity-building, and awareness. They ask states to promote and facilitate international collaboration to support outer space's long-term sustainability and to share their experience in this field. Furthermore, nations and international intergovernmental organizations should assist countries in gathering human and financial resources and achieving efficient technical capabilities, standards, regulatory frameworks, and governance methods that support the long-term sustainability of outer space activities and sustainable development on Earth. Finally, states should raise general institutional and public awareness of the important societal benefits of space activities and the consequent importance of enhancing the long-term sustainability of outer space activities.

4. Guidelines on scientific and technical research and development:

    - These guidelines concentrate on the scientific and technical development of space technologies for space sustainability. They ask states to promote and support R&D of space technologies, processes, and services to support sustainable exploration and use of outer space. Finally, nations should investigate the necessity and feasibility of possible new measures, to address the evolution and management of the space debris population in the long term.

Inter-Agency Space Debris Committee

In 2002, the IADC drafted probably the most important space debris mitigation guidelines, as they were used as a foundation for the development of the Space Debris Mitigation Guidelines of the UN COPUOS and for the ISO standard 24113 "Space Systems – Space Debris Mitigation Requirements"[41]. These guidelines ask for[42]:

1. The limitation of debris released during normal operations and the verification that the effect of any program, project or experiment on the orbital environment, and the hazard to other operating spacecraft and orbital stages, is acceptably low in the long-term;

2. The minimization of the potential for on-orbit break-ups during operational phases and for post-mission break-ups resulting from stored energy and the avoidance of intentional destruction and other harmful activities;

3. Post-mission disposal program for both Low Earth Orbit and GEO. Objects in LEO should be deorbited (direct re-entry is preferred) or, where appropriate, maneuvered into an orbit with an expected residual orbital lifetime of 25 years or shorter with a probability of success of at least 90%, while for objects in GEO a maneuver should place orbital stages and spacecraft in an orbit that remains outside the GEO Protected Region for at least 100 years;

4. Prevention of on-orbit collisions with estimation and limitation of the probability of accidental collision with known objects during the spacecraft or orbital stage's orbital lifetime, consideration of avoidance maneuvers for spacecraft during all operational phases, co-ordination of launch windows for launch vehicle orbital stages, and minimization of the integrated collision risk during

the remaining orbital lifetime after the end of all operational phases of a spacecraft or orbital stage.

Furthermore, IADC have recently published two additional documents to support the 2002 guidelines[5]. The first one is the “Support to the IADC Space Debris Mitigation Guidelines” of 2021, which furnishes additional information and guidelines to enhance the implementation of the prior IADC Space Debris Mitigation Guidelines[43]. The second one is the “IADC Statement on Large Constellations of Satellites in Low Earth Orbit” of 2021, in which some specific procedures for large constellations are provided[44]. For example, this document recommends “to consider sufficient altitude separation between all parts of the constellation to minimize the potential collision risk among constellation members”[44]. Furthermore, it redefines the standard IADC mitigation guidelines, tailoring them to large constellations[44].

International Standard Organization

In 2010 ISO published the top-level International Standard “Space Systems – Space Debris Mitigation Requirements” [ISO 24113], defining the primary space debris mitigation requirements for unmanned systems[45]. These requirements are intended to reduce space debris growth and to minimize the casualty risk on the ground associated with atmospheric re-entry of space objects[46]. Furthermore, they are organized in a hierarchical structure with several lower-level standards and technical reports below[5]. These documents are fundamental to standardizing all aspects of a space object’s lifetime to minimize the risk of space debris generation, including design, post-mission disposal, preventing on-orbit break-ups, estimating orbit lifetime, limiting re-entry risk, avoiding collisions, and assessing survivability against debris impacts[47]. It is important to notice that this is one of the very few instruments that integrate mechanisms for compliance verification, as the ISO system is structured around certification and can be scrutinized via an audit, even if a negative outcome has no negative consequences beyond losing the certification[5].

Other International Initiatives

Other notable documents compose the international policy framework for space sustainability. One of these documents is the “Recommendation ITU-R S.1003-2 Environmental Protection of the Geostationary-Satellite Orbit” of 2010. With these guidelines, the International Telecommunication Union (ITU) recommends some actions to protect the area near the GEO altitude from the fragmentation of space debris following a collision[29]. In particular, they recommend minimizing debris creation and shortening of debris lifetime near GEO region and transferring geostationary satellites, at the end of their lifetime, to a graveyard orbit with a perigee no less than 200 km above the geostationary altitude[48].

Another instrument that adds something new to the guidelines mentioned before, is the document titled “Best Practices for the Sustainability of Space Operations” by the Space Safety Coalition of 2019, in which the probabilities of successful post-mission disposal of space objects are increased to 95% in case of removal from LEO within 5 years and GEO, and to 99% in case of removal from LEO within 25 years[49]. Furthermore, this is an example of how guidelines can come also from industrial companies and non-governmental organizations.

Finally, it is worth citing the “Space Industry Debris Mitigation Recommendations” of 2023 by the World Economic Forum. This document reduces the demanded LEO post-mission disposal time to 5 years, increases the probability of successful post-mission disposal to 95-99%, and sets the altitude requiring active maneuverability or collision avoidance systems to 375 km. Moreover, it encourages the consideration of some financial measures, such as insurance mechanisms and cost-sharing schemes, to not impose an unreasonable burden on space operators and not disrupt competition in the commercial space sector[50].

2.2.3 The National Policy Frameworks

This section analyzes the national policy framework of the most important space-faring nations. Since, in the space sector, European Union (EU) is a direct competitor of US, Russia, and China, it is included in this analysis even if it is not a single nation in the strict sense.

European Union

EU has been particularly active in formulating space debris mitigation guidelines, especially in recent years. For example, the “ESA Space Debris Mitigation Requirements”, in the updated version of 2023, require an orbital clearance of a spacecraft or launch vehicle orbital element from the LEO protected region to have an orbital lifetime less than 5 years starting from either the orbit injection epoch, if it is injected into an orbit crossing the LEO protected region and has no recurrent maneuver capability, or the end-of-life epoch, if it operates in the LEO protected region and has a recurrent maneuver capability[51].

Furthermore, the “Zero Debris Charter” of 2023 aims to stop generating space debris by 2030. To do this it demands a probability of generating debris through collisions or break-ups in both LEO and GEO below 0,001 over the whole lifetime, and a probability of successful disposal from both LEO and GEO of at least 99% after the end of mission[52]. Finally, the “Zero Debris Charter” is completed with other requirements, following the other guidelines presented in this chapter.

United States

Regarding US, the policy framework for space sustainability is pretty developed. The US Government Orbital Debris Mitigation Standard Practices of 2001 were the first example of guidelines for space junk mitigation. They served as one of the primary sources for the development of the IADC Space Debris Mitigation Guidelines and the later Space Debris Mitigation Guidelines of the UN COPUOS[53]. This is why they are very similar to these two documents and contain pretty much the same guidelines[5].

Moreover, the Federal Communications Commission (FCC), which controls every communication satellite launched in US, has drafted another important US regulation mechanism. In its last update, the Second Order and Report requires operators of space stations ending their missions in or passing through the LEO region below 2,000 kilometers to plan disposal no more than five years after the end of the mission[54]. Other than that, this organization demands compliance with IADC guidelines. The difference from other situations is that compliance with FCC's guidelines for communication satellites is mandatory since they need the license issued by FCC to be free to operate[53].

Another important regulatory body is the Federal Aviation Administration, which is the organization that approves all commercial launches and attempts at object reentry in the US[55]. To obtain approval for launch or re-entry, operators must ensure that[56]:

- There is no intended physical contact between the vehicle or any of its components and the payload after payload separation;
- Debris generation does not result from the conversion of energy sources into energy that fragments the vehicle or its components;
- Stored energy is removed by depleting residual fuel and leaving all fuel line valves open, venting any pressurized system, leaving all batteries in a permanent discharge state, and removing any remaining source of stored energy.

Russia

The Law of the Russian Federation “On Space Activity” of 1993 generically states that “space activities are carried out with a view to ensuring the level of permissible anthropogenic burden on the environment and the near-Earth space”[57]. Furthermore, the Russian Federal State Unitary Enterprise Central Research Institute for Machine Building developed the GOST R 52925-2018 "Space Technology Items. General Requirements for Space Vehicles for Near-Earth Space Debris Mitigation", adopted in 2019. This document provides several guidelines consistently with the IADC Space Debris Mitigation Guidelines and the Space Debris Mitigation Guidelines of the UN COPUOS[57].

China

In 1995, China National Space Administration became an active member of the IADC and contributed to establishing the 2002 Space Mitigation Guidelines[58]. Furthermore, the China Aerospace Industry Corporation, and the Commission of Science, Technology, and Industry for National Defense drafted in 2005 the Requirements for Space Debris Mitigation with reference to the 2002 version of the IADC Guideline to be implemented in each stage of spacecraft's development to minimize debris creation[58]. Finally, Article 6 of China's Interim Measures on the Administration of Permits for Civil Space Launch Project declares that technical standards of pollution and space debris prevention must be met to obtain state approval for space missions[29]. Unfortunately, given the 2007 anti-satellite test, China is a notable example of how guidelines and requirements can be a virtuous commitment, which is not always mirrored in practice.

2.2.4 The Gaps of the Current Policy Framework

This section examines the deficiencies in the existing policy framework for space sustainability. Following an in-depth analysis, the subsequent gaps have been identified as significant weaknesses in the current framework:

- Lack of a thorough approach to space sustainability;
- Lack of an official definition of space debris;
- Lack of a clarifying entity;
- Lack of hard law specifically addressing space debris;
- Liability problem;
- Lack of incentives for debris remediation;
- Lack of consideration of the role of private companies.

Addressing these issues is critical to fostering a regulatory environment that promotes sustainable practices, economic growth, and innovation within the space industry. The next paragraphs provide a detailed analysis of each gap.

Lack of a thorough approach to space sustainability

Space sustainability is an extensive topic that is composed of several aspects. As has been illustrated in this chapter, the regulatory framework focuses on the space junk issue, but other important questions need to be addressed[59]. For example, the sustainability of access to space is a significant topic that is not regulated because it was never considered a problem[60]. Given the expected future increase in rocket launches, getting a deep understanding of this question is fundamental to guarantee sustainable access to space[61]. Therefore, it is necessary to have a comprehensive policy framework to address space sustainability in all its aspects.

Lack of an official definition of space debris

One of the most critical shortcomings of the regulatory framework on space debris is the absence of a clear and common definition of "space debris"[11]. All the international hard space laws only define "space objects", while space debris is never mentioned in these treaties. Whether these two concepts overlap, intersect, or are completely different is crucial in understanding how space debris has to be treated. For instance, it remains unclear whether the principles of the Liability Convention extend to space debris or are limited to spacecraft, launch vehicles, and trans-orbital vehicles, leaving ambiguity over the responsibility of launching states for debris generated by their objects[62]. Furthermore, supposing space debris is classified as a space object, it must be registered under the Registration Convention, which may be impractical given the vast quantity and often small dimension of debris[62].

Lack of a clarifying entity

As can be noticed by looking at the climate change situation, strong global cooperation is crucial to face a global problem such as space sustainability[63]. For this reason, the role of international organizations is fundamental to incentivize collaboration between governments, agencies, and private actors. Nowadays, also because of the vagueness of the hard space laws, there is some confusion on how to ensure space sustainability, especially regarding ADR, and, therefore, an international clarifying entity is needed[62]. This organization could either be chosen from existing institutions, such as the UN COPUOS, after some enhancements to its effectiveness, or established as an entirely new entity, as proposed during the UNISPACE conferences[62][7]. Its roles might encompass tasks such as promoting international collaboration, improving the regulatory framework, fostering the development of technologies, collecting and redistributing space situational awareness information and data, actively coordinating the launches of space objects, and managing space debris in orbit[62].

Lack of hard law specifically addressing space debris

As already illustrated in this thesis, the current hard space law is outdated and too generic, thus there is the urge to regulate space debris specifically[7]. This is because until notions such as liability, ownership, causation, and negligence are defined clearly, the motivations for more incisive actions against space junk are too weak[11]. Furthermore, it is time for all the guidelines drafted in past years to evolve into hard laws, in the form of a new space treaty or a customary rule [7]. According to some experts, the creation of a new space treaty is unlikely due to the lack of consensus on the mere discussion of a new treaty, and this idea can be supported by the fact that the last treaty to be stipulated was the Lunar Agreement of 1984, with only 18 signatories and no major space-faring nations[64]. For this reason, evolution into customary law seems to be the most probable scenario[7].

Liability problem

Because of the lack of clarity in addressing space debris, liability for collision and responsibility for removal are major issues[6]. According to the current legal framework, there are two possible scenarios, regarding how space junk is considered. In the case of space debris treated as space objects, under the registration convention, its jurisdiction remains under the state of registry, assuming that registration of space debris is feasible[38]. Thus, due to the absence of a salvage law for outer space, removal of debris is possible only if it is performed by the state of registry or with its permission, and since there is no legal obligation to do that, this can generate some legal impasses[6]. Furthermore, even in case of collisions, things are not simple. The Liability Convention states that launching states are responsible for damages caused by their objects, but it declares that the state is liable only if "the damage is due to its fault or the fault of persons for whom it is responsible"[36]. The problem is that it neither defines fault nor the procedure to determine it[30]. A significant example of this situation is the 2009 Iridium-Cosmos collision described before, where it was particularly challenging to assign fault. Indeed, Russia quickly declared that its derelict satellite was incapable of maneuvering, and since there was no obligation under international law to dispose of Cosmos 2251, it held no responsibility[65]. At the same time, Iridium answered that it had no obligation to avoid the collision even if it had foreseen it. Yet, the question could not be resolved under the Liability Convention and it ended with no determination of fault[65].

In other situations, it can be very problematic to assess the state of registry of a piece of debris, especially when it has a diameter of 1 *cm* or less. This further complicates the application of the Liability Convention, along with the considerable challenge of determining the link between a collision and a specific piece of debris[62].

Lack of incentives for debris remediation

As illustrated in this work, hard space law does not specifically handle space debris issues, while the amount of soft laws on this topic is pretty elevated. At the same time, guidelines and requirements for space sustainability focus on space junk mitigation, leaving space debris remediation unhandled, even if studies underline how the removal plays a crucial role in dealing with this situation[8][62]. Therefore, it is fundamental to address this question, providing legal and financial incentives to promote ADR.

Lack of consideration of the role of private companies

Another consequence of the outdated nature of the space regulatory framework is the absence of regard for private actors[66]. Indeed, the hard space law was entirely drafted before 1980, when governments held all the power. On the contrary, this is no longer the case, with non-governmental parties more and more involved in space activities, as shown by the US privatization of outer space flights via public-private partnership agreements[11]. For these reasons, it is crucial to specifically regulate private companies, clarifying their position within the policy framework.

Chapter 3

Research Methodology

This thesis aims to evaluate the economic impact of the current policy framework for space sustainability and to assist in developing an effective framework. To achieve this objective, the research focuses on three different case studies that represent both the constraints and the opportunities generated by the space sustainability policy framework:

- Case study 1: Economic impact on a satellite value chain. Most policies for space sustainability deal with the issue of space debris and, therefore, satellites are the inevitable targets of guidelines and restrictions, which demand minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life[5]. Thus, this will inevitably cause an increase in costs in all the life phases of the satellite, i.e., design, production, and operation.

- Case study 2: Economic impact on the in-space servicing sector. As policies for space sustainability increasingly mandate the mitigation and prevention of space debris and promote sustainable practices such as extending the operational life of satellites, reducing replacement needs, and minimizing the accumulation of space debris, the in-space servicing sector, which includes activities such as satellite maintenance, repair, refueling, and debris removal, becomes a crucial component in achieving space sustainability[5][9]. Consequently, compliance with space sustainability guidelines is expected to boost demand for these services.

- Case study 3: Economic impact on space start-ups. The space sector is extremely capital-intensive since its industry segments are based on highly innovative and expensive technology, especially in the upstream sector[10]. This is a great challenge and one of the most important barriers to entry for new ventures, given that sources of capital are one of the major concerns for start-ups and lack of financing or investors is among the main causes of business failure[67]. For this reason, introducing policy instruments that require more efficient technologies will worsen the situation.

In addition to these segments, others have been evaluated and subsequently discarded since they were not valuable enough to answer the research question. For example, the economic impact on segments like Earth Observation, the Global Navigation Satellite System, or communication satellites mostly depends on the effect on the satellite value chain, thus it would be a repetition of case study 1. Another segment considered is the launch vehicles sector, but, although significant opportunities exist to enhance sustainability within this sector, current research and understanding of the impacts of a launch are not advanced enough to support the development of comprehensive policies[68].

To understand and investigate these case studies, as shown in Figure 3.1, the workflow that underpins this thesis combines:

- Primary and secondary sources research to understand the current policy framework and its future perspective comprehensively.
- Interview campaign conducted with industry actors, policy experts, and policy developers to understand the point of view of all stakeholders involved in this matter.
- Analysis of data obtained to propose a possible policy framework development.

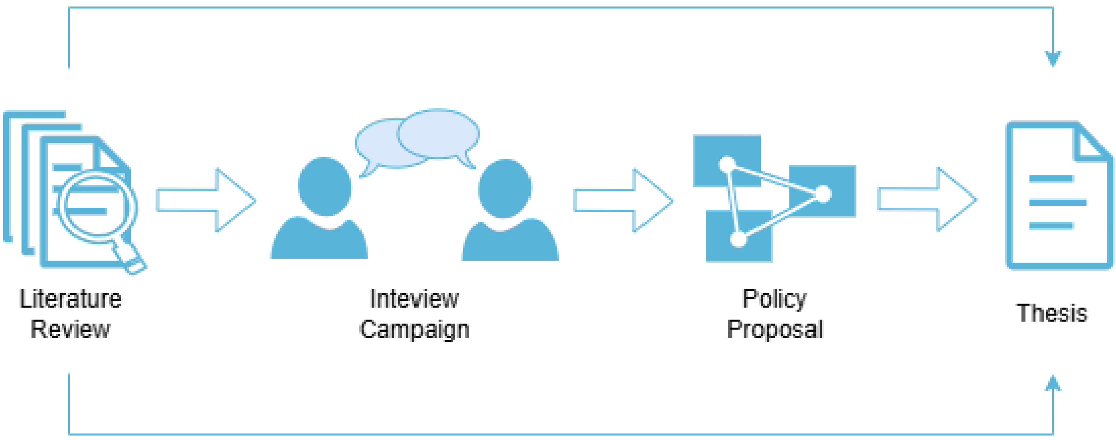


Figure 3.1: Methodology Workflow.

Each of these activities is further described below.

3.1 Research of Primary and Secondary Sources

The analysis initially focuses on researching primary and secondary sources concerning existing policy treaties, agreements, instruments, and guidelines directly related to space sustainability at the international and national levels. This extensive literature review provides the basis for understanding the policy drivers, priorities, and gaps currently present within the framework.

3.1.1 Primary sources

Primary sources provide raw information and first-hand evidence and give direct access to the research subject. The primary data evaluated for this thesis are international agreements, treaties, and industry guidelines that focus on space sustainability. These legally and non-legally binding documents are the key to comprehending this complex topic and understanding how the major players in the space field deal with this issue. The pool of documents analyzed for this thesis reflects that most of these tools concentrate on the issue of space debris, even if there are other important aspects of space sustainability.

In addition to these international agreements, some national and communitarian policies for space sustainability are analyzed to understand how the main actors of the space sector face the issue of space sustainability. Therefore, the national policies of the US, Russia, and China, and the communitarian policies of ESA are comprehensively examined.

3.1.2 Secondary sources

Secondary sources provide second-hand information and commentary from other researchers. In other words, secondary research describes, interprets, or synthesizes primary sources. Therefore, a complete review of the literature and reports on the legal documents previously mentioned is performed, to identify the strengths and the weaknesses of current policy frameworks. Furthermore, similar sectors like aviation are analyzed to understand how they underwent this process and how the sustainability guidelines affected their economy.

3.2 Interview Campaign

The second step of the research process is the interview campaign, an essential tool designed to gather qualitative insights from industry professionals and experts directly involved in sectors affected by space sustainability policies. The interview campaign is conducted with industry stakeholders, policy experts, and developers to obtain a comprehensive view of the topic and compare the two sides at play.

While primary and secondary sources provide foundational knowledge, interviews offer first-hand perspectives, helping to deepen the understanding of the practical and economic implications of current and potential policy frameworks.

3.2.1 Questionnaires Design

The questionnaire is structured around four questions, tailored to each group of interviewees. While the specific phrasing of the questions may vary depending on the interviewee's expertise and sector, the thematic focus remains consistent across all interviews to ensure comparability and comprehensive coverage of the research objectives. Therefore, the interview campaign addresses four topics:

- Current economic impact of the policy framework for space sustainability.
  - Objective: To understand how the current policy framework for space sustainability influences the various space sectors today.
- Future economic impact of a development of the current policy framework for space sustainability.
  - Objective: Assess how the evolution of the current policy framework for space sustainability might affect the various space sectors in the future.
- Effectiveness of Policy Instruments and Incentives.
  - Objective: Evaluation of the efficiency of existing policy instruments and incentives in supporting compliance with space sustainability guidelines.
- Suggestions for Policy Improvement.
  - Objective: Collect recommendations for new or improved policy instruments or incentives that could better support firms in meeting sustainability demands.

Regarding the industry stakeholders, the interview subjects are identified through a comprehensive analysis of the Italian space ecosystem. The analysis leverages some databases such as Dealroom and Crunchbase, alongside the official websites of all the Italian European Space Agency Business Incubation Center (ESA BIC), and the Italian Space Industry Online Catalogue. These resources provide a detailed overview of companies and start-ups actively operating in the space sector, enabling the identification of potential participants whose expertise aligns with the objectives of this research. Based on this, the analysis provides a pool of companies per case study, ensuring diverse representation while maintaining a manageable scope for the interview campaign. The number of companies is not equal between the different case studies, reflecting the fragmentation and size of each sector. The selection process adhered to the following criteria:

- Italian Companies: Only companies based in Italy were considered to ensure the maximum probability of establishing contact and to leverage local expertise.
- Business Area Coherence: The selected companies operate in sectors directly related to one of the three case studies considered.

Regarding policy-makers and policy experts, the interviewees are identified thanks to Professor Nicoli, the supervisor of this thesis, and some personal contacts.

Now, the specific interview for each group will be further illustrated.

3.2.2 Interview: Case Study 1

For the first case study, the objective is to understand the economic impact of the policy framework for space sustainability on a satellite value chain, and, therefore, questions and companies are chosen following this criterion. The firms selected are:

- 2NDSpace: An innovative start-up operating in the New Space Economy environments as a competitive and reliable partner for platform developers and launch service providers. The company provides cutting-edge cubesat platforms and components with the mission to disrupt the space value chain, combining excellence and a customization-as-a-standard approach with outstanding lead times and flexibility. The company's ambitious vision is to bring circular economy concepts into space with the scope to create a sustainable space environment by developing the capability of providing in-orbit services for platform maintenance, repair, and upgrade.
- Apogeo Space: An innovative small and medium-sized enterprise active in the production and management of space projects. The company has qualified its proprietary picosatellite platforms able to perform Internet of Things/Internet of Vehicle activities in LEO, which allowed further growth toward technology readiness and development. In addition, thanks to its experience in project and innovation management, Apogeo Space enabled different non-space companies and institutions to enter the space sector. The company is also actively engaged in scientific projects for both ESA and National Aeronautics and Space Administration (NASA).
- Argotec: An Italian aerospace company specialized in the design, manufacture, and operation of highly reliable microsatellites (up to 200 kg) from Earth Orbit to deep space, as well as the development of advanced solutions to support the comfort and well-being of astronauts and future space explorers.

Since its foundation, Argotec has collaborated with leading international space agencies, including NASA, and serves as prime contractor for major projects with the ESA and the Italian Space Agency (ASI).

- ARCA Dynamics: A New Space company providing innovative solutions for environmental and Space exploitation sustainability. Using and operating its proprietary nanosatellites, ARCA offers Space Traffic Management and Earth Observation services. In-house skills and capabilities cover the whole value chain of a nanosatellite mission, from mission/subsystem design to development, launch, and operations. The company is constantly evolving by carrying out Research and Development (R&D) activities for enabling cutting-edge technologies aimed at sustainable space exploitation and human resilience in space.

- Delta Space Leonis: An Italian start-up specialized in designing, engineering, and manufacturing picosatellites and the deployer that places them in orbit. The startup invests in the miniaturization process to reduce the cost of the missions and targets the Internet of Things industry to offer new space services. It is committed to designing and manufacturing small satellites adaptable to different needs and uses. More specifically, Delta Space provides space services to address the coverage connection problem to the Internet of Things sensors in remote/inaccessible zones of the world by developing a space-based infrastructure (a satellite constellation) that transmits data and connects sensors worldwide.

- GAUSS: An Italian limited liability company based in Rome, founded in 2012 as a spin-off of the Scuola di Ingegneria Aerospaziale of Sapienza University of Rome, carrying on the School's more than thirty-year tradition in the field of microsatellites. Active in the space technology field, its aims are the research, development, and implementation of aerospace projects, plus the educational aspect and the execution of related cultural initiatives. GAUSS has gained experience from ten differently shaped and sized satellite launches. Its business is mainly related to designing and manufacturing micro, nano, pico, and femto satellites, intended as Small Sats, CubeSat, PocketQube, and their deployers.

- IMT: A forward-looking company focused on space activities with the design and development of nano and microsatellites and relevant on-board units for space commercial, scientific, and defense applications, alongside engineering activities with characterization and testing of electrical, electronic, and electro-mechanical components and Internet of Things solutions activities with design and development of Internet of Things solutions for smart cities, environmental monitoring, infrastructure monitoring, and agriculture.

- NPC Spacemind: The aerospace division of the company NPC New Production Concept, which provides nanosatellite platforms and ground equipment for civil and defense applications. The space business unit was created in 2013 with the mission focus on becoming a leader in nanosatellite platform procurement and space-related applications, offering complete package solutions to bring scientific research to a commercial and industrialized product and service. The company's strength is to offer qualified space engineering know-how and technology exploiting automotive and World Class Manufacturing methodology and lean production strategy to shift the paradigm in the space business scenario.

- OHB SE: A recognized national leader in the fields of Satellite and Missions, Earth Observation, Space Situational Awareness, Electronics and Mechanisms, and Scientific and Planetary Instruments. It provides innovative solutions combined with the development and integration of complex equipment and a strong focus on customer satisfaction.

- Sitael: The largest privately-owned Space Company in Italy and worldwide leader in the Small Satellites sector. With highly qualified employees and state-of-the-art facilities, SITAEL covers a wide range of activities in developing small satellite platforms, advanced propulsion systems, and onboard avionics, providing turn-key solutions for Earth Observation, telecommunication, and science. Being one of the main players in the space economy, SITAEL is changing how space products are conceived in the upstream and downstream segments and providing competitive smart services for a wide range of applications, thanks to its Internet of Things capabilities.

- Tyvak International: one of the operating groups and the first international branch of Terran Orbital Corporation. Terran Orbital teams are leading innovators and providers of nanosatellites and micro-satellite space vehicle products that target advanced state-of-the-art capabilities for government and commercial customers to support operationally and scientifically relevant missions. Tyvak International represents the most advanced and vertically integrated offering in the market of small space vehicle products and services. The proprietary technology and know-how, based upon continuous progress in the miniaturization of semiconductors, enable the development, design, and commercialization of small satellite platforms faster and cheaper than traditional satellite systems. This also provides considerable opportunities to exploit the space more effectively and profitably.

For this case study, according to the objective of the research and the interviewees' characteristics, questions are customized in the following way:

- The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on your business (e.g., costs, revenue, R&D expenditure, etc.)?
- Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect your business (e.g., costs, revenue, R&D expenditure, etc.)?
- Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?
- What policy instruments or incentives would you recommend to help firms in your sector achieve the demands of space sustainability guidelines more effectively?

3.2.3 Interview: Case Study 2

The second case study is focused on evaluating the economic impact of the policy framework for space sustainability on the in-space servicing sector. Consequently, the selected firms are:

- D-Orbit: A global market leader in the space logistics and transportation service industries with a track record of space-proven technologies and successful missions. The company has developed proprietary space logistics technology and transportation solutions through an incremental strategic approach to the space marketplace to deliver successful customer outcomes today while developing advanced products and services for the needs of tomorrow. As it looks to the future, D-Orbit is already developing and testing new technologies to extend the life of satellites in orbit, perform active debris removal, enable interplanetary space logistics, and more.
- Ecosmic: An Italian-Dutch startup with the goal of transforming space into a sustainable and cost-effective industry. Its mission is to provide modular, innovative, and seamlessly integrable solutions for space operators, enabling them to maximize the effectiveness of their missions. The first challenge it is trying to solve is space traffic management. With its product SAFE, it enhances the safety of space by offering a service that generates alerts whenever a satellite is at risk of colliding with another satellite or debris. Ecosmic is committed to up-cycling space technology, ensuring a cleaner and more efficient use of the orbital environment.

- Kurs Orbital: An Italian start-up formerly incubated in ESA BIC Turin, aiming to democratize in-orbit servicing solutions, including space debris removal, satellite orbital transfer, de-orbiting, and satellite inspections, by providing reliable and cost-effective rendezvous and docking technology. Its innovative ARCap module enables space servicing and logistics industries, otherwise unable to afford operations in the orbital market, to scale their businesses effectively.

- SpaceDyS: A Spin-Off company of the University of Pisa, founded by the researchers of the Celestial Mechanics Group of the Department of Mathematics. It provides software and services for Space applications to ASI and ESA and other public institutions and private companies. SpaceDyS has gained very well-recognized leadership in the orbit determination field for asteroids or artificial objects in Europe and worldwide. The team and partners of SpaceDyS have a long experience and a strong background in the field of space debris. They took part at the beginning of the 90s in the development of the first European models for a long-term evolution study of the space debris population, by shedding light on the risk of the impact's proliferation and on the need to undertake mitigation measurements. From that moment, the team continued to develop theories and instruments in this field, by achieving important results in the orbit determination and the correlation of space objects.

- Spaice: An Italian start-up incubated in ESA BIC Turin, addressing the need to scale on-orbit services, currently accessible to only 1% of the satellite market due to customized operations and prohibitive costs. Leveraging proprietary AI tools, SPAICE enables autonomous operations that are adaptable to any target (even non-cooperative), orbit, and lighting conditions. Through a plug-and-play kit, SPAICE allows any satellite to perform multitasking robotic services, including life extension and debris removal.

- Thales Alenia Space: A Joint Venture between Thales (67%) and Leonardo (33%), Thales Alenia Space is a global space manufacturer delivering high-tech solutions for telecommunications, navigation, Earth Observation, environmental management, exploration, science, and orbital infrastructures. In its effort to guarantee space sustainability, it is developing a new solution that will perform repairs, maintenance, refueling, inspection, and de-orbiting of space debris[1].

[1]First, this company was classified as a satellite manufacturer, and therefore it was included in the first case study. Nevertheless, when the company received the questionnaire, the interviewee preferred to respond to the questions about in-space servicing.

For this case study, given the intent of the research and the knowledge base of the interviewees, questions are tailored in the following way:

- The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on your business (e.g., costs, revenue, R&D expenditure, etc.) and what opportunities do they create?
- Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect your business (e.g., costs, revenue, R&D expenditure, etc.) and what use cases it will enhance?
- Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?
- What policy instruments or incentives would you recommend to help firms in your sector achieve the demands of space sustainability guidelines more effectively?

3.2.4 Interview: Case Study 3

Finally, the third case study concentrates on the analysis of the economic impact of the policy framework for space sustainability on the development and management of space start-ups. For this case study, the companies selected to respond to the questionnaire were chosen from start-up incubators, accelerators, and venture capital firms operating in the space sector to obtain the broadest and most complete perspective on the space start-up ecosystem. Accordingly, the pool of companies is composed by:

- CDP Venture Capital: the largest Venture Capital manager in Italy and among the largest in Europe. It operates on strategic sectors for the future by investing directly and indirectly in startups, innovative small and medium enterprises, and Venture Capital funds for the creation of a market infrastructure that can support the entire life cycle of startups. It owns 70% of the “Italia Space Venture” Fund, which will invest in innovative entrepreneurial projects in the space and aerospace sectors, such as acceleration activities and technology transfer, addressing a gap in the availability of specialized venture capital funds.

- ESA BIC Turin: An Italian incubator supporting the creation and development of Italian startups in the Space Economy sector. It is managed by I3P, with the scientific and technological support of the Polytechnic of Turin and the LINKS Foundation. The incubation program provides financial incentives, strategic business consulting, scientific and technological support for product and service development, and direct access to a broad network of highly qualified industrial, financial, and scientific partners.

- Primo Space Fund: The first venture capital fund in continental Europe exclusively focused on space technologies. The fund's goal is to support new businesses based on the transfer and use of space technologies, while also improving the identification of national and European industrial needs and their correlation with space technologies.

- TLI Space: An experienced early-stage investor in the space and tech sector. TLI Space invests in the intersection between space and digital technologies along the entire value chain that goes from space to the end users on Earth. On Earth, TLI Space seeks tech companies across various sectors, including Finance and Insurance, Energy and Utilities, Sustainability and Climate Change, Food and Agriculture, and Health. In space, TLI Space seeks companies that own and manage space infrastructure, as well as those offering services to the space infrastructure itself.

For this case study, considering the goals of the research and the expertise of the interviewees, the questions are formulated as follows:

- The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on upstream space start-up management and development (e.g., barriers to entry, competitiveness, R&D expenditure, etc.)? Are there any differences in the impact on the downstream space start-up management and development?

- Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect upstream space start-up management and development (e.g., barriers to entry, competitiveness, R&D expenditure, etc.)? Are there any differences with the downstream space start-up?

- Do you consider the current policy tools and incentives adequate to support space start-ups in compliance with space sustainability guidelines? Why?

- What policy instruments or incentives would you recommend to help space start-ups achieve the demands of space sustainability guidelines more effectively?

3.2.5 Interview: Policy Experts and Policy-Makers

To ensure the feasibility and robustness of the proposed policy framework, this interview involves critical feedback from leading experts with diverse expertise in policy-making, industry analysis, and economic research. The following list describes all of them:

- Marie Le Pellec: Space sustainability Engineering at the ESA, she leads strategic initiatives to mitigate environmental impacts of ESA space programs. Moreover, she supports and advances initiatives in collaboration with the ESA Clean Space team, including Life Cycle Assessment guidelines update and ESA Life Cycle Assessment policy development.

- Matija Rencelj: Research Manager at European Space Policy Institute (ESPI) where he oversees the full spectrum of the Institute's research work and contributes to ESPI's strategic direction as part of the Management team.

- Alessio Terzi: Economist at the Directorate General for Economic and Financial Affairs of the European Commission and Assistant Professor in Public Policy at the University of Cambridge, with over a decade of experience at the intersection of EU policy-making.

- Akhil Rao: The acting agency chief economist for NASA. He serves as principal advisor to NASA's administrator on matters relating to markets, the space economy, and NASA's role in the US economy.

For this case study, the questions are very similar to the other cases to obtain a comprehensive view of the topic and to ease the comparison. Nevertheless, given the nature of the interviewees, one question is specifically tailored for policy experts and policy-makers to fully exploit their knowledge. Therefore, questions are customized as follows.

- The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What economic impact do these guidelines have on space sectors, particularly satellite manufacturers, in-space service providers, and space start-ups?

- Do you consider the current policy tools and incentives adequate to support satellite manufacturers, in-space service providers, and space start-ups in compliance with sustainability guidelines? Why?
- What policy instruments or incentives would you develop to help satellite manufacturers, in-space service providers, and space start-ups achieve the demands of sustainability guidelines more effectively?
- In your opinion, could a nation's strong focus on space sustainability, through the implementation of stringent guidelines and requirements, create a competitive disadvantage compared to countries with less strict policies? If so, do you think this might slow down the development of policy frameworks for space sustainability?

3.3 Proposal for a Policy Framework Development

The last step of the research workflow is the proposal for a policy framework development. The first two steps, i.e. the primary and secondary sources review and the interview campaign, are the basis for gathering the data and the information needed to formulate the proposal. For example, the literature examination allows for an understanding of the topic in all its facets, even the ones not addressed by the current policy framework. At the same time, the interview campaign helps to collect some crucial insights from within the space sector, which is fundamental for identifying areas where the current policy framework is falling short and where improvements can be made, according to industry stakeholders. The objective of the proposal is to support the current policy framework in guiding the space sector towards a sustainable future by connecting the space environment necessities with the space companies' demands. Furthermore, it wants to support a comprehensive approach to this question in order to address the economic impacts identified during the research, offering practical and actionable recommendations that align with the needs of stakeholders, and face all aspects of space sustainability, including those not currently covered by the policy framework.

Chapter 4

Case Study 1: Satellite

In Chapter 2, it is explained why it is so important to develop the space sustainability policy framework from an ecological and legal point of view. Additionally, analyzing the economic aspect can offer better insight into this concept. In macroeconomics theory, policy-makers aim to maximize social welfare, the sum of consumer and producer surplus[69]. Nevertheless, according to some studies, the current situation of space debris is not of social optimum, and the projections are even worse[70][71]. This is because space debris generation can be seen as a negative externality of space activities and, therefore, competitive firms don't account for its damaging effects and social costs[71]. As a result, companies tend to exceed the socially optimal launch rate and, operating on the basis of marginal costs and revenues, react to increasing collisions with even more launches until orbits become unprofitable, causing the so-called "economic Kessler Syndrome"[71][72]. For these reasons, it is important to stipulate policies that maximize social welfare without, at the same time, suppressing economic and technological growth, especially considering the cascading effect that can hit dependent sectors such as Earth observation, navigation services, communication, and weather forecasts. This chapter analyzes how the policy framework for space sustainability economically impacts the satellite value chain.

4.1 Literature Analysis Result

This section studies the economic impact of the policy framework for space sustainability on satellite manufacturers from a literature perspective. As explored in Chapter 2, mitigation guidelines establish some improvements that satellite manufacturers need to achieve to minimize space debris generation. In general, it has been estimated that the economic impact of debris mitigation maneuvers may amount to approximately 5-10% of the overall mission cost, often reaching hundreds of millions of dollars[73]. More in detail, the most costly guidelines enlighten after the policy framework review are[74]:

- De-orbiting and re-orbiting maneuvers;
- Shielding;
- Collision avoidance capabilities.

These represent all direct costs that impact R&D, design, and production costs. Furthermore, some indirect costs also affect the satellite value chain, such as space situational awareness activities expenses[74]. Now these cost sources are presented in detail.

De-orbiting and Re-orbiting Maneuvers

A point on which mitigation guidelines insist firmly is the orbit clearance, the de-orbiting of LEO satellites, and the transfer of GEO ones to a graveyard orbit. These maneuvers require some modifications in the satellite's subsystems to be implemented, inevitably causing a cost increase. For example, moving a satellite from its orbit, whether to de-orbit it or to re-orbit it, requires an extra Δv with respect to normal operations, meaning extra fuel, implying extra mass, resulting in additional costs[75]. Wiedemann et al. quantified this cost for both de-orbiting and re-orbiting[76]. For GEO satellites, they hypothesized no extra fuel at the beginning of the mission, resulting in a reduced lifetime, meaning fewer years to amortize hardware cost. Following their calculation, a lifetime shortened by 2.5 months produces a minimum loss of 9.0 $FY02\$M$ for a satellite with a starting mass of 1000 kg and a design lifetime of 7 years. Subsequently, the study analyzes the cost of deorbiting a LEO satellite, equipped with an enlarged propulsion system to perform the maneuver. In this case, the extra Δv causes an increase in development, production, and launch costs, leading to an additional minimum expense going from 28.7 $FY02\$M$ to 38.5 $FY02\$M$, depending on the Δv required[76]. Furthermore, other scholars investigated the de-orbiting maneuver, analyzing its different economic impact between small and large satellites using system cost figures[75]. The result is that the system cost figure is 10 times smaller for the large satellite. This is unsurprising since adding systems on small satellites is always more expensive due to their tiny dimension.

Shielding

To prevent debris generation, guidelines demand a strengthened structure for satellites. This is achieved thanks to shielding, meaning the improvement of collision resistance through small modifications, such as additional tiny walls[77].

Of course, this increase in structural mass results in additional costs. Again, Wiedemann et al. estimated this cost in their study[76]. According to them, protecting an entire satellite with a starting mass of 1000 kg with an aluminum shield with 1 mm thickness requires an extra expense of 8.3 $FY02\$M$.

Collision Avoidance Capabilities

Unfortunately, scholars have not deeply examined the economic impact of collision avoidance systems, but something can still be mentioned. For example, collision avoidance capabilities are the union of space debris tracking and avoidance maneuvers[78]. Therefore, a satellite operator needs to constantly know the trajectories of dangerous debris, through a proprietary space debris tracking system or a third-party service, inevitably increasing operational costs. Moreover, when a collision avoidance maneuver is initialized, beyond the fuel cost, it is important to consider the loss due to science instruments and mission operations downtime to address the space debris issue[78]. A 2020 Euroconsult report declares that an emergency maneuver can cost about 25000 € for a single LEO satellite[79]. The document also reports that managing a 300-satellite constellation may result in around 580 alerts annually that require manual intervention and orbital adjustments, leading to an annual expenditure of 14 million € for personnel, analysis, infrastructure, and related efforts.

4.2 Interview Result

This section reviews and analyzes the answers to the questionnaire to understand the considerations of the sustainability policy framework within the satellite manufacturers' industry. During the interview process, out of the 12 companies contacted, 4 responded, giving a response rate of 33%. The full responses are detailed in Appendix A.

Current Economic Impact

The first question aims to assess the economic impact of the current policy framework for space sustainability on the satellite value chain, as perceived by the interviewees. The question is:

> "The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on your business (e.g., costs, revenue, R&D expenditure, etc.)?"

The first respondent explains that satellite producers with electric propulsion systems are much less concerned than other satellite producers about mitigation guidelines, given this system's advantages from the space sustainability perspective.

The second answer effectively shows the concern of classical satellite manufacturers. It underlines the impact of mitigation guidelines on program costs, especially when these guidelines evolve into mandatory requirements. This consideration highlights the respondent's different perceptions of simple recommendations and compulsory obligations. Furthermore, the interviewee explains that the imposition of standards that were not previously planned could further increase costs.

The third interviewee illustrates how its company has developed a de-orbiting system for nanosatellites in response to the recent attention given to the new regulation for space sustainability.

The fourth response points out that, given their low maturity, developing critical technologies for space debris mitigation requires increased investment in R&D, which may impact mission costs and schedule.

Economic Impact Perspective

The objective of the second question is to understand the foreseen economic impact on the satellite value chain, according to respondents, in the case of a policy framework development. The question is the following:

> "Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect your business (e.g., costs, revenue, R&D expenditure, etc.)?"

In the first answer, the respondent points out that strict policy on orbital lifetime will increase the costs of space missions while maintaining equal performances. Of course, the percentage of the increment will depend on the criteria.

The second response states that costs will increase, firstly for programs and R&D, and subsequently for revenue.

The third interviewee declares that this development may positively impact revenue and enhance R&D activities.

The fourth answer stresses that developing low-maturity technologies would increase R&D expenditure, with consequences on mission cost and schedule.

Effectiveness of Current Incentives

The third question investigates whether the incentives or policy instruments given to satellite manufacturers to ease compliance with space sustainability guidelines and recommendations are sufficient and effective from the interviewees' perspective. The question is formulated as follows:

> "Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?"

The first interviewee explicitly declares that there are no incentives to sustain the implementation of space debris mitigation principles.

The second answer states that the effort to understand their impact on commercial programs does not match the commitment to implementing requirements for space debris mitigation.

In the third answer, the interviewee states that the framework is still in a very early stage, with limited mechanisms to encourage industry players to implement effective guidelines.

The fourth response expresses that the political environment for space sustainability is still in its childhood. Even if some initiatives show the right direction to follow, the missing link between these measures and space law hinders the transition. This connection would stimulate the in-space servicing market and create new business cases.

Policy Instrument Proposal

The fourth question asks the interviewees to suggest an incentive or policy instrument to help companies adhere to guidelines and recommendations. The question posed is:

> "What policy instruments or incentives would you recommend to help firms in your sector achieve the demands of space sustainability guidelines more effectively?"

The first respondent suggests the introduction of contractual incentives, i.e. rewards, for companies that meet space sustainability requirements ahead of schedule, along with the organization of awareness-raising and educational sessions.

The second interviewee proposes implementing more funds and support for space companies that want to comply with mitigation requirements. Furthermore, they underline the lack of involvement of private companies in making such decisions, leaving them as simple passive players in addressing space sustainability issues.

The third answer recommends all governmental entities promoting space sustainability initiatives that could prevent future complications that all the world would face, especially given the rise of LEO mega-constellations.

In the fourth response, the interviewee demands a strong governmental upfront investment to sustain the development of zero debris technologies.

Discussion

These answers are consistent with the findings of the literature analysis, especially in the case of producers of satellites with non-electric propulsion. Indeed, the interviewees point out the impact of the policy framework on program cost and R&D expenditure. Furthermore, the questionnaire highlights the difference in consideration between guidelines and mandatory requirements. If the former are seen as simple indications, the latter are way more impactful. In addition, it emphasizes that while significant focus is placed on establishing mitigation guidelines, there is a lack of corresponding support for companies to facilitate their compliance with these recommendations. Finally, interviewees declare the need for more incentives, such as contractual rewards and funds, and they highlight the absence of involvement of private companies in the decision process within the analyzed sector.

Chapter 5

Case Study 2: In-space servicing

This Chapter discusses the economic impact of the current policy framework for space sustainability on the in-space servicing sector. This evaluation is crucial because, as mentioned in Chapter 2, in-space services can play a game-changing role in the fight against orbital pollution. Indeed, orbital clearance is largely recognized as a fundamental activity for space debris mitigation, and in-space servicing companies can be beneficial in that sense, performing activities such as de-orbiting, re-orbiting, and refueling[5]. Furthermore, ADR is essential for the orbital debris situation improvement. Studies agreed that without the implementation of such technologies, debris will continue to increase, making it more and more challenging to prevent the occurrence of the Kessler Syndrome[8][62]. For these reasons, in-space servicing is an important sector, and, given that it is at an early stage of development, the policy framework must be designed to sustain its evolution and enhance its growth.

5.1 Literature Analysis Result

In this section, the impact of the current policy framework on the in-space servicing sector is analyzed from the perspective of the literature. As it has already been explained, in-space services and ADR technologies are crucial in facing the space junk issue. Fortunately, the set of guidelines for debris mitigation creates a great opportunity for creating this kind of company. For example, in Europe, 75% of stat-ups established from 2018 to 2022 belonged in the spacecraft servicing and debris removal category[80]. Nonetheless, strong investments in this sector have not followed this trend. From 2018 to 2025, the average of angel, early venture capital, seed, and series A investments in Europe in spacecraft servicing and debris removal has been 42.8 million \$, not a great amount considering that 76.5 million \$ and 101 million \$ have been invested in Earth observation satellites and semiconductors for space in the same period, respectively[81]. However, it has to be said that from 2023 to 2024 the investments grew significantly, doubling investments in Earth observation satellites[81]. The importance of investments in this sector comes from the fact that in-space servicing technologies are both very recent and extremely costly. For instance, Liu et al. analyzed the cost of an in-space servicing mission, and the cost just for the manufacture and launch of the servicing spacecraft resulted in 111 million \$[82]. Another valuable example is provided by Braun et al., who evaluated the cost of a multi-target mission[83]. In this kind of mission, the servicing spacecraft removes more than one object, meaning an additional maneuver is needed to navigate between targets. In their study, the cost just for R&D, test, and evaluation ranges from about 400 $FY14\$M$, in case of 2 removed objects, to about 650 $FY14\$M$, in case of 10 removed objects. These examples show how capital-intensive this sector is and, therefore, how crucial financial incentives for in-space servicing companies are in helping the development of this fundamental technology.

Beyond the problem of the great amount of capital needed for the initial investment, a significant challenge lies in defining sustainable revenue streams for these activities[84]. Right now, due to the unresolved liability problem explained in Chapter 2, there is no clear consensus on who should pay for such services. This uncertainty creates a major financial and strategic obstacle for companies operating in the in-space servicing sector, discouraging investment and long-term planning. Moreover, given that the existing policy framework does not provide sufficient incentives for ADR as illustrated before, potential customers, such as satellite operators or governmental agencies, are left without a strong motivation to invest in these services. Without clear financial incentives or regulatory obligations, the perceived value of ADR remains low, and the growth of the demand for such services is hindered. This lack of incentives, combined with the ambiguity in liability allocation, significantly slows down the development of the in-space servicing market, further delaying the achievement of a sustainable space environment[84].

5.2 Interview Result

This section examines and interprets the responses to the questionnaire, aiming to understand how in-space service providers perceive the sustainability policy framework. During the interview phase, 6 companies were contacted, with 3 providing replies, resulting in a response rate of 50%. All answers referenced below are included in Appendix B.

Current Economic Impact

The first question seeks to evaluate the economic impact of the current policy framework for space sustainability on the in-space servicing sector, based on the interviewees' perspectives. The question reads as follows:

> "The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on your business (e.g., costs, revenue, R&D expenditure, etc.) and what opportunities do they create?"

The first answer underlines how the policy framework can positively impact this sector, creating a favorable situation. However, it points out the lack of regulation for ADR technologies, and that the presence and the entity of the impact can be determined only after the creation of these regulations. Finally, it explains how, in this case, there is constant contact between the company and the policy-makers, highlighting a different situation from what has been observed before.

The second response declares that the current policy framework for space sustainability has an impact on costs, future revenue, and R&D expenditure.

The third interviewee explains how mitigation guidelines for space debris are opening up valuable opportunities for the growth of the in-space servicing market.

Economic Impact Perspective

The second question aims to assess how the in-space servicing sector might be economically impacted, according to respondents, if the policy framework undergoes further development. The question is:

> "Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect your business (e.g., costs, revenue, R&D expenditure, etc.) and what use cases it will enhance?"

In the first response, the interviewee explains how developing these systems is extremely challenging in terms of time and expenditure, especially if they are autonomous and/or able to deal with non-cooperative targets. Furthermore, the respondent highlights the crucial role of the policy framework for this sector. Indeed, they describe how if ADR technologies were somehow incentivized by regulations, other space firms would be interested in purchasing such services instead of developing them in-house.

The second answer underlines that the development of the policy framework will benefit the in-space servicing sector.

The third respondent highlights the importance of space debris policies for the growth of this sector, declaring that the development of the framework will enhance the development of key technologies.

Effectiveness of Current Incentives

The third question is designed to assess the sufficiency and effectiveness of the incentives or policy tools offered to in-space service providers to ease compliance with space sustainability guidelines and recommendations, in the interviewees' opinion. The question is stated as:

> "Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?"

The first answer declares that the current framework is the application of good practice for the responsible use of space. However, it underlines how these guidelines are not followed in the same way by every country, and therefore, the effectiveness of these guidelines entirely depends on nations' behavior. Finally, it points out that, as of today, since ADR is not a profitable activity, it is hard for companies whose business case focuses on this type of use case to emerge and thrive without governmental help.

The second interviewee states that, in their opinion, policy tools are effective and they will become even more so after the issue of the so-called "European Space Law" and its ratification in the member states.

In the third answer, the respondent points out how the policy framework's inability to address the liability problem and the lack of clarity on how the demand for in-space services can be sustainable in the long term, meaning who should pay for such services, are hindering the efficacy of policy tools and incentives.

Policy Instrument Proposal

The fourth question invites the interviewees to recommend potential incentives or policy measures to assist companies in aligning with established guidelines and recommendations. The question is formulated as follows:

> "What policy instruments or incentives would you recommend to help firms in your sector achieve the demands of space sustainability guidelines more effectively?"

The first response explains the importance of collaboration between governmental bodies and private companies, stressing that this cooperation is crucial to working everybody in the same direction and avoiding future challenging situations.

In the second answer, the respondent states that economic support and tax breaks can be useful incentives for the companies of the sector.

The third interviewee declares that before the implementation of further incentives, it is mandatory to address the liability problem and the demand sustainability question.

Discussion

These answers reflect the literature review outcome, underlining how the policy framework for space sustainability can create the right conditions for the development of this sector. However, almost all interviewees point out how the framework's shortcomings are causing uncertainties within the industry. Indeed, they explain that, given the high upfront investment required for developing this kind of technology, companies need economic support and guarantees on the sustainability of the demand for in-space services. For this reason, they declare that through a strong collaboration between governmental entities and private companies, more incentives, such as economic support and tax breaks, should be implemented and uncertain situations, such as the liability problem and the demand sustainability, should be clarified.

Chapter 6

Case Study 3: Space Start-up

This Chapter evaluates the economic impact of the current policy framework for space sustainability on space start-ups. Of course, space start-ups are very diversified, ranging in many different segments, including those investigated in Chapters 4 and 5. Therefore, the analyses performed in those case studies are valid even for space start-ups, especially for the in-space servicing sector given its early stage of development. The only difference is that for start-ups, which typically operate with constrained resources and little financial cushion, any cost increase can be far more destabilizing than large companies, potentially leading to immediate failure. This is a characteristic of every start-up, but in a capital-intensive market, such as the space sector, this situation is even worse, because initial investments needed to start the business are greater, particularly for upstream start-ups. For this reason, it is fundamental for the policy framework to sustain new ventures to avoid causing a slowdown in the space industry development.

6.1 Literature Analysis Result

This section illustrates how scholars have evaluated the economic impact of the current policy framework for space sustainability on space start-ups. Unfortunately, data available on this topic are minimal. However, something can still be illustrated by comparing space start-ups with new ventures in general, or with a similar sector such as aviation. In general, great policy uncertainty, as described in Chapter 2, can intensely impact the development of start-ups. In such cases, companies tend to adopt a cautious approach, delaying investments and strategic decisions[85]. This "wait-and-see" attitude slows down technological advancements, as firms hesitate to allocate resources to projects that may become unfeasible under future regulations.

Consequently, such circumstances can act as a barrier to the development of essential technologies for space sustainability, especially in a capital-intensive industry such as the space sector.

Furthermore, regulatory uncertainty is a major deterrent for venture capitalists when considering investments[86]. Unclear, evolving, or inconsistent regulations increase risk, making predicting long-term profitability and compliance costs difficult. This uncertainty can lead to delays in obtaining licenses, unforeseen legal barriers, or sudden policy shifts that could render business models unviable. As a result, investors often prefer sectors with well-established regulatory frameworks, where risks are more predictable, and returns on investment are more secure. In highly uncertain regulatory environments, venture capitalists may either demand higher returns or avoid investing altogether.

To understand the dynamics affecting new ventures in the space sector in the case of development of the current policy framework for space sustainability, due to the lack of data regarding the space industry, it can be useful to analyze the situation in similar capital-intensive sectors that have already faced the implementation of sustainability requirements, such as the aviation industry. In this sector, according to a survey performed by KPMG International, 67% of the respondents think that current tax policies and incentives are not sufficient to support sustainability in the sector[87]. In this industry, companies, especially those with international operations, a kind of venture that is very common in the space industry even for start-ups, have to adhere to evolving regulations, analyze the potential tax and legal effects, plan for future financial and investment demands, and leverage grants and incentives, all while formulating effective transition strategies. In addition, companies must comply with detailed reporting requirements imposed by both regulations and government incentives. All these operations can place a huge burden on the limited resources of small firms such as start-ups, making the management of these ventures even more critical.

6.2 Interview Result

This section examines and discusses the answers to the questionnaire, to evaluate the impact of the current policy framework on space start-ups. During the interview phase, 4 companies were contacted, with 2 providing replies, resulting in a response rate of 50%. Detailed answers can be found in C.

Current Economic Impact

The first question is designed to explore how, according to the interviewees, the current policy framework for space sustainability economically affects the space start-up ecosystem, underlining the differences between upstream and downstream ventures. The question posed is:

> "The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on upstream space start-up management and development (e.g., barriers to entry, competitiveness, R&D expenditure, etc.)? Are there any differences in the impact on the downstream space start-up management and development?"

The first interviewee explains how the increase in technical and regulatory requirements, such as collision avoidance and safe disposal of space vehicles, causes the rise of technical complexity and R&D expenditure for upstream start-ups. Regarding downstream start-ups, the impact is limited since these ventures don't directly face compliance costs, because their business is focused on data exploitation. However, strict regulation for upstream companies can lead to an increase in data access costs.

The second respondent declares that the current policy framework for space sustainability does not adequately address the needs of space start-ups, as most regulatory measures have primarily focused on major space industry players.

Economic Impact Perspective

The objective of the second question is to examine, based on respondents' views, the projected economic consequences for space start-ups in the context of policy framework advancements, highlighting the distinctions between upstream and downstream businesses. The question reads as follows:

> "Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect upstream space start-up management and development (e.g., barriers to entry, competitiveness, R&D expenditure, etc.)? Are there any differences with the downstream space start-up?"

The first response points out that the development of the current policy framework for space sustainability would make upstream companies increase initial investment to meet more stringent requirements, making market entry more challenging for startups with limited resources. Furthermore, the need to develop advanced technical solutions would require higher investments in research and development, increasing even more expenditures. However, this situation may foster the creation of innovative patents and expand business opportunities, creating an advantage for most visionary start-ups. From the point of view of downstream start-ups, this development would mean an indirect increase in data access costs, due to the higher costs for data providers. At the same time, it would ensure data with higher quality and, thanks to preventing potential disruptions in space-based data supply through collision reduction, higher reliability, opening opportunities for innovative downstream applications.

In the second answer, the interviewee illustrates that downstream ventures typically operate within a more simplified regulatory framework.

Effectiveness of Current Incentives

The third question examines whether, based on the interviewees' perspectives, the current incentives or policy mechanisms for space start-ups effectively support compliance with space sustainability guidelines and recommendations. The question is stated as:

> "Do you consider the current policy tools and incentives adequate to support space start-ups in compliance with space sustainability guidelines? Why?"

The first respondent highlights that current policy tools and incentives are not effectively supporting space start-ups in sustaining the high compliance costs. Furthermore, they explain that regulations often favor large companies, leaving start-ups to face economic and technical barriers without sufficient support.

The second answer emphasizes that situations can differ between geographical areas. Regarding Europe, few measures can effectively promote the progress of space sustainability companies, particularly when it comes to private entities' adoption of their services.

Policy Instrument Proposal

The fourth question requests the interviewees to recommend potential incentives or policy measures to aid companies in aligning with established guidelines and recommendations. The question is formulated as follows:

> "What policy instruments or incentives would you recommend to help space start-ups achieve the demands of space sustainability guidelines more effectively?"

The first answer points out that potential measures can be economic incentives or programs such as financial incentives, in the form of grants, tax credits, or easier access to funding for space sustainability projects, public-private partnerships, namely technology co-development programs with space agencies to reduce R&D costs, and standardization, meaning establishing clearer and more uniform technical guidelines to facilitate compliance.

The second interviewee states that start-ups in the space sustainability sector would benefit from incentives that encourage large companies and space agencies to adopt them as suppliers.

Discussion

These answers align with the literature review. They highlight how the current policy framework for space sustainability increases the initial investment needed to develop space technologies, especially for upstream start-ups. Conversely, downstream ventures operate in a more favorable regulatory situation, even if an increase in cost for upstream companies can result in higher data access costs. Furthermore, interviewees underline how current incentives are not effective in sustaining space start-ups, particularly given that policy tools often focus on large companies. For these reasons, they suggest the introduction of measures such as financial incentives, easier access to funding for start-ups that are carrying out space sustainability-related projects, public-private co-development programs to reduce R&D expenditures, and standardization. Moreover, they point out the importance of incentives that may lead larger companies and space agencies to choose space start-ups as suppliers.

Chapter 7

Interview: Policy Experts and Policy-Makers

The previous chapters analyzed the impact of the current policy framework for space sustainability from the perspective of those who experience its consequences without directly participating in the decision-making process. This chapter illustrates the view of policy experts and policy-makers, those actively involved in shaping regulations, to provide a comprehensive outlook. This is crucial to thoroughly understanding the needs and perceptions of everyone involved in the space sector and formulating a balanced policy framework proposal. Therefore, this Chapter presents and examines the outcome of the questionnaire to gain insights into how policy experts and policy-makers evaluate the impact of the policy framework for space sustainability. During the interview campaign, 4 people were contacted with 1 answering, leading to a response rate of 25%. All the answers discussed in this Chapter are reported in Appendix D.

Current Economic Impact

The first question seeks to identify the economic impact of the current policy framework on space sectors, especially on satellite manufacturers, in-space service providers, and space start-ups, as perceived by the respondents. The question is formulated as follows:

> "The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What economic impact do these guidelines have on space sectors, particularly satellite manufacturers, in-space service

> providers, and space start-ups?"

The first respondent considers the existing requirements to have a minimal economic impact and to be dependent on actual national regulatory frameworks. In their opinion, many of these requirements are already inherent in standard operations, such as reducing collision probability.

Effectiveness of Current Incentives

The objective of the second question is to examine whether the incentives or policy instruments provided to satellite manufacturers, in-space service providers, and space start-ups are adequate and effective in facilitating compliance with guidelines and recommendations, as perceived by the interviewees. The question posed is:

> "Do you consider the current policy tools and incentives adequate to support satellite manufacturers, in-space service providers, and space start-ups in compliance with sustainability guidelines? Why?"

The first answer explains how there is little motivation for compliance at the policy level, beyond signaling "good intentions" and general Corporate Social Responsibility commitments. Furthermore, it declares that compliance tools need to be adjusted to encourage wider adherence.

Policy Instrument Proposal

The third question explores potential incentives or policy tools that, according to the interviewees, could better support companies meeting guidelines and recommendations. The question reads as follows:

> "What policy instruments or incentives would you develop to help satellite manufacturers, in-space service providers, and space start-ups achieve the demands of sustainability guidelines more effectively?"

The first response suggests that compliance could be encouraged through prioritization in procurement processes for companies adhering to the guidelines. On the other hand, enforcing stricter licensing regulations could improve compliance, but it may also raise concerns regarding costs, return on investment, and competitive disadvantages against regions with looser regulations.

Impact on Nation's Competitiveness

The fourth question aims to investigate the consequences of variation in the level of regulatory stringency across different countries and whether these effects can hinder the development of policy frameworks for space sustainability. The question is:

> "In your opinion, could a nation's strong focus on space sustainability, through the implementation of stringent guidelines and requirements, create a competitive disadvantage compared to countries with less strict policies? If so, do you think this might slow down the development of policy frameworks for space sustainability?"

In the first answer, the respondent states that such a scenario is possible. Hence, they indicate that the European sustainability approach should be implemented thoughtfully, positioning it to boost competitiveness rather than diminishing it.

7.1 Discussion

These answers point out the difference in the degree of concern between private industry players and institutions. However, the interviewee aligns with the contacted companies, regarding the inefficiency of policy tools in sustaining space firms in compliance with the space sustainability guidelines and requirements. Furthermore, they illustrate how dealing with space sustainability questions on a national level can represent a source of disequilibrium in the competitiveness of the states with different regulations. Indeed, nations with a rigorous policy framework can suffer a competitive disadvantage compared to countries with more relaxed laws, which may lead to firm delocalization and hinder the local space economy growth. Therefore, these threats can act as a disincentive to implementing an effective national policy framework, highlighting the importance of dealing with space sustainability issues on an international level.

Chapter 8

Enhancing Space Sustainability Policies

This Chapter addresses the gaps in the current policy framework for space sustainability highlighted within this work. In Chapter 2, the regulatory framework has been evaluated through a deep literature analysis that has produced a list of deficiencies. Furthermore, in Chapter 4, 5, 6, 7, interviews results have been presented and discussed, pointing out what are the shortcomings of the current framework from the perspective of space industry stakeholders and experts. Therefore, the combination of these two has produced a set of gaps that are listed below:

- Lack of a thorough approach to space sustainability;
- Lack of an official definition of space debris;
- Lack of a clarifying entity;
- Lack of hard law specifically addressing space debris;
- Liability problem;
- Lack of incentives for debris remediation;
- Lack of consideration of the role of private companies;
- Lack of tools to sustain space companies in the sustainability transition.

The identified gaps in the current policy framework for space sustainability vary significantly in nature and scope. While some gaps can be analyzed in detail, leading to concrete policy recommendations, others require extensive legal, political, and economic considerations beyond this thesis's reach. In this case, this Chapter proposes potential directions for future policy development rather than attempting to resolve them definitively.

In the next sections, each gap is examined in detail.

8.1 Lack of a Thorough Approach to Space Sustainability

As already discussed, sustainability in space is a broad subject that includes various topics. For these reasons, limiting the discussion to the space debris issue means dealing with just a fraction of the question[59]. Therefore, international organizations such as the UN COPUOS should start addressing aspects like sustainability of access to space, and the preservation of extraterrestrial environments, such as the lunar or the Martian one. For example, regarding the sustainability of access to space, it is important to understand the impact of rocket launches on Earth's environment and the possible consequences on space traffic management of the continuous increase in mega constellation satellite projects observed in recent years. Furthermore, given the growing presence of lunar colonization and soil exploitation projects, a program for the sustainable use of the lunar environment should be developed.

8.2 Lack of an official definition of space debris

One of the first difficulties in addressing the space junk problem is the lack of an official definition of space debris[30]. This absence creates confusion because it is hard to understand which law addresses debris and which does not, and even if the law explicitly cites space debris, nobody knows what this term really comprises[6]. For example, the Outer Space Treaty, the Liability Convention, and the Registration Convention do not mention space debris, but they only partially define space objects. Therefore, there is no clear determination of whether their principles extend to space debris. Finally, without a clear definition of space debris, creating a policy framework specifically addressing space junk is impossible.

For these reasons, the definition of space debris should:

- Declare the non-functionality and non-controllability of space debris to distinguish space debris from space objects to allow the draft of a new regulatory framework addressing space junk and to prevent different regulations from overlapping;
- Clarify the artificial origin of space debris to differentiate it from other objects that can cross Earth's orbits;

- Express that space debris can comprise entire satellites, rocket bodies, payload, and their components, further than fragments of them, to include as many scenarios as possible.

Following this list of characteristics, a definition for space debris could be:

> Space debris is defined as all non-functional and non-controllable, human-made objects, including no longer functioning and controllable spacecraft, rocket bodies, or payload and their components or fragments, either orbiting the Earth or following trajectories crossing Earth's orbits.

Moreover, international organizations should formulate a clear definition of space objects as well. Indeed, Liability and Registration Conventions provide only a partial definition of space objects, stating that "the term "space object" includes component parts of a space object as well as its launch vehicle and parts thereof". Therefore, a formal definition of space objects may enhance clarity within the space regulatory framework.

8.3 Lack of a Clarifying Entity

The absence of strong international cooperation creates significant challenges in the governance and regulation of space sustainability. Indeed, without global collaboration, policies are developed in a fragmented manner, leading to inconsistencies in regulatory approaches, and uncertainty for both public and private stakeholders. This question can be addressed by an international organization coordinating the development of space sustainability[62]. Currently, no dedicated entity for space sustainability brings together nations, space agencies, and private stakeholders. Instead, space sustainability issues are handled by organizations with a much broader scope, such as the UNOOSA and the COPUOS. This fragmented approach reduces efficiency, as these entities must balance sustainability concerns with a wide range of other responsibilities, leading to an overload of different topics. Additionally, the lack of a specialized authority weakens the efficacy of policy implementation, as existing organizations may not have the necessary technical expertise to address the complex and evolving challenges of space sustainability[88].

Given these limitations, a viable solution could be establishing a new international entity specifically dedicated to guiding and supporting the sustainability transition of the space sector. The creation of an entirely new organization can be a particularly slow process, thus the most realistic option could be the creation of a new sub-agency of the UN, following the example of a comparable sector such as the aviation industry with the International Civil Aviation Organization[88]. As Larsen studied, this model would allow a specialized technical commission to analyze the most effective technical and physical approaches to addressing space sustainability challenges.

Using as a reference case the space debris situation, an entity of this kind can play a fundamental role in dealing with space junk. It would be in charge of:

- Enhancing international cooperation between nations, agencies, and private companies;
- Drafting international hard laws for space debris;
- Collecting and redistributing space situational awareness information and data;
- Organizing space traffic management;
- Managing ADR activities and formulating a debris removal priority list;
- Ex-post monitoring of regulatory compliance.

This model could be followed to address every aspect of space sustainability.

8.4 Lack of Hard Law Specifically Addressing Space Debris

One of the purposes of the new international entity described in Section 8.3 is formulating international hard law to regulate space debris. This is fundamental to improve the clarity within the regulatory framework and properly work against space debris proliferation, given that the current hard laws regulating space are outdated and too vague. The first step would be drafting an official definition for space debris, as presented in Section 8.2. After that, the regulatory entity would concentrate on converting current soft laws and guidelines into legally binding regulations. This can be done mainly with two instruments: an international treaty or customary international laws[7]. The path toward a new international treaty on space debris could be intricate given the great amount of time and consensus needed by this kind of agreement to be effective. Therefore, customary international laws seem to be the best option. However, the way that customary law is enacted can also have obstacles. Indeed, a rule becomes an international customary law if a significant number of states have adhered to and relied upon it, without substantial opposition from other states, and they follow the rule out of a sense of legal obligation, believing that they are legally bound to accept its legitimacy under customary international law[7]. These two conditions can represent a problem in a young sector such as space sustainability, because state practices may still be developing. To overcome this issue, the source of international customary laws can be found in other policy frameworks that already addressed the sustainability question, such as aviation, maritime, and environmental international laws[88][11].

From these regulatory regimes, it is possible to derive some important pillars that a new set of policies should have to guarantee space sustainability. These principles are:

- The precautionary principle, according to which if an activity poses potential risks to human health or the orbital environment, precautionary actions must be implemented even in the absence of full scientific certainty regarding cause-and-effect relationships;
- The polluters pay principle, providing that whoever conducts debris-generating activities bears full responsibility for the associated environmental costs;
- The transboundary harm principle, mandating that space operators are prohibited from using or authorizing the use of their property in a way that leads to serious harm to another's property or people therein;
- The environmental impact assessment principle, under which an orbital environmental impact assessment must be conducted for proposed activities that are expected to have a substantial negative effect on the orbital environment, and approval from a competent international authority is required.

Furthermore, following what has also been highlighted by the responses to the questionnaires presented in Chapter 6, an international standard for guidelines should be developed[7][11]. The standardization should include both technical and operational indications, following the model of the International Civil Aviation Organization flight standards.

8.5 Liability Problem

As of today, the only documents that regulate liability and jurisdiction in space are the Liability Convention and the Registration Convention. However, these documents, as already presented in Chapter 2, are vague and outdated, leaving several critical situations incompletely addressed or subject to regulatory gaps. For example, if their indications on space objects are applied to space junk, the removal of space debris is possible only if conducted by the state of registry, who retain jurisdiction over such debris, or with its explicit permission. Therefore, since there is no legal obligation to undertake such actions, this situation may result in legal standstills[6]. Furthermore, the lack of clarity in defining the notion of fault and how to determine it creates some difficulties in managing liability in case of collision[30]. Consequently, the policy regime regulating these situations should be reviewed to address these challenges. Formulating an official definition for space debris introduces a legal landscape no longer addressed by the Liability and Registration Conventions. However, the legal principles provided by these documents are solid and should be considered the starting point for constructing the framework.

Moreover, some new regulations should be formulated. Firstly, an analog of the right of salvage present in maritime law should be introduced[30]. This rule guarantees compensation for anyone who recovers someone else's ship or cargo in peril at sea, which is paid by the vessel owner, vessel operator, and cargo owners who benefited from the salvage operation. It is important to underline that the salvor does not become the owner of the recovered cargo unless it is judged as abandoned[89]. The similarity between shipwrecks and no longer functioning and controllable spacecraft is significant. Therefore, a comparable principle can be developed in space law to facilitate ADR activities. This rule should be formulated considering these concepts:

- Once a dangerous piece of debris is individuated, the international entity described in Section 8.3 should inform its owner, if identifiable;
- In the absence of a contract for removal services, the owner should have a period of 3 years for stipulating a contract with an ADR service provider. The owners should have the priority to remove their debris to protect possible military or industrial secrets;
- If the contract is not defined within the deadline, the international entity should obtain the right to perform the removal, billing the owner of the piece of debris for its cost;
- After the stipulation of the contract, the piece of debris should be removed within 10 years;
- Once the piece of debris is disposed of, the remover, subsequently to the payment of the service, should return the piece of debris to the owner;
- If the owner is not identifiable, the international entity should obtain the right to perform the removal. In this case, the remover becomes the owner of the piece of debris.

This approach is contingent upon developing an effective ADR service provider network. Furthermore, the deadlines indicated are not definitive but should be discussed and refined following the evolution of the technologies and the necessities of space sector stakeholders.

Moreover, to improve clarity within the regulatory framework the following notion should be precisely legally defined in the space context:

- Liability;
- Fault;
- Causation;
- Negligence;
- Ownership.

Finally, an international space dispute settlement body should be established to handle matters of responsibility and liability in the space context. Indeed, currently, the International Court of Justice is the only international body with jurisdiction to settle space-related disputes. Similarly to the situation of the regulatory entity previously described, this condition can lead to an excessive burden on the institution while also suffering from a lack of specialized expertise necessary to address the complexities of technical space-related matters[62]. Therefore, an international space dispute resolution entity is needed.

8.6 Lack of Incentives for Debris Remediation

Another critical issue the regulatory entity should address is the lack of incentives for debris remediation. Currently, most efforts have been focused on mitigating debris generation, with guidelines and standards to minimize the creation of new space debris. While these measures are essential, they do not solve the problem of the existing debris population, which continues to pose significant risks to operational satellites and future missions while contributing to further debris accumulation. The key to achieving space sustainability is the initiation and large-scale adoption of ADR activities, which require dedicated policy support to become viable and scalable solutions[8][62].

First of all, international funds and incentives should be introduced to enhance the maturation of ADR technologies, and to develop an effective ADR service provider network[6]. This would be the foundation for establishing a sustainable international system for space debris removal.

This system could be structured, based on the polluters pay principle explained in Section 8.4, following the carbon credits model used in the fight against greenhouse gas emissions. Carbon credits serve as regulatory permits for emissions. When a company acquires a carbon credit, usually from a governmental authority, it secures the right to emit one ton of CO_2. This system vertically channels carbon revenue from businesses to regulators, while allowing companies with excess credits to sell them on the market[90]. Following this model, a “debris credit” system could be established, collecting some of the revenue generated while creating space debris and using it to finance ADR activities. Unlike carbon credits, which are spent on long-term projects whose success can be difficulty guaranteed, such as reforestation initiatives, debris credits can be invested in shorter-term projects with a higher success rate, enhancing system effectiveness. Furthermore, this instrument would work as collective insurance for the space sector, internalizing the negative externalities produced by satellite launches in the system.

The system should be structured in the following way:

1. Whenever a space operator wants to put an object that has a certain probability of generating space debris, it should warn the international organization, sharing all the useful information regarding the case, following the precautionary principle;

2. Once the notification is received and the information is verified, the international organization should calculate and communicate to the operator the amount of debris credits needed to compensate for the debris generation;

3. Afterwards the space operator should pay the amount required and subsequently receive the permission to proceed with the mission.

4. Following the payment, the international organization should finance a removal mission following the priority list.

Furthermore, when the system functions properly, it will be possible to consider introducing a mechanism similar to carbon offsets. Unlike credits, offsets flow horizontally, transferring carbon revenue between companies. When a company removes a unit of carbon from the atmosphere as part of its regular business operations, it can generate a carbon offset. Other companies can then purchase these offsets to compensate for their carbon emissions and reduce their overall carbon footprint[90]. Similarly, in the space context, ADR service provider can generate a “debris offset” whenever they remove a piece of debris from Earth’s orbits, proportionally to the priority of the piece of debris. Space operators may purchase this debris offset to compensate for the debris generation caused by their missions.

8.7 Lack Tools to Sustain Space Companies in the Sustainability Transition

Answers presented in Chapters 4, 5, and 6 highlight that private companies are worried about a new policy framework for space sustainability putting an excessive economic burden on them. For this reason, they requested the implementation of incentives for easing regulation compliance and rewards for the most virtuous companies in the context of space sustainability. Indeed, a system like the one described in previous sections would increase cost and R&D expenditure for private companies and cause a rise of barriers to entry for new space ventures, as anticipated in Chapter 4, 5, and 6. Therefore, a mechanism to support private companies in regulatory compliance should be introduced. While scholars have given much attention to technical and regulatory aspects of space sustainability or the implementation of taxes, fees, or penalties to discourage unsustainable practices, there is a noticeable absence of studies exploring positive financial incentives that could facilitate the adaptation of space businesses to evolving sustainability requirements. This is evidence of the lack of consideration of private companies and of the economic impact of policy implementation, as presented in Chapter 2. However, a mechanism to sustain space companies in the sustainability transition should be developed.

This mechanism should be structured as a reward for those companies that excel in compliance with space sustainability regulations. The ability of companies should be measured by the "Space Sustainability Rating" implemented by the Space Center of the École Polytechnique fédérale de Lausanne and promoted by the World Economic Forum, the ESA, the Massachusetts Institute of Technology, BryceTech, and the University of Texas at Austin[91]. This tiered scoring systems awards space operators with points measuring and quantifying their sustainability decisions. The Space Sustainability Rating examines the decisions a space actor can make throughout the design, operation, and end-of-life phases of a space mission, assigning a score according to the positive impact on the space environment of such choices[91]. Thus, actions that result in a greater sustainable impact receive more points. Utilizing this scoring system to rank space operators and reward those more virtuous in complying to sustainability guidelines and regulations could sustain private companies in the transition and incentivize them to adhere to these requirements.

8.8 Lack of Consideration of the Role of Private Companies

As previously explained and underlined through the discussion of the questionnaire's responses, due to the period in which the current hard space law was drafted, there is a lack of consideration of the role of private companies within the policy framework for space sustainability[66]. This absence is evident in both the source and the objective of hard space laws, failing to include the interests and obligations of private firms. This situation can no longer be maintained, due to the rising influence of private companies in the space sector. Consequently, the role of private businesses in the space sector should be defined.

First, the responsibility of private companies over their space objects and debris should be clarified. This means declaring whether states retain jurisdiction over private firms or whether private companies are internationally responsible for their behavior. Due to the international nature of missions and the number of firms from different nations that can work on a space project, the second option seems to be the most viable.

Finally, private companies should be actively involved in the decision-making process of the international entity described in Section 8.3. This inclusion could be achieved by appointing a select number of industry representatives within the entity. Their participation would broaden the entity's perspective and allow it to address a wider range of interests, leading to more balanced and comprehensive regulatory approaches.

Chapter 9

Conclusion

Space sustainability is gaining increasing importance as space activities continue to expand and Earth's orbital environment becomes more congested. The growing number of satellites, the rise of mega-constellations, and the persistent issue of space debris have made it clear that long-term access to space has to be actively guaranteed. If no concrete actions are taken, the accumulation of debris could lead to a cascade effect, severely compromising the usability of key orbits and endangering future missions. To avoid this undesirable future, the establishment of an effective policy framework for space sustainability is crucial. Governments and international organizations have recognized this challenge, as shown by the increasing number of initiatives and guidelines addressing space sustainability issues enacted recently.

However, existing regulations consist of pre-1980 international hard laws that did not account for sustainability, national hard laws that remain excessively loose to maintain state competitiveness, and fragmented soft laws at both international and national levels, that lack proper enforcement. Therefore, the current policy framework for space sustainability remains vague, fragmented, and largely outdated, lacking the necessary clarity and enforcement mechanisms to guide a structured transition toward space sustainability. Moreover, existing regulations primarily focus on mitigation strategies without adequately considering their economic impact on industry players. For example, debris generation mitigation requirements, such as shielding and de-orbiting and collision avoidance capabilities, cause extra costs and higher R&D expenditure for satellite manufacturers. In contrast, space sustainability policies create growth opportunities and new use cases for the in-space servicing industry. However, they fail to provide sufficient incentives to support the development of the costly assets required in this sector, such as ADR technologies. Furthermore, within an already strongly capital-intensive industry, policies forcing higher upfront investments for developing space equipment and capabilities exert substantial pressure on start-ups, raising barriers to entry. These economic repercussions act as a significant disincentive for policy compliance, especially within an international framework where effective law enforcement is problematic. Therefore, considering these questions is crucial for designing a robust policy framework.

Consequently, this thesis investigates existing hard and soft space laws, pointing out major shortcomings in addressing space sustainability issues and establishing a balanced and effective policy framework.

As a result of this analysis, a new policy framework for space sustainability is proposed, centered on the establishment of a United Nations sub-agency responsible for defining and enforcing international space regulations. This new set of policies would include an official legal definition of space debris, clarifying what constitutes debris and laying the basis for formulating new regulations specifically tackling space junk. Furthermore, the agency would implement policy mechanisms aimed at solving the liability problem, such as an analog of the maritime right of salvage creating a framework for ADR activities. In addition, it would be in charge of defining some critical concepts within the space context, such as liability, fault, causation, negligence, and ownership. Moreover, following the carbon credit model, a "debris credit" system is developed to guarantee a sustainable market for in-space service providers. Under this system, space operators purchase credits whenever their planned missions carry a risk of generating debris, while the collected funds are used to support ADR activities to offset the debris generation. Finally, the framework provides rewards for those companies that excel in compliance with space sustainability policies, intending to support space companies in their transition to sustainable practices, helping them adapt to the new regulations without jeopardizing their financial viability or operational success.

This thesis lays the foundation for a more comprehensive approach to space sustainability, but further in-depth analysis is necessary for each identified gap. Future research should focus on refining and expanding the proposed solutions, assessing their feasibility, and evaluating their effectiveness through real-world case studies and policy simulations. Only through continuous refinement and adaptation can the policy framework for space sustainability ensure the long-term viability of space activities.

Appendix A

Satellite Manufacturers Questionnaire

This Appendix presents the transcription of the questionnaire responses regarding the economic impact of the current policy framework for space sustainability on satellite manufacturers. For privacy reasons, all answers are reported anonymously.

Current Economic Impact

> "The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on your business (e.g., costs, revenue, R&D expenditure, etc.)?"

1. "Siccome produciamo satelliti con propulsione elettrica, siamo automaticamente conformi ai requisiti correnti."

2. "These guidelines have a direct impact on program costs, specially if they'll become sooner or later requirements and not simple guidelines. Indeed, at a certain point they will impose some specific subsystem/modificaiton/hardare/software, not previously planned, with the consequence of an increase of costs."

3. "Nel corso degli ultimi anni ********* ha sviluppato un sistema di deorbiting per nanosatelliti proprio per ovviare a quanto sopra. Solo negli ultimi anni dopo l'attuazione della nuova regolamentazione si è posta maggiore attenzione al problema. il nostro prodotto, chiamato ******, https://www.**********.com/******-******-******/, ha già volato nello spazio diverse volte con successo deorbitando il satellite molto velocemente ed in sicurezza"

4. “Nowaydays the level of maturity of the enabling technologies focused on debris mitigation is still very low. To be able to develop it, it would be necessary to increase invest in R&D, which may directly impact in the mission costs and schedule.”

Economic Impact Perspective

> “Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect your business (e.g., costs, revenue, R&D expenditure, etc.)?”

1. “Politiche restrittive sulla permanenza in orbita dopo le operazioni aumenterebbero i costi delle missioni spaziali a pari prestazioni. L’entità percentuale dell’aumento dipende dai criteri di sostenibilità.”
2. “Initially, it’s just an impact on costs (both for porgrams and for R&D), then of course it will have an impact on revenues, with the start of new missions/services based on those new applications.”
3. “Certamente potrebbe avere un impatto positivi sui ricavi e far crescere le attività di R&D.”
4. “Same as the answer of the previous question.”

Effectiveness of Current Incentives

> “Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?”

1. “Non esistono incentivi specifici per adeguarsi alle norme.”
2. “Absoultely not: there is this idea of imposing such strict requirments, without thinking at the impact on the commercial programs.”
3. “Assolutamente no. Siamo in una fase ancora molto embrionale e ci sono ancora pochi strumenti volti ad incentivare gli operatori del settore a porre in essere delle linee guida efficaci.”
4. “The political environment related to sustainability in space is still in its childhood. Initiatives as zero Debris Charter and Booklet are now starting to pave a path for sustainable operations in space. However, there is still missing the link between these initiatives and space laws. These would boost the IOS market and create some new business cases.”

Policy Instrument Proposal

> "What policy instruments or incentives would you recommend to help firms in your sector achieve the demands of space sustainability guidelines more effectively?"

1. "Definire incentivi contrattuali (premialità) per le aziende che anticipano i requisiti di sostenibilità spaziale rispetto alle date di entrata in vigore, organizzazione di eventi di sensibilizzazione e di formazione."
2. "More funds, more support to companies, more involvement of the companies in taking such decisions."
3. "A partire dalle agenzie spaziali fino alle regioni dovrebbero incentivare tematiche di sostenibilità spaziale che possano in un futuro evitare problematiche complesse con le quali tutto il globo dovrà fare i conti, vista la crescita di mega costellazioni di satelliti in orbite LEO"
4. "The development of zero debris friendly technologies request a strong govermenetal upfront investment."

Appendix B

Appendix B

This Appendix presents the transcription of the questionnaire responses regarding the economic impact of the current policy framework for space sustainability on the in-space servicing sector. For privacy reasons, all answers are reported anonymously.

Current Economic Impact

> “The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on your business (e.g., costs, revenue, R&D expenditure, etc.) and what opportunities do they create?”

1. “La normatizzazione della gestione dei detriti spaziali è, purtroppo, ancora non completo. Come ha giustamente fatto presente, si concentra ancora sulla riduzione di detriti in maniera "passiva", ovvero imponendo regole (più o meno stringenti) che evitino la creazione di ulteriori detriti. ******* sta lavorando ad un prodotto che vuole agevolare la rimozione "attiva" dei detriti spaziali: si tratta di un modulo che abilita un generico spacecraft ad effettuare operazioni di prossimità, anche con target non cooperativi. Tale modulo può quindi permettere ai nostri clienti di svolgere missioni come l’estensione vita di satelliti, il loro rifornimento o anche piccole riparazioni (che rientrano nei metodi di riduzione "passiva"), o missioni di rimozione di detriti e decommissionamento dei satelliti (che fanno ovviamente parte dei metodi di rimozione "attiva"). Per noi è ovviamente una situazione favorevole, poiché siamo allineati nella fornitura di una tecnologia critica per quella che è la normativa attuale. Quando poi verrà affrontata la normatizzazione della parte "attiva" si vedrà

se e come inficerà il nostro prodotto. Quello che già stiamo facendo è stare in contatto e collaborare attivamente con tutti gli organi che si stanno occupando di standardizzazione e normatizzazione delle operazioni di servicing e della gestione dei detriti spaziali (CONFERS e ESA su tutti)."

2. "Costi, Ricavi nel futuro, Spese di R&D."

3. "La capacità di effettuare operazioni automatiche in orbita per rimuovere detriti spaziali e/o per effettuare operazioni su satelliti già in orbita è un mercato in continua crescita (2.5 milioni di dollari attuali con proiezione a più di 5 nel 2030)."

Economic Impact Perspective

> "Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect your business (e.g., costs, revenue, R&D expenditure, etc.)?"

1. "I sistemi di rendezvous e docking come il nostro modulo sono una tecnologia molto difficile da sviluppare da zero. Ci vuole molto tempo e molte missioni operative nello spazio per poter essere sicuri di avere un sistema pienamente operativo, sicuro e affidabile. Rendere questi sistemi autonomi e/o in grado di gestire target non cooperativi complica ulteriormente (ed enormemente) lo sviluppo. Se la normativa si sviluppasse incentivando in qualche maniera la rimozione attiva dei detriti in orbita, allora le aziende potrebbero essere interessate ad acquisire un sistema "Commercial Off-The-Shelf" (COTS) come il nostro piuttosto di doverne sviluppare uno da zero. Non intravedo però altri casi in cui uno sviluppo della normativa possa portarci dei benefici o degli svantaggi."

2. "Migliorerebbe in-Orbit Servicing"

3. "Sicuramente darebbe una spinta a migliorare ulteriormente le tecnologie chiave (automation & robotics, refuelling, Guidance, Navigation & Control, sensoristica, ecc.)"

Effectiveness of Current Incentives

> "Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?"

1. “Ritengo l’attuale normativa l’attuazione di un "buona pratica" per l’utilizzo responsabile dello spazio. Con l’assunto che "tutto ciò che va su, deve tornare giù" già si può evitare il peggioramento della situazione e un (lento) miglioramento della situazione. Va da sé che la normativa europea non viene necessariamente seguita da altri prime dell’esplorazione spaziale moderna come gli Stati Uniti o la Cina. Lo stesso bando ai test di armi antisatellitari è stato firmato solo da 37 paesi e anche nella votazione alle Nazioni Unite alla moratoria solo 155 paesi si sono espressi in maniera positiva (Russia, Cina e India non hanno votato a favore). La sostenibilità di queste norme è quindi molto soggetta al numero di eventi distruttivi che avverranno in orbita e al numero di satelliti che verranno immessi in orbita (e correttamente decommissionati) nei prossimi anni. Si potrebbe fare tranquillamente di più, ma non esiste attualmente un modo per mettere d’accordo tutti gli attori internazionali (e far rispettare le eventuali più stringenti normative). A questo si può anche aggiungere il fatto che (attualmente) la rimozione attiva di detriti spaziali non è un’attività profittevole se non attraverso missioni pagate direttamente dai governi interessati: ergo, è difficile che nascano e prosperino aziende il cui business case sia incentrato sulla rimozione di detriti spaziali.”

2. “Va chiarita la sostenibilità della domanda (chi paga?) e la responsabilità in caso di incidenti (liability).”

3. “Si, quando verrà emessa la cosìdetta Legge spaziale europea e le relative declinazioni negli stai membri.”

Policy Instrument Proposal

> “What policy instruments or incentives would you recommend to help firms in your sector achieve the demands of space sustainability guidelines more effectively?”

1. “Probabilmente aderire e seguire attivamente le organizzazioni che si occupano della standardizzazione dei vari aspetti del servicing e della rimozione detriti. Già molte aziende sono iscritte al CONFERS e stanno seguendo i lavori dell’ESA al riguardo: è importante trovare dei terreni comuni in modo che le attività siano il più possibili ripetibili e che la nazionalità dei target delle missioni non obblighino l’utilizzo di pratiche o (addirittura) hardware dedicati.”

2. “Supporto economico/sgravi fiscali.”

3. “Va chiarita la sostenibilità della domanda (chi paga?) e la responsabilità in caso di incidenti (liability).”

Appendix C

Appendix C

This Appendix presents the transcription of the questionnaire responses regarding the economic impact of the current policy framework for space sustainability on space start-ups. For privacy reasons, all answers are reported anonymously.

Current Economic Impact

> "The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What is the economic impact that these guidelines have on upstream space start-up management and development (e.g., barriers to entry, competitiveness, R&D expenditure, etc.)? Are there any differences in the impact on the downstream space start-up management and development?"

1. "Upstream: Aumento dei requisiti tecnici e regolatori; Le startup devono integrare soluzioni avanzate per evitare collisioni e garantire lo smaltimento sicuro dei veicoli spaziali. Ciò aumenta la complessità tecnica e le spese di R&D - Downstream: impatto limitato, le startup downstream non affrontano direttamente i costi di compliance delle piattaforme spaziali, poiché si concentrano sull'uso dei dati (es. geolocalizzazione, osservazione terrestre). Tuttavia, normative stringenti upstream possono riflettersi in un aumento dei costi di accesso ai dati."

2. "Il quadro normativo attuale non valorizza a sufficienza le necessità del segmento di imprese di recente costituzione e ad alta crescita, vale a dire le startup. Il grosso delle misure regolative (ad esempio le space law costruite dai singoli stati) hanno speso un focus sui grandi player del settore aerospaziale."

Economic Impact Perspective

> "Given the demands of the current policy framework for space sustainability, if it were further developed, how do you anticipate it would economically affect your business (e.g., costs, revenue, R&D expenditure, etc.)?"

1. "Upstream Barriere all'ingresso: Un ulteriore inasprimento normativo aumenterebbe i costi iniziali per soddisfare requisiti più stringenti, rendendo più difficile l'accesso al mercato per le startup con risorse limitate Competitività: Le startup più innovative potrebbero avvantaggiarsi grazie a nuove tecnologie sostenibili Spese di R&D: La necessità di sviluppare soluzioni tecniche avanzate incrementerebbe la necessità di investimenti in ricerca e sviluppo, favorendo però la creazione di brevetti innovativi e quindi le possibilità di business Downstream Impatto indiretto: I costi più elevati potrebbero tradursi in un aumento dei prezzi per l'accesso ai dati Opportunità: Normative più rigide upstream potrebbero garantirebbero dati di maggiore qualità e affidabilità, creando opportunità per applicazioni innovative downstream e si scongiurerebbe il pericolo di una interruzione nella fornitura dei dati dallo spazio."

2. "Le società downstream tipicamente vivono un quadro regolativo molto più semplificato sia per quanto riguarda le tematiche di normative sulla sicurezza, sia per quanto riguarda le normative ambientali."

Effectiveness of Current Incentives

> "Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?"

1. "Gli strumenti normativi e gli incentivi attuali non paiono abbastanza adeguati per supportare le start-up spaziali. Sebbene esistano linee guida internazionali e norme nazionali, manca un sostegno concreto per aiutare le start-up a superare i costi elevati di conformità. Inoltre, le norme spesso favoriscono le grandi aziende, lasciando le start-up a fronteggiare barriere economiche e tecniche senza sufficienti agevolazioni."

2. "Dipende da quale area geografica, per quanto riguarda l'area Europea ci sono poche misure che possono favorire efficacemente i progresso delle società di space sustanability, in particolare per quanto riguarda l'adozione dei loro servizi da parte di soggetti privati."

Policy Instrument Proposal

"What policy instruments or incentives would you recommend to help firms in your sector achieve the demands of space sustainability guidelines more effectively?"

1. "Potrebbero essere incentivi economici o programmi, ad esempio a puro titolo indicativo: - Incentivi finanziari: sussidi, crediti d'imposta o accesso agevolato a fondi per progetti di sostenibilità spaziale - Partnership pubblico-private: programmi di co-sviluppo tecnologico con agenzie spaziali per ridurre i costi di R&D - Standardizzazione: creazione di linee guida tecniche più chiare e uniformi per facilitare la conformità."

2. "Per le startup nell'ambito della space sustainability servirebbero degli incentivi che possano favorire la loro adozione come fornitori da parte di grandi aziende e agenzie aerospaziali."

Appendix D

Appendix D

This Appendix presents the transcription of the questionnaire responses regarding the perspective of policy experts and policy-makers on the economic impact of the current policy framework for space sustainability on space sectors. For privacy reasons, all answers are reported anonymously.

Current Economic Impact

> "The current policy framework for space sustainability is mostly focused on the space debris issue, demanding minimization of collision impacts, break-ups, and malfunctions, avoidance of collisions with existing space debris or other operational assets, and reduction of orbital lifetime after spacecraft end-of-life. What economic impact do these guidelines have on space sectors, particularly satellite manufacturers, in-space service providers, and space start-ups?"

1. "Currently, I assess the current requirements as a minor in terms of their economic impact, and also dependent on actual national regulatory frameworks. A lot of these "requirements" are already implied as part of nominal operations (e.g. minimising collision probability)."

Effectiveness of Current Incentives

> "Do you consider the current policy tools and incentives adequate to support satellite manufacturers, in-space service providers, and space start-ups in compliance with sustainability guidelines? Why?"

1. "There is little incentive, apart from signalling "good will" and general "CSR" commitments at policy level. Should we strive for wider compliance tools should be adapted."

Policy Instrument Proposal

> "Do you consider the current policy tools and incentives adequate to support demand for compliance with space sustainability guidelines in your sector? Why?"

1. "Depending on the product/service they offer, but priritisation in terms of product/service procurement for those in compliance with the guidalines would be beneficial. Alternatively, stricter scrutiny in regulatory applications (licensing) would likely increase compliance, but the question of cost and return on investment would come into play - also in light of global competition with potentially more relaxed licensing rules."

Impact on Nation's Competitiveness

> "In your opinion, could a nation's strong focus on space sustainability, through the implementation of stringent guidelines and requirements, create a competitive disadvantage compared to countries with less strict policies? If so, do you think this might slow down the development of policy frameworks for space sustainability?"

1. "Yes that could happen. Therefore a European approach to sustainability should be nuanced, and be used as a tool to regain competitiveness rather than falling further down the competitiveness ladder."

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