D2.1 Overview of the Trends and Challenges for the European Space Sector

Document Author(s)	Mari Kolehmainen (ESF), Emmanuel Detsis (ESF), Jean-David Bodénan (ESF), Robin Pradal (PwC France; Section 3)
Document Contributor(s)	Miraslava Kazlouskaya (PwC France), Siddharth Shihora (PwC France), Robin Pradal (PwC France)

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Abstract

This report delivers an analysis of the future trends in the space sector in an effort to predict and anticipate the skill requirements of the field over the next decades. To fully cover this large and expanding sector, two approaches were taken.

The first approach focuses on the future scientific developments in Europe, both at the EU and national levels through European institutions and national space strategies. It was conducted through an in-depth analysis of their science and education, earth observation, and human and robotic exploration programmes. Reports, white papers, and documents from the representative entities managing space policies and activities of each country were analysed via desktop research and the future trends and projects were identified and listed.

The second part consists of a comprehensive analysis of future trends in the space services and businesses sector, underpinning its importance in modern industry growth and sustainability. Segregated into five primary sections, it emphasises distinct domains crucial to the space industry: Earth Observation, Satellite Communication, Satellite Navigation, Access to Space and Launch Systems, and Space Safety. The document meticulously navigates through each domain's value chain, key programmes, market dynamics, and anticipated downstream activities. Additionally, an evaluation of technologies, services, and applications relevant to each domain is provided.

Keywords

Skills, Space Sector, Research, Industry

Demand and supply trends – Existing and future space technologies, applications and services – Earth Observation – Satellite Communication – Satellite Navigation – Access to Space – Space safety

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Information Table

Contract Number	**101082636**
Project Acronym	ASTRAIOS
Project Title	Analysis of Skills, Training, Research, And Innovation Opportunities in Space
Topic	HORIZON-CL4-2022-SPACE-01-72
Type of Action	HORIZON-CSA
Start date of project	1 January 2023
Duration	36 months
Project Coordinator	ESF
Version	#1.0
Responsible Partner (organization)	ESF
Actual Date of Delivery	22 December 2023
Dissemination Level	PU

Document History

Version	Date	Status	Author	Description
1.0	14/05/2024	Final	Mari Kolehmainen - ESF	Public version for dissemination

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Disclaimer

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).
The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS consortium. These represent the opinion and findings of the author(s). The European Union (EU) is not responsible for any use that may be made of the information they contain.

Table of Contents

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

List of Figures

List of Tables

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

1. INTRODUCTION

Space as an industrial and research sector has been critical worldwide for the past decades and its importance should only grow in coming years. European countries have been an active force in space research and industry with strong independent space capabilities, access to space, research institutions, and space industry. Beyond exploration and developing a better understanding of other planets, space activities are essential for sustainability, security, and a growing part of the economic strategies of Europe and its countries.

As the global space sector undergoes significant transformation and rapid industrialisation, the national and European space policies continually evolve and adjust to this dynamic ecosystem. This ensures they can effectively address current challenges and anticipate future needs. In the face of this growing importance, future generations of professionals with essential skills to contribute to the different facets of the space sector will be needed.

To answer this need for qualified professionals in the space sector, the ASTRAIOS project aims to build an inventory of skills offered by higher education institutions in all EU countries and compare them to the current and future demand in the space sector to assess how well the current skill offering serves the future evolution of the sector.

This document is a report of the preliminary analysis for Task 2100 from the ASTRAIOS project. The main goal of this task is to assess the current and future knowledge demand in the space sector (Section 1.1 below).

The report is divided into four sections. The first introduces the context of this report and its place in the ASTRAIOS project. Sections 2 and 3 address a different facet of the space sector in the EU and the UK. The first two sections, written by members of the European Science Foundation, focus on the scientific trends and challenges of national and European-wide space programmes, as defined by national space governing entities (e.g., space agencies and ministries), and the European Space Agency (ESA). The third section is an in-depth analysis of the services and business applications in the European space sector, subcontracted from PriceWaterhouseCoopers Advisory SAS (PwC).

1.1 Deliverable updates in 2024

Task 2100 and D2.1 (this report) are part of a larger effort to map the educational offer and the possible skills gaps in the EU and the United Kingdom, that covers work in WP1000, WP2000 and WP3000 of the ASTRAIOS project. The current report is the first effort to define potential future needs of the space sector as a whole in terms of skills needed by future workforce, based on strategic directions of the EU and ESA member states, as well as the EC and ESA.

The qualifications needed to answer these needs will be explored in WP3000 of ASTRAIOS. From them, the knowledge and skills that are and will be in demand in the space sector in the next 10 to 15 years will be derived (Deliverable D3.1).

The comparison of the skills currently being offered by higher education institutions and the future demand will be comparatively analysed in WP3000 to identify any gaps, thematical or geographical that might be present in Europe. Recommendations for measures to overcome these gaps will be generated in WP4000, as well as Massive Open Online Courses (MOOC) to fill in some of the gaps in an easily accessible manner.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

2. SCIENTIFIC PROGRAMMES OF NATIONAL SPACE GOVERNING ENTITIES AND THE EUROPEAN SPACE AGENCY

2.1 Introduction

Scientific discovery is a fundamental human endeavour that enriches our lives, expands our horizons, and challenges our intellect. It advances society through the basic knowledge that it generates, the technological, industrial, and organisational advances that it drives, and the commercial applications that it enables.

The space environment provides a unique laboratory for studying fundamental physical and biological processes and testing new ideas. The development of instrumentation capable of surviving the harsh ride to space and operating successfully under its extreme conditions presents engineering challenges that drive technological progress unlikely otherwise to occur. The knowledge and capabilities generated underpin a cornucopia of practical applications crucial to the functioning of an advanced, culturally vibrant, secure, and prosperous society. Observations from space play a critical role in addressing pressing societal challenges such as climate and environmental change, natural disaster response, and resource management. The vista opened up by space inspires new generations of scientists and engineers. It fosters international collaboration and generates interest and pride in the general public. Europe's position at the scientific and technological forefront, achieved through the collaborative efforts of the 27 EU member states and/or the 22 ESA member states, is a remarkable feat, unique globally.

Traditionally, the space sector has required substantial investments in areas such as human space exploration, making it the domain of large nations and organisations with considerable financial resources. However, the swift evolution of technology in recent decades has facilitated the exploration and exploitation of space through innovations such as small satellites, allowing even the smallest EU nations to participate. This has brought about an increased focus on the potential for European businesses, researchers, and public authorities to exploit the space economy.

The space sector is becoming an ever more important international catalyst for technological development and for innovation in general. The implementation of Galileo, Europe's Global Navigation Satellite System (GNSS) and Copernicus, the European system for Earth Observation (EO), have unlocked new opportunities for the space economy that is only expected to grow in the coming years. The European Commission (EC) adopted the new EU space programme in 2021 and presented its new strategy for European Union space security and defence in March 2023. Several small European countries have initiated their very first national space strategies, while the larger, more established European space nations have presented their updated space programmes.

2.2 Methodology

The analyses presented in this section of the report are based on desk research of publicly available documents that were collected online during the second half of 2023. National space programmes and space strategies are available for all EU nations with established national space agencies, as well as the United Kingdom. For many smaller countries, however, space activities operate under various government ministries, and finding a cohesive space strategy for many of them was challenging. For these nations the collected documentation includes any official programmatic or strategic information found on government websites, or through their association with the European Space Agency (ESA). All documents used in this analysis are listed in Appendix A.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

The majority of the documents were directly available in English, in addition to the national languages. In six cases – Belgium, Finland, Italy, Romania, Netherlands, and Slovenia – the documents were either translated using common translation software or read by a native speaker. All EU-27 countries and the United Kingdom were included in this analysis. All European-level agency documentation analysed in this section was publicly accessible in English through the agencies' websites.

2.3 How do we define science?

For the purpose of this report, and considering the vast scientific and engineering disciplines that are utilised in the space sector, we will consider the "Pasteur's Quadrant"[1] classification of scientific research as the framework that helps us answering the question "what is science". In this scheme, there are three classes of *research*:

1. Pure basic research which deals with fundamental sciences that seek fundamental understanding of nature (i.e., theoretical astrophysics, quantum mechanics, etc.)
2. Pure applied research, which aims to solve immediate problems (i.e., power production, propulsion, etc.)
3. Use-inspired research, which seeks both to understand nature at a fundamental level and provide solutions to current societal problems (the principal example being the vaccine development by Luis Pasteur).

For the purpose of considering the **scientific aspects of European activities in space**, we will mainly focus on pure basic research and use-inspired research. Additionally, the report remains at a high-level outline of science related strategic guidelines (i.e. focus of programme, specific large scale missions), without going into details on the scientific roadmaps or scientific disciplines engaged. Finally, the report concerns agency only input, without dealing with science communities roadmaps or similar initiatives.

2.4 The European Space Agency

The European Space Agency (ESA) has been central to developing Europe's capabilities in space science, technology, Earth observation, and human and robotic space exploration for over five decades. Through skilful coordination, its achievements far exceeded what would have been possible through the separate efforts of the 22 member states. This accomplishment is widely respected and admired in the rest of the world. Scientific research within the Mandatory Science Programme (SCI), the Earth Observation programme (EOP), and the Human and Robotic Exploration programme (HRE), formed the bedrock upon which ESA's science related capabilities and successes have been built.

The ESA mandatory and optional programmes have facilitated research that spans from understanding the origins of the Universe through astronomy and astrophysics to unravelling Earth's complex processes, enabling physical access to a growing number of solar system bodies and the scientific exploitation of the human occupation of zero gravity. The science enabled by ESA programmes nurtured the growth of a European academic community at the global forefront, and a highly skilled space-based workforce, attracting and developing talent from across Europe and worldwide. In doing so, it catalysed the creation of world leading scientific, industrial, technical, and programmatic capabilities.

[1] *Stokes, Donald E. (1997). Pasteur's Quadrant – Basic Science and Technological Innovation. Brookings Institution Press. p. 196. ISBN 9780815781776.*

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

We review the scientific plans for the next decades of the ESA Science directorate (ESA/SCI - the ESA mandatory program), ESA Earth Observation directorate (ESA/EO) and ESA Human and Robotic Exploration directorate (ESA/HRE). Given the breadth of the ESA programmes, this report only touches on the major elements of the programmes that directly deal with *science* matter, primarily fundamental and/or use inspired research. Applied research will not be considered, although in several cases it is not possible to discuss the science without the engineering that underpins it.

2.5 National governance of space activities

Space science encompasses traditional elements such as astronomy, fundamental physics, planetary science, human space exploration, and space flight, as well as studies focused on satellite navigation, Earth observation, and telecommunications. Despite this broad scope, very few European countries currently have a comprehensive overview of space research carried out in the nation. Gaining an insight into the research activities conducted by various research communities throughout the European Union, including ongoing projects and the extent of international collaborations in space research, is challenging at best.

For most European nations, and for all smaller EU countries, access to secure, reliable, and relevant space infrastructure is through the common European programmes of Galileo, EGNOS (European Geostationary Navigation Overlay Service), and Copernicus, as well as those developed nationally and through programmes in ESA. The participation in ESA especially gives European researchers access to vital infrastructure for exploration, space research, Earth observation, and data exploitation of all the aforementioned.

For the larger European nations such as France, Germany, Italy, and the UK, space industry is built around the cooperation between national space agencies, the Large System Integrators (LSIs), and the industry primes, such as Arianespace, Thales Alenia, or Airbus. Their relationship with smaller European national industries is often established on a complementarity basis, which provides opportunities for smaller nations to participate in their value and supply chains, leading to a more stable and secure workload as well as involvement in innovative space development challenges.

National space strategies for the smaller countries in particular call for a closer cooperation between industry and research. Concentration of expertise and a strong focus on specialisation are desirable for the smallest nations and the new ESA associated members, such as Estonia’s focus on nanosatellites and most of Slovakia’s space industry focusing on Earth Observation. Assistance is needed for industry to obtain ready access to component testing and qualification laboratories and equipment, while facilities can be shared among individual companies, institutes, government entities, or with cooperating laboratories in Europe.

2.6 Space Science and Education

2.6.1 ESA SCIENCE Programme

The ESA mandatory Scientific Programme forms the backbone of the Agency and of related activities of the national agencies of the member states, regarding space science activities. The programme has a legacy of scientific and technical excellence and leads the world in key areas of space science with many historic firsts:

- Pioneering research in studies of the X- and gamma-ray sky, opening up new windows on the high energy Universe (EXOSAT, XMM-Newton, INTEGRAL)
- The first ever flyby encounter with a comet (Giotto) and the first cometary soft landing (Rosetta Philae-lander)
- The first landing on Saturn's moon Titan (Cassini-Huygens)
- The mapping and understanding of the primordial cosmic microwave background radiation (Planck)

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

- Laying foundations of European planetary science via Mars Express and Venus Express
- The pioneering development of space astrometry (Hipparcos) leading to the revolutionary mapping of the three-dimensional structure and evolution of our entire Galaxy (Gaia)
- Advances in understanding of the interaction between our Sun, the surrounding heliosphere, and the Earth (Ulysses - which uniquely operated out of the ecliptic, providing a new view of the Sun, SOHO, Cluster, SWARM, Solar Orbiter). These missions together provide Europe's central underpinning of the scientific basis of Space Weather
- The first space-based measurements of stellar seismology and Exoplanet transits (CoRoT) and the Exoplanet observatory CHEOPS, positioning Europe at the forefront of Exoplanet research
- The demonstration of technology enabling a gravitational wave detector in space (LISA pathfinder)

The science programme missions contribute to making Europe a highly attractive destination for scientists and engineers worldwide. With its achievements and high visibility, the programme plays a key role in continuing to inspire a flow of students in STEM disciplines, necessary to ensure a healthy pool of talent and skills to support European academia and industry.

The current cycle of ESA's long-term planning for space science missions is called **Cosmic Vision 2015–2025**. This is a series of mechanisms through which ESA's science missions are implemented, a necessary long-term plan because space missions typically take over two decades to go from initial concept to the production of scientific results. **Cosmic Vision 2015-2025** was created in 2005 and it is still ongoing with several missions to be launched in the future.

2.6.2 ESA Cosmic Vision 2015-2025

The missions that are part of Cosmic Vision[2] are classified in three categories: L for large flagship missions, M for medium size missions, and F for fast (smaller) missions. There are also other missions of opportunities, in cooperation with international space agencies, in which the European contribution is normally as a payload to an existing mission. The cosmic vision missions are selected by a bottom-up approach, where the scientific community proposes missions based on open slots of a call of opportunity. The Cosmic Vision is built around several scientific themes, which can be seen on the following table.

Table 1: Scientific pillars of the Cosmic Vision programme.

Theme	Scientific Topics	Key Missions	Launch Date
Planets and life	- Planet formation - Emergence of life	M3 – Plato, exoplanets telescope M4 – Ariel, exoplanets	2026 2029
The Solar System	-Plasma and magnetic fields in the solar system -Gaseous planets and	L1 – Juice, Jupiter exploration probe M1- Solar Orbiter,	2023

2 ESA COSMIC VISION website: https://sci.esa.int/web/cosmic-vision/-/46510-cosmic-vision?fbodylongid=2152. Last accessed: Nov 2023. Report: "*ESA's 'Cosmic Vision'"*. *ESA. 19 February 2014.* http://www.esa.int/Our_Activities/Space_Science/ESA_s_Cosmic_Vision

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Theme	Scientific Topics	Key Missions	Launch Date
	Moons -Asteroids and small bodies	heliophysics mission M5 – EnVision, Venus orbiter F1 – Comet Interseptor	2020 2031 2029 (with Ariel)
Fundamental Laws	- General Relativity, fundamental constants, quantum physics and UHE cosmic rays -Gravitational Universe -Matter under extreme conditions	L3 – LISA. Gravitational Wave observatory	2037
The Universe	- Early Universe, origin of Dark Matter and Energy - First structures - Evolution of matter formation	L2 – NewAthena, an X-ray observatory M2- Euclid, visible & NIR telescope F2 – ARRAKIHS, dwarf galaxies and stellar streams	2035 2023 – 2029 2030+

As can be seen in the above table, there are several missions that are yet to be launched. Given that the average life of a space mission is between 3 – 10 years (of producing data), and that it might takes years for the full data to be exploited, the scientific communities served by the above missions will have important data to be looking forward to. The next sections will take a bit closer look to the two large scale mission (L-class), LISA and NewAthena, as these are the biggest European missions to come in the future and will define their decade (2030s) regarding the science output.

2.6.2.1.1 Special Focus on Future Mission: LISA

The Laser Interferometer Space Antenna (LISA)[3] will be the first European space-based gravitational wave observatory. Gravitational waves are ripples in the fabric of space-time emitted during the most powerful events in the Universe, such as pairs of black holes coming together and merging. Gravitational waves have been detected by ground-based observatories before – by experiments such as LIGO and the European Virgo observatory – but these facilities are limited in size and sensitivity. While ground-based detectors are sensitive to gravitational waves with frequencies of around 100 Hz – or a hundred oscillation cycles per

[3] *The ESA–L3 Gravitational Wave Mission Gravitational Observatory Advisory Team Final Report* https://sci.esa.int/science-e/www/object/doc.cfm?fobjectid=57909

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

second – an observatory in space will be able to detect lower-frequency waves, from 1 Hz down to 0.1 mHz Gravitational waves with different frequencies carry information about different events in the cosmos, much like astronomical observations in visible light are sensitive to stars in the main stages of their lives while X-ray observations can reveal the early phases of stellar life or the remnants of their demise.

In particular, low-frequency gravitational waves are linked to exotic cosmic objects than their higher-frequency counterparts: supermassive black holes with masses of millions to billions of times that of the Sun, that sit at the centre of massive galaxies. The waves are released when two such black holes are coalescing during a merger of galaxies, or when a smaller compact object, like a neutron star or a stellar-mass black hole, spirals towards a supermassive black hole. Observing the oscillations in the fabric of spacetime produced by these powerful events will provide an opportunity to study how galaxies have formed and evolved over the lifetime of the Universe, and to test Einstein's general relativity in its strong regime.

LISA will be able to observe the entire Universe in high-frequency gravitational waves, but also low-frequency ones from other sources (such as those from merging supermassive black holes at the cores of massive galaxies). To detect lower-frequency gravitational waves, an observatory must span millions of kilometres – something that can only be achieved in space. This is the key requirement that makes LISA so particular. The mission will comprise three spacecrafts flying in a triangular formation 50 million km behind the Earth as our planet orbits the Sun. The three LISA spacecrafts will be placed in orbits that form a triangular formation with a centre 20° behind the Earth and a side length of 1 million km. Each spacecraft will be in an individual Earth-like orbit around the Sun. To be able to detect the minute movement of the spacecrafts when affected by gravitational waves, the distance between each of them will be precisely measured and monitored.

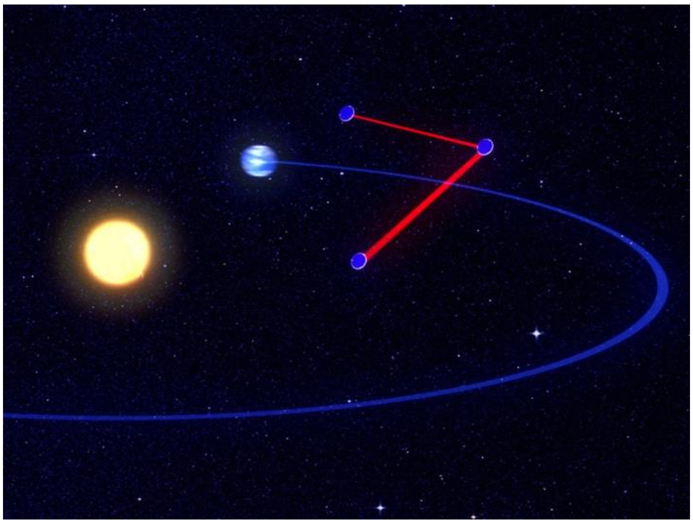

Figure 1: Schematic design of the position of the LISA spacecrafts (not to scale). Credit: AEI/MM/exozet.

Significant progress/advancement in several scientific fields are expected from LISA, most notably on cosmology and galactic evolution, as well as general relativity. Most importantly perhaps, LISA science will lead to improvements on the physics of gravity. It will also give rise to significant new methodologies for observations in the electromagnetic field that other observatories are sensitive to. The nature of gravitational waves allows for LISA to observe events months in advance from the time that such an event would register in the electromagnetic spectrum. As such, exciting science is expected when LISA is used in tandem with other observatories to observe events.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

LISA builds on the success of LISA Pathfinder and the US-based Laser Interferometer Gravitational-Wave Observatory (LIGO). LISA Pathfinder, launched in late 2015 and operational until mid-2017, successfully paved the way for LISA by demonstrating the key technologies needed for a large gravitational wave observatory to operate in space.

Regarding data, there are no conceptual barriers to the principle of laser-data interferometry data analysis. The overall volume of data from the satellites to earth is expected to be relatively small per year (~0.2 billion points per year). The difficulty comes in the numerical processing where the difficulty lies in developing the algorithms to differentiate between the various gravitational waves that are expected to be superimposed with each other when detected, thus disentangling them would be the key operation to be performed. It is estimated that the current algorithms that are used in LIGO, need to be improved by several orders of magnitude in terms of speed to be utilised in LISA data. However, the community remains positive that this is feasible, if work begins now to develop such computational methods.

2.6.2.1.2 Mission Focus: NewATHENA

NewAthena in an X-ray observatory-class mission based on ESA’s Silicon Pore Optics (SPO) technology which provides large effective area with excellent angular resolution, to be used for spatially resolved high resolution X-ray spectroscopy. NewAthena is expected to deliver superior wide field X-ray imaging spectroscopy and timing capabilities, far beyond those of any existing or approved future facilities. NewAthena is based on a conventional design retaining much heritage from XMM-Newton. Placed in an L2 orbit (behind the Earth, as viewed from the Sun for shielding from sunlight), Athena+ will be an observatory whose program will be largely driven by calls for proposals from the scientific community but may be complemented by key programs for science goals requiring large time investments. The observatories contribution to modern astrophysics will affect almost all fields of astrophysics. NewAthena is designed to investigate primarily two main topics:

- How did ordinary matter assemble into the large-scale structures we see today?
- How do black holes grow and shape the Universe?

Current communication capabilities of ESA are sufficient for NewAthena Operations. The Athena archive is expected to be ~500 TB after 5 years, which is comparable to current mission archives, such as the Herschel archive.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

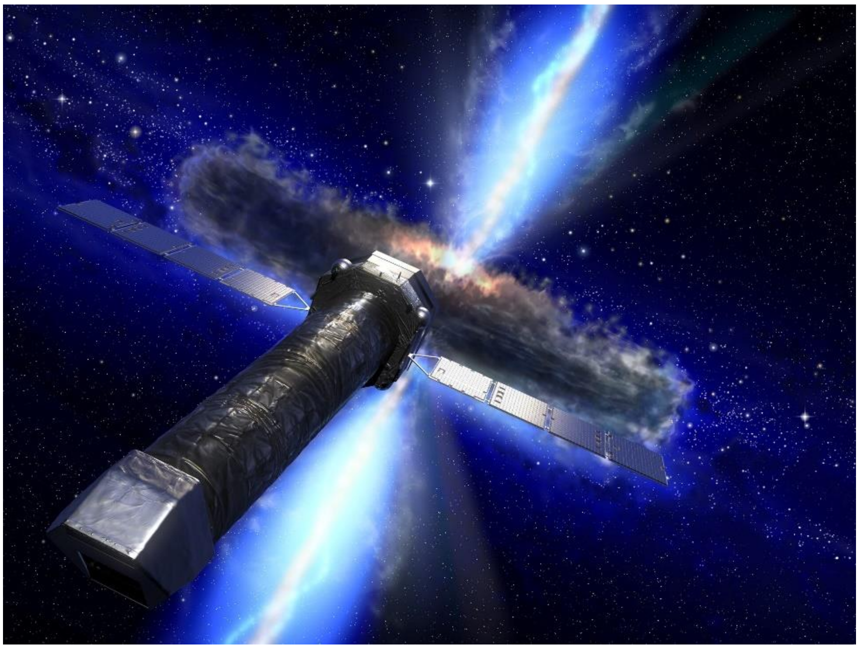

Figure 2: Artistic impression of the Athena X-Ray Observatory, whose mission is to survey a violent Universe of exploding stars, black holes, and million-degree gas clouds. (Credit: ESA)

2.6.2.1.2.1 LISA and Athena synergies

While LISA and Athena are individually impressive missions, the additional science the two missions will achieve by operating concurrently and gathering coordinated observations (so-called 'multi-messenger' astronomy) will provide further breakthroughs and address fundamental questions in modern astrophysics, investigating the physics of distant and merging black holes, bright quasars in active galaxies, rapid jets around spinning black holes, the cosmic distance scale, and the speed of gravity.

2.6.2.2 What comes after: Voyage 2050

The next ESA roadmap for Large and Medium class science mission is called Voyage 2050[4], targeting the decades 2040+, with missions to be realised in that timescale. The need for such long term planning is again routed in the long timeline that space missions require, sometimes reaching 20-30 years to go from idea to reality.

A call for ideas for Voyage 2050 was issued in March 2019 which generated a number of science themes and recommended areas for long-term technology development beyond the scope of Voyage 2050. The specific missions themselves will be selected in due course when ESA issues individual calls for mission proposals. The top three identified themes:

1. ***Moons of the giant planets:*** Investigating the habitability potential of worlds in our Solar System is an essential element for understanding the emergence of life, and is of particular relevance in the search for Earth-like planets beyond our Solar System. The mission profile might include an in-situ unit, such as a lander or a drone.

[4] Voyage 2050 : Final Recommendations from the Voyage 2050 Senior Committee. ESA Publications, May 2021.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

2. ***From temperate exoplanets to the Milky Way:*** Aiming at a detailed understanding of our Galaxy's formation history, including its "hidden regions" and the characterisation of temperate exoplanets in the mid-infrared. Such a mission could also target the return of thermal emissions from exoplanet atmospheres.
3. ***New physical probes of the early Universe:*** Aiming at missions exploiting new physical probes, such as detecting gravitational waves with high precision or in a new spectral window, or by high-precision spectroscopy of the cosmic microwave background – the relic radiation left over from the Big Bang. This theme follows the breakthrough science from Planck and the expected scientific return from LISA.

2.6.3 Science and space education as part of national space strategies

Success and key competence in space science is traditionally measured through successful EU funding bids made by national entities. These show that high-level research is carried out in virtually all fields of space research in the EU-27 and the UK[5]. In fact, many national space strategies list continued, and increased, European Commission Horizon framework funding as one of their key targets in the next decade.

While traditional space nations focus more on the upstream space exploration industry and tend not to emphasise fundamental science or space education in their space programmes, the opposite is true for some of the former eastern bloc nations. Several eastern European countries have seen national cosmonauts go out to space during the second half of the twentieth century, and many of them have national research institutes established during the cold war space race era which were featured prominently in their national space programmes. Many of these space sectors have since stagnated, however, and are only recently undergoing a revival. Space education is considered crucial in ensuring the competence and skills for the future workforce.

Countries with the longest histories of participation in European space programmes, notably France, Germany, Italy, and the UK, have grown to cover most if not all facets of the space sector. From fundamental research in related fields such as Astrophysics or planetary science, to engineering and deployment of satellites, to the use of EO data in the downstream sector. However, in these large countries and many others, any specific field of space science and research, although being actively pursued, are rarely mentioned in the national space programmes.

One of the main reasons for this omission is likely the academic independence of research institutes. A widely adopted approach to research follows a bottom-up scheme with researchers proposing subjects or areas of research for funding. This is generally seen falling under the umbrella of academic freedom of universities and academic researchers, and is therefore not detailed in governmental space strategies.

It is thus noticeable that a few countries do mention research in their strategy documents.

A national programme in Luxembourg (LuxIMPULSE) supports initiatives focused on the development of innovative space technologies, more specifically in the fields of material sciences for lightweight spaceflight materials, network provision, software development for plasma simulations, and in-situ production of solar panels on the Moon. The Czech Republic will concentrate on developing space technologies for both spacecraft and ground-based segments. The development of scientific payloads for missions is also intended to strengthen synergies and cooperation between academia and industry. The overarching goal is to engage

[5] EU SPACE – EU Space Skills factsheets prepared by STARS*EU: EU Space Education - Stars EU

in more ambitious projects and missions, providing the country with strategic objectives in space, accelerating capability development, and enhancing visibility.

The establishment of stable commercial space markets and facilitation of successful technology transfer to the non-space economy is widely mentioned in national space strategies. The legal and regulatory environment for space activities should be favourable to capitalise on the expansion of commercial research and development and help encourage and nurture start-ups. Sweden aspires to play a significant role in the space sector policy and legislation development.

One of these countries is Latvia, which possesses a robust STEM foundation with potential applications in the space sector. According to its national space programme, however, the existing opportunities in this domain have been recognised as insufficient. In response, the Ministry of Education and Science is establishing traineeships in collaboration with ESA. Universities in the country are actively committed to designing new courses and lifelong training programmes with a focus on space studies.

Another example is Hungary, which is working towards implementing and sustaining educational programs in space science, research, and engineering at both secondary and higher education levels. This initiative aims to boost prosperity in the space sector and provide additional support to national research institutions. Similar goals have been introduced in Slovenia, which concentrates on efforts to guarantee the presence of the next generation of scientists by promoting STEM subjects and strengthening university curricula.

Poland aims to increase support in both upstream and downstream domains, including scientific research units as well as universities. Particular emphasis is put on space education and continuing space research at the highest level, with specialised training programmes and workshops for the space sector.

Recognising the importance of the specialised skills and advanced knowledge developed through space-related graduate programmes at the University of Malta, the country is committed to ongoing investment in these programmes. Additionally, a scholarship programme will be implemented to promote participation in space sciences. The University of Malta will also explore the introduction of new modules in space-related subjects aligned with emerging technologies such as cyber-security and space regulation. Offering these modules as electives to students in disciplines outside of space education would foster and stimulate space learning among those studying subjects that complement, though may not be directly connected to, space studies. The ongoing development of educational courses and opportunities in the field of space will position Malta as a distinguished destination for space education, facilitated by making the programs accessible through initiatives like the Erasmus scheme and other international student programs.

2.7 Earth Observation

The current climate change and the biodiversity crisis threaten the natural systems upon which we depend. The evidence that this is so, and that human activities are the cause, was derived from a combination of theory, modelling, and a multitude of observations, both *in situ* and from space. But it is the vantage point of space that has transformed our ability to observe the planet as a complex, unified, interconnected whole. Geostationary and low-orbiting satellites provide the bedrock upon which rely the understanding of the Earth system, the monitoring of its behaviour, and the management of human affairs to mitigate and adapt to climate disruption.

ESA identified Earth Observation as a priority in the early 1980s and previous work within ESA, the EC and the member states has resulted in a programme that is second to none worldwide. The ESA and EC missions constitute fundamental components of the global Earth Observing System, contributing to regular IPCC (Intergovernmental Panel on Climate Change) syntheses and yearly reports on the State of the Global

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Climate by the World Meteorological Organization (WMO), which in turn address the pressing need for evidence-based decision making regarding the climate and the environmental crises, and service development in ESA Member States. The ESA and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) close coordination on meteorological satellites in Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO) contribute to day-to-day citizen life. ESA's technology developments in cooperation with EUMETSAT provide the critical foundation for the 'Next Generation' of GEO and LEO operational meteorological satellites.

The next section focuses on ESA EO programme elements that concerns scientific elements (in contrast to operational EO that is the domain of EC and EUSPA. These are considered in the sections 3 and 4).

2.7.1 European Space Agency's Earth Observation programmes

There are three main components of the ESA EO Programme:

FutureEO which aims to develop new Earth Observation Systems that respond to scientific and societal challenges concerning the climate. This is the R&D part of the ESA EO Programme and technology and applications that result from its activities are then utilised in the other components.

Customised EO: which addresses specific institutional or commercial user needs for operational services.

Operational EO: this includes large operational infrastructures such as Copernicus and EUMETSAT. The systems and technologies used within this component are prepared in FutureEO. The Copernicus constellation, comprising Sentinels 1 – 3 and 6, provides a comprehensive data stream covering the atmosphere, oceans, land, and ice, which supports a huge variety of scientific applications, operational services and a vast user base. This close coordination of the ESA Future EO Earth Observation Envelope Programme with the European Commission has established European global leadership in Earth Observation.

We will focus on the FutureEO, which is the scientific part of the EO programme and forms the backbone or tree trunk of the ESA EO activities. The main element of FutureEO are its current Earth Explorer satellite series, originating with the pioneering ERS-1/2 missions and Envisat. The European Earth observation programmes lead the world from the scientific, technological and applications standpoints. They provide the biggest volume of data and most of the insights about climate and global environmental challenges.

2.7.1.1 Earth Explorers

The series of Earth Explorer research satellite missions, started in 2009, are central to the ESA EO programme. These missions are created based on mission proposals by the scientific community. They demonstrate how breakthrough science and technology can contribute to deeper understanding of our planet, from different aspects in the climate system such as atmospheric dynamics and ice melt, to societal issues such as food security and freshwater resources. Additionally, and most importantly, Earth Explorers provide a sound heritage for developing operational missions. For instance, some of the current and future suite of Copernicus Sentinel missions and the technology underpinning their functions, were demonstrated by the Earth Explorers.

The Earth Explorer series of satellites and their mission objectives can be seen in Table 2[6].

[6] https://earth.esa.int/eogateway/missions/earth-explorers

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Table 2: List of Earth Explorer series of satellites.

EE#	Mission	Objective	Status	Launch Date
1	GOCE	Gravimetry	Completed	2009
2	SMOS	Water Cycle and Climate	Active	2009
3	CryoSat-2	Glaciology, polar regions	Active	2010
4	Swarm	Earth's magnetic field	Active	2010
5	ADM-Aeolus	Global Wind profiles, weather forecast	Active	2018
6	EarthCare	Clouds and Aerosols, Earth IR emitted Radiation, Solar reflection	Future	2024
7	Biomass	Carbon cycle and forest ecology	Future	2024
8	FLEX	Chlorophyll fluorescence	Future	2025
9	FORUM	Earth's surface temperature regulation	Future	2027
10	Harmony	Ocean circulation patterns, Glacial dynamics, land-surface topography	Future	2029

The Earth explorer 11 candidates as of 2023 are:

- CAIRT intends to take measurements needed to make a necessary step change in understanding the links between climate change, atmospheric chemistry, and dynamics in the altitude range of about 5 to 115 km. CAIRT would be the first limb-sounder with imaging Fourier-transform infrared technology in space.
- WIVERN which would provide the first measurements of wind within clouds and precipitation. There is a notable gap in global observations of wind in cloudy regions. The mission would also deliver profiles of rain, snow, and ice water. The mission would improve forecasts of hazardous weather and provide new insights into severe storms.

The EE 11 will be decided in 2025, with projected launch dates in 2032/33.

2.7.1.2 EO Data Exploitation

Given the plethora of data available from the Earth Explorers and other missions, as well as the climate imperative, it doesn't come as a surprise that there is considerable investment in EO downstream services and EO missions derived data products. These are offered for free to the community and the public. The current ESA EO data catalogue includes data from 82 missions, most of them with several datasets[7]

[7] https://earth.esa.int/eogateway

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

2.7.1.3 From Climate Science to Climate Action

The ESA Earth Observation programme is uniquely structured in regard to the ESA programmes, in the sense that it is the only programme that deals with science, technology, as well as applications. The urgency of climate change and the importance of space observation and space derived data products, necessitate a continuous engagement between all relevant stakeholders, in order to create the necessary data and information that society needs to take action. This is not a trivial exercise as the data products that the scientific community uses need substantial processing, placement in the correct context and augmentation with other sources of data to be useful to other stakeholders. Thus, ESA has initiated a new programme that is not part of the EO programme but is closely related and intertwined with: the **Space for a Green Future Accelerator.** This is a co-governed and independent non-profit partnership of Green Transition actors. It engages governments, businesses, multilateral institutions, civil society groups, end users and citizens. Its objective is to consider the complex social-environmental economic dynamics, including pollution and biodiversity, energy security and transport optimization and produce actionable information, assess scenarios for policy implementation, and offer tailored services. This is a very new development with 2022 being the initiation of the accelerator initiative, which was validated by the member states in 2023. The results are still to be produced but this initiative indicates the future direction that ESA considers regarding Earth Observation, as a provider of data and producer of tailored services.

2.7.2 National activities in EO

Space sector provides a significant part of the knowledge we have about our planet's climate and general state. In times of disasters like earthquakes, forest fires, or floods, satellites play a crucial role by providing immediate information, facilitating better coordination among emergency and rescue teams. In the future this contribution will be even more significant with data and digital infrastructure supporting researchers, businesses, and authorities in finding sustainable and cost-effective solutions to the challenges we are facing.

At national level, the scientific knowledge gained through space research is generally seen as an opportunity for the development of new methods and new products and services in the business community, and for the development of the public sector.

Virtually all national reports surveyed in this study list involvements in Earth observation, which centre on advancing space-based infrastructure to enhance understanding of the environment and climate. Initiatives such as urban sustainability, promotion of green values, national security, and EO contributions to the development of smart cities are listed for most countries with national space agency space programmes.

Many strategies describe a growing reliance on space-based monitoring systems, as more tasks of crucial importance to society depend on space-based systems being accessible, resilient, and reliable. In the future these systems will contribute to further security and contingency preparedness throughout Europe. National authorities in hard-to-reach areas, such as the Arctic, can become better at handling extreme weather and natural events, rescue operations, as well as enforcing national safety as a whole.

2.7.3 Space based applications for climate and society

Data and signals derived from space have great potential to support decision-making and action across a wide range of sectors, involving both private and public stakeholders. While the utilisation of space data is still not fully realised, information from remote sensing and navigation satellites, including data from Copernicus (fig. 3) and Galileo/EGNOS, is becoming more accessible. This trend is expected to encourage greater use of space applications in downstream segments at the national level. Virtually all EU nations name

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

the utilisation of space data and services to facilitate sustainability and green policies as one their main goals.

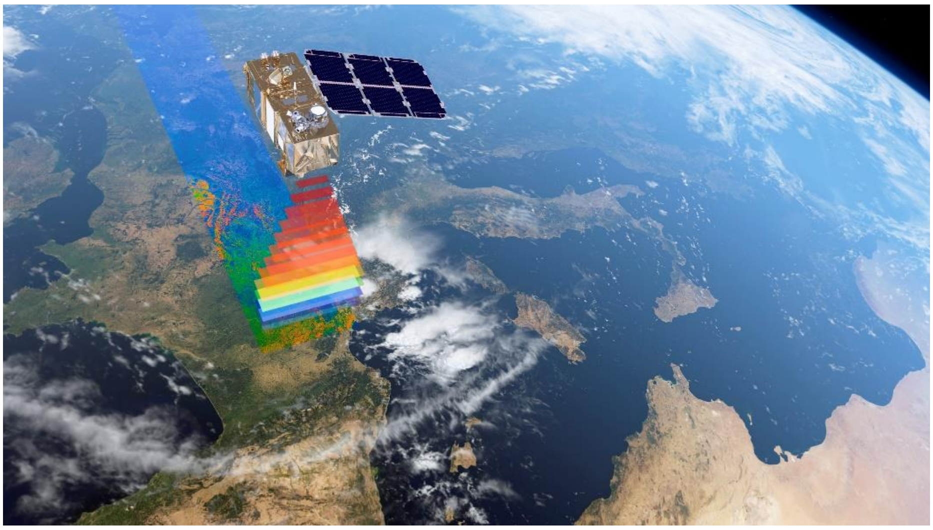

Figure 3: Artist vision of a Sentinel-2 satellite acquiring high-resolution multispectral data, as part of the Copernicus programme (Credit: ESA).

Space is one of the central enablers of digital economy. The emergence of the New Space economic model, or Space 4.0, focusing on commercialising the space sector through small satellites and innovative services, presents a significant change to the traditional, institutionally led space industry. This new paradigm enables easier and cheaper access to space than ever before and offers small businesses an entry to a market that was formerly only publicly funded at national level.

While spacecraft development has historically been dominated by LSIs, components for small satellites in Europe are mostly produced by small enterprises founded in the last 10-15 years. Technical conditions are evolving due to miniaturisation and advancements in electronics, enabling higher functionality in smaller satellites at a significantly reduced cost compared to previous standards. The availability of smaller, flexible launchers presents better opportunities for launching small satellites. The need for information by companies and organisations that can be addressed using space data creates a demand, and thus a foundation, for a commercial space market. Access to venture capital has led to the privatisation of segments of space infrastructure and its information flow. Public funding for technology development is no longer primarily driven by the needs for international cooperation in space. Success for private entities in the New Space era requires a high level of competitiveness, albeit in somewhat different areas than before.

Increased digitalisation and the introduction of new data management tools make it possible to handle large amounts of data, thereby becoming a strategic resource. Space data are increasingly integrated into various societal functions, driving technological development across multiple domains, such as the rapidly growing area field of Artificial Intelligence.

The growing potential thus exists for not only space businesses, but also for enterprises that can enhance their production activities through the use of space data and space services. This extends to public authorities capable of optimising their operational processes, contributing to the overall growth of the space economy.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

2.8 Human and Robotic Space Exploration

2.8.1 ESA HRE

The exploration programme of the European Space Agency, named "Terrae Novae" (former Exploration Envelope Programme – E3P-) builds on and expands 50 years of rich history in ESA Low Earth Orbit and Solar System human and robotic exploration, independently and with international partners, from Spacelab to Columbus and the Cupola, and now I-Hab and ESPRIT, and from Mars and Venus Express, Huygens and Rosetta (executed under the science programme), to ExoMars and the Mars Sample Return mission[8].

The four cornerstone campaigns - Humans in Low Earth Orbit, Humans beyond LEO, Lunar Surface Activities, and Mars Robotic Explorations - provide a well-crafted foundation for enhanced ambitions as humans embark on extending their permanent presence at the three exploration destinations: LEO, the Moon, and Mars.

The programme of opportunistic science that accompanies the Solar System exploration activities, reflects the longstanding European excellence in the domain. It covers fundamental research in physics, biology, and planetary sciences, as well as applied sciences such as health research, energy transfer, and material processing.

The programme's current strategy for the next decade is currently structured around three goals:

- Humans in LEO which aims to ensure a continuing present to the International Space Station, until its end of life, in 2030+ and prepare for the post-ISS activities.
- Exploration of the Moon, with the ultimate objective of the first European Astronaut on the Moon in the coming years/decade. The aim is to develop the necessary capabilities within Europe with European led projects as well as international efforts, develop the necessary infrastructure and scientific assets for such an endeavour and develop the necessary capabilities in human landing and surface mobility.
- Robotic exploration of Mars that will create the foundations for an eventual European to Mars mission. Several technologies need to be developed and tested (i.e., landing, power production, entry, ascent, landing) as well as mastering the necessary logistical chain for such an endeavour. Scientific studies of Mars take prominent place here with several missions that seek to understand better the Red Planet.

Science is an integral part of the programme, integrated in the exploration activities. "Exploration Science" is a concept of scientific goals that are opportunistic in nature (i.e., what science can we do once we get at the destination) or an enabler (i.e., what do we need to know in order to get there).

Recent successes in these areas include advances in the understanding of fundamental processes in multi-phase systems such as foams, granular materials and complex plasmas, diffusion and solidification processes in molten alloys, and a better understanding of quantum systems (Bose-Einstein condensates), as well as plant growth, signal transduction in plant and animal cells, physical and (mal)-adaptation of organ system functions when exposed to the extremes of the space exposome (i.e., the measure of all the exposures of an

[8] Terrae Novae 2030+ Strategy Roadmap, ESA, June 2022

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

individual in a specific time frames or in a lifetime and how those exposures relate to health), and heat transfer in capillary systems.

The following sections will describe the two main destinations In the near future, the post ISS human presence in orbit, and the Moon and Mars plans for the next decade.

2.8.1.1 Post-ISS human presence in Space

The post-International Space Station (ISS) human future in LEO or beyond is not yet defined as of 2023. The US and NASA are promoting and assisting the creation of commercial space stations, via industry contracts and competition, whereas China plans to continue expanding its space station Tiangong, which has reached 20% of the ISS size.

Europe's current plan for the immediate future centres around the development of a cargo vehicle for ISS and post-ISS utilisation, announced in the Space Summit 2023. This is planned in a similar manner as the US "commercial space" approach to LEO transportation, utilizing industrial competition and the award of commercial contracts, with the target of a commercial vehicle to transport cargo to and from the International Space Station by 2028. This is the first step towards developing a crewed vehicle.

The cargo vehicle can supply targeted space stations, as well as used as an exchange medium to ensure European astronauts access to ISS and beyond.

The current international plans for beyond LEO focus around the concept of Gateway, which will be a space station around the Moon. Gateway is an integral component of the NASA-led Artemis suit of missions to return to the Moon. The space station (which will be much smaller than ISS) will be a multi-purpose outpost orbiting the Moon and providing support for lunar surface missions. Scientific experiments would be possible inside Gateway albeit with a much-reduced available volume and power. The details of Gateway are not yet decided and thus the scientific community is not very sure on what science it can be done there.

From a Scientific perspective, Low Earth Orbit and beyond should be continuously utilised as a critical test platform for all deep space operations and protocols. There is a potential to create a partial gravity in LEO for different scale experiments – from microbes to humans and physical systems in partial gravity, including Moon and Mars gravity levels. This can help determine what countermeasures are needed to counteract the adverse effects of partial gravity, test operational procedures, identify human performance and sensory changes, as well as help identify microbes and crops that grow in closed environments in altered gravity levels. On-site production is a critical capability for a large range of vital items including tools, food, and pharmaceutical production.

The next generation of astronauts will go farther than humans have ever travelled in space before. Analytical tools and assessment mechanisms are needed to understand what biopsychosocial characteristics are required for humans to adapt to new destinations. Current astronauts working in LEO offer the baseline sample for characteristics that affect their performance, both positively and negatively, to evaluate the characteristics preferred for each destination. Pheno- and genotyping under ethical considerations, development of biomarkers and psychological testing were listed as key capabilities needed to select the best astronauts/crews for future space destinations. Going beyond LEO brings increasing levels of autonomy and isolation for the crews, requiring training for destination-specific operations.

2.8.1.2 Exploration of the Moon

The main development in Lunar exploration in recent years and for the future decades is the NASA Artemis programme that aims to return astronauts to the Moon, including significant surface infrastructure. China also announced plans to put astronauts on the Moon by the 2030 decade, with India recently announcing similar plans for 2040, following the successful landing of the Chandrayaan-3 spacecraft to the Lunar South Pole.

ESA and Europe are partners with NASA in Artemis and plan to have European Astronauts participate in Artemis missions and visiting Gateway, the lunar space station.

There are no concrete scientific plans on what to do on Gateway or the Lunar surface as the main driver of the ESA overall strategy is the development of the necessary capabilities that will allow for Europeans on the Moon. The plans have been evolving the last years and have yet to solidify in a concrete roadmap (as of 2023). However, key capabilities that are considered widely necessary for solving multiple aspects of humans living on the Moon can be identified and have been discussed in the scientific community.

The simulations of space conditions should be applied in realistic analogues to long-term missions, with development of improved countermeasures to mitigate the combined stressors that affect the health and performance of astronauts. Understanding both the biopsychosocial characteristics and operational needs required for each destination, as well as for the ultimate astronaut selection process itself is necessary. Training programs with operation integration, VR and asynchronous training materials are deemed necessary to identify the training and adjustments to operational needs for each destination (Gateway, Moon, Mars).

Comprehensive, non-invasive, integrated systems are key capabilities needed to measure the exposure to space conditions in the human body, and to evaluate the efficacy of countermeasures are also necessary for such endeavours. The Moon (and Mars) offer a platform to monitor the effects of radiation on the human body, study dust contamination and hazards associated with habitat atmospheres, the logistics required to support an extraterrestrial (crewed) base and the sustainability of transportation. Development of AI and robotic assisted rescue technologies are seen as key to assessing risks and protecting human health and maximizing surface performance.

2.8.1.3 Mars, the final destination

The Mars sample return (MSR) campaign is the cornerstone of mars exploration for the next years, with a human landing being the final goal for the future. There is already significant infrastructure around and on Mars, including communications and navigation network mission, weather satellite and several landers. Key technologies like in-situ resource utilisation (ISRU) and power generation from regenerative fuel cells have been demonstrated as well. The Mars robotic element of the programme continues to invest in the realisation of longstanding sciences objectives, such as searching for signatures of past and present life and will subsequently provide novel opportunities for Mars science, including the ability of European scientists to analyse returned Martian samples in the next decade. The two main elements of the Mars robotic exploration are now the Rosalind Franklin Rover (past name: ExoMars) and the Mars sample return mission. Both missions are currently considered in cooperation with NASA.

The future of Rosalind Franklin Mission is still being debated, after considerable setbacks in the area of cooperation with international partners in the past, that resulted in delays for the mission. The current target for launch is 2028. Scientifically, the rover is an extremely important mobile laboratory because it is the only rover able to investigate organic molecules at depth, and thus singularly suited to discover signs of extra-terrestrial life. This finding would be of such scientific and societal importance that it would change the way we, as humanity, perceive our position in the Solar System and Universe, and pave the way for future planetary exploration. No other mission, presently in operation or in planning, can offer these capabilities and with a very significant and enhanced role of Europe in exploring life on Mars.

MSR is especially ambitious, as it aims to bring back the first samples from the Martian surface by 2033. The samples are currently collected by the NASA Perseverance rover in Jezero crater and stockpiled on site. NASA and ESA are preparing the return mission that will launch toward the end of the decade to retrieve the samples and return them to Earth. If successful, the returned samples will provide an unparalleled resource to investigate the Martian surface.

Sample analysis will be available to European researchers and the possibility exists for European institutions to receive samples for further study, after the initial invitations that will take place in the US curation facility.

2.8.2 National HRE activities

The fast expansion of commercial activities in LEO and the global interest in Moon and Mars exploration has led to an increased focus on the design and development of innovative space technologies in Europe. National activities focus mostly on hardware and software development, strengthening existing capabilities to support the industrial base across the entire space sector value chain by developing space-qualified products with clear commercial potential.

Overall, national space programmes in Europe rely on operating and expanding their participation in human space exploration missions through the European Space Agency. This is particularly the case for smaller EU nations, while larger countries with well-established space agencies have the necessary capabilities for independent programs.

The French space agency CNES (Centre National d'Études Spatiales) is committed to advancing its space program with a focus on enhancing launch capabilities, working with ESA and other European partners on the upcoming Ariane 6 (fig. 4). CNES and their industrial partners (e.g., ArianeGroup, ArianeWorks) have a goal to establish a more sustainable and environmentally friendly launch facility at the Guiana Space Centre by integrating renewable energy solutions, requiring further expertise in environmental sciences. Additionally, CNES aims to integrate Artificial Intelligence more extensively into space transportation and introduce a new generation of compact launchers, requiring skills in the field of computer science. Furthermore, CNES actively participates in the Artemis Accords, contributing to the ongoing progress in Human and Robotic Space Exploration towards Lunar exploration. One notable initiative involves the development of a lunar seismometer for deployment on the Moon.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Figure 4: Ariane 6 - Test Removal of Mobile Gantry at Europe's Space Port in Kourou, French Guiana on 23 June 2023 (Credit: ESA).

The German space agency DLR (Deutsches Zemtrum für Luft- und Raumfahrt) intends to enhance its expertise in areas where it already possesses significant capabilities, ensuring its continued status as a leading nation in domains such as Synthetic Aperture Radar and satellite communications. Germany is actively engaged in developing sustainable access to space, conducting research on reusable launcher components and 'green' propellants in space.

Along with France, Germany is committed to expanding the exploration efforts within the solar system and beyond, including the exploration of extrasolar planetary systems. A crucial focus for future development is space safety, both for the detection of space threats and the removal of debris and other potentially hazardous objects from orbit.

The Italian space programme is focused on maintaining the country's involvement in space sector key capabilities. These include advancing both upstream and downstream activities in alignment with other European nations, such as space debris monitoring and removal, access to space, telecommunications, security, and Earth observation. An emphasis is put on developing and fostering space culture and international collaboration, not only through the development of STEM subjects, but also by establishing economic and legal frameworks. A distinct national focus appears dedicated to suborbital and stratospheric flight opportunities for conducting experiments relevant to the space sector.

Similarly to the other established space nations, the United Kingdom actively participates in various aspects of the space sector. With an objective to establish leadership in some of the emerging sectors related to space activities, a focus is set on in-orbit servicing, debris removal, in-space manufacturing, and space travel, as well as in-situ resource utilisation. A strong emphasis is put on further developing the monitoring of space weather and response preparedness to extreme space weather events. This particular focus seems somewhat unique and noteworthy, requiring the development of new skills and technologies.

2.9 Preliminary Conclusions

All facets of the space sector are ongoing important evolution. From the Earth's surface with the development of new, cleaner launchers and the use of EO data, to Mars and beyond. European countries

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

and their national institutions, both scientific and industrial, have a proven record of excellence in most aspects of the space sector that is reflected in their current capabilities and future developments.

2.9.1 European Space Science

Europe's ambitions for space and related sciences are high. The Cosmic Voyage programme includes missions such as LISA and NewATHENA to study fundamental physics of our Universe. The Earth Explorer missions, as part as FutureEO, show that upstream EO is not only driven by science but also allows breakthrough discoveries. EO provides a wealth of data and information for natural sciences such as climate science, and important applications for society at large. Exploration out of the atmosphere to LEO, the Moon, and Mars will also be one of the main challenges for the coming decades with many countries taking part in a rekindled space race, requiring critical capabilities in space but also on Earth to further prepare for such endeavours. The skills to carry out these ambitious programmes (physics, astrophysics, planetary sciences, biology spacecraft and instrument engineering, robotics, etc.) are already present in European institutions and research organisations in the member states as shown by recent successful missions.

It is important to note that most *scientific* programmes have a bottom-up approach in the definition of their priorities. Therefore, future developments reflect for the most part the status of the community. Thus, future skill needs in scientific endeavours, for the most part, are covered within the European universities and research institution plans, rather than governmental and supra-governmental organisations.

Member states will have a critical role in these programmes. While some countries such as France, Germany, and the UK have a long history of diverse space science activities, others, especially Eastern European countries, are re-launching or further developing their capabilities in the space sector, notably in electronics and EO. These developments show that a workforce skilled in a diversity of fields such as remote sensing, environmental sciences, software, data processing, or aerospace engineering, is already in place and/or being reinforced in European countries, and that it will need to be maintained to carry out their national space objectives.

There are perhaps three major developments that will create a new need for skills in future space science and apply to Europe as a whole:

1) *LISA mission*. The mission itself is technologically challenging and scientifically unique, and has the opportunity to open a new window to the universe for Europe and the world with novel discoveries expected in the field of gravitational waves. Gravitational wave data can enrich all areas of astrophysics with additional and complementary views to the objects in study. It will provide an opportunity for various areas of cosmology and astrophysics to progress further, faster, and thus support additional scientific staff in the field. Yet, it is the prospect of expanding our understanding of gravitation and spacetime itself which might lead to new physics and give rise to unprecedented scientific disciplines.
2) *Human exploration of the Moon and Mars*. The scientific disciplines involved in human exploration are briefly examined in section 2.8.1. In addition, if indeed sending European astronauts on the Moon and Mars becomes an accepted goal for the ESA member states, a necessary increase in the skilled workforce to support this endeavour will be needed, as this endeavour will require much more effort than the current status of supporting astronaut rides with international partners. Gateway as a destination might not differ (in the aspect of skills) from the ISS, but the Moon, and certainly Mars are very different destinations, and the astronaut support base in Europe will need to expand significantly.
3) *Earth Observation*. Earth Observation is perhaps the most active and important element regarding future skills needs. The urgency of climate change is widely known, and both EUSPA and ESA,

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

together with all European nations, are taking concrete steps to support a thriving EO data industry. However, a possible transition seen in certain space agencies becoming more involved in society as tailored data providers and climate product providers will necessitate a change of mindset, from space as a ‘scientific’ dataset provider to space as a ‘useful’ dataset provider. It is not clear that this occurs in many recent cases, and the ongoing paradigm shift still requires finalisation and implementation. This will require both traditional space disciplines to develop additional skillsets that help communication with societal actors. Conversely, people not traditionally experts in space data need fundamental space data understanding. The associated commercial opportunities are also significant. Given the importance and urgency of addressing climate change across all sectors of society, this represents the most important area of focus and growth.

Funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Figure 5. Mosaic of Europe made up of ESA satellite images (Credit: ESA)

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3. Provision of Service and Business Applications Analyses

This section presents a comprehensive exploration of the space services and business sector, emphasizing domains pivotal to the industry's growth and longevity. Aimed at delivering an evaluation of prevailing trends, market shifts, and up-and-coming technologies, the report is structured into five primary sections. These sections delve into Earth Observation, Satellite Communication, Satellite Navigation, Access to Space and Launch Systems, and Space Safety. Each section offers an insight into the value chain, key programs, market dynamics, and forecasts on emerging technologies and applications pertinent to the specified domain.

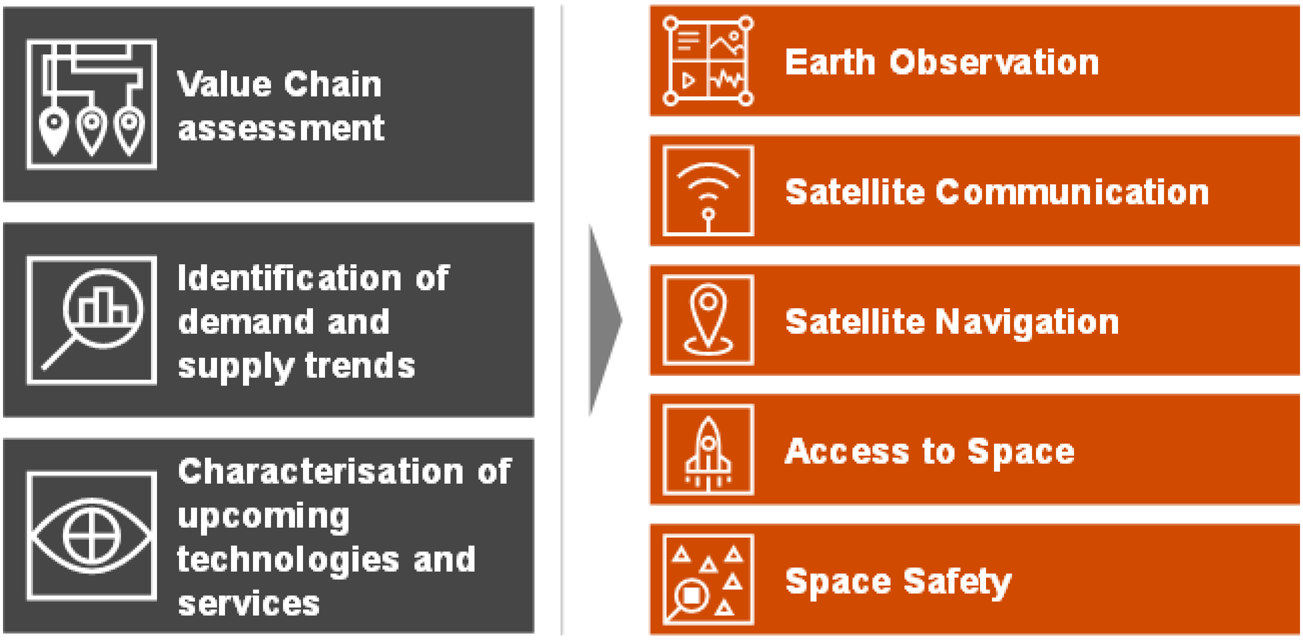

Figure 6: Scope of the report

Earth Observation

The Earth Observation (EO) value chain is an integral component in the acquisition, processing, and utilization of satellite-based data. The chain is meticulously structured, encompassing segments from Upstream to Downstream, with a special emphasis on serving satellite operators, data analytics providers, and government institutions.

Delving into the operational intricacies of the EO, there are several layers. The first is data acquisition and storage, which has seen a significant surge in recent years due to an increased deployment of satellites. This influx has enriched the volume and diversity of data available. Next, we have the Value-Added Services, where the focus is keenly placed on refining and enhancing the raw satellite data through advanced processing techniques. The Information Products stage melds VAP/VAS data with other external data sources to craft imagery that resonates with the end-user's needs. Lastly, the Big Data Analytics segment is about harnessing large-scale data. A prime example of this is the European Union's Copernicus DIAS platform, which stands as a testament to what advanced data processing can achieve.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Among the myriad of EO programs, two stand out. The Copernicus Programme, an initiative by the EU, is the continent's most ambitious EO venture, having evolved and expanded continuously since its 1998 inception. On the other hand, the Landsat Program, a collaborative effort by the USGS and NASA, has the distinction of being the longest-running EO initiative, with roots tracing back to 1972.

On the market front, the EO landscape is delineated by two primary revenue streams: the EO data revenues and the value-added service revenues. Projections by EUSPA for the 2021-2031 decade paint an optimistic picture. In the European Union, the data revenue, which stood at 82 million euros in 2021, is expected to rise to 117 million euros by 2031. On a global scale, the data revenue for 2021 was 536 million euros and is projected to leap to 797 million euros by the end of the decade.

The Earth Observation (EO) value chain plays a pivotal role in the acquisition, processing, and utilization of satellite-based data. This report outlines the various segments and operations involved in the EO value chain and provides an overview of significant EO programs and market dynamics.

The EO market is evolving due to various influencing factors. The conflict in Ukraine has spotlighted the importance of satellite data for military and intelligence purposes. Major insurance entities are harnessing EO data to refine their risk management tactics. Additionally, the agri-food sector is using EO for enhanced transparency, especially concerning chemical fertilizer usage. The rise of environmental and sustainability monitoring further propels the market. Meanwhile, a shift from traditional licensing to subscription models is enabling SMEs to incorporate big data more flexibly. Collectively, these elements are reshaping the EO industry landscape.

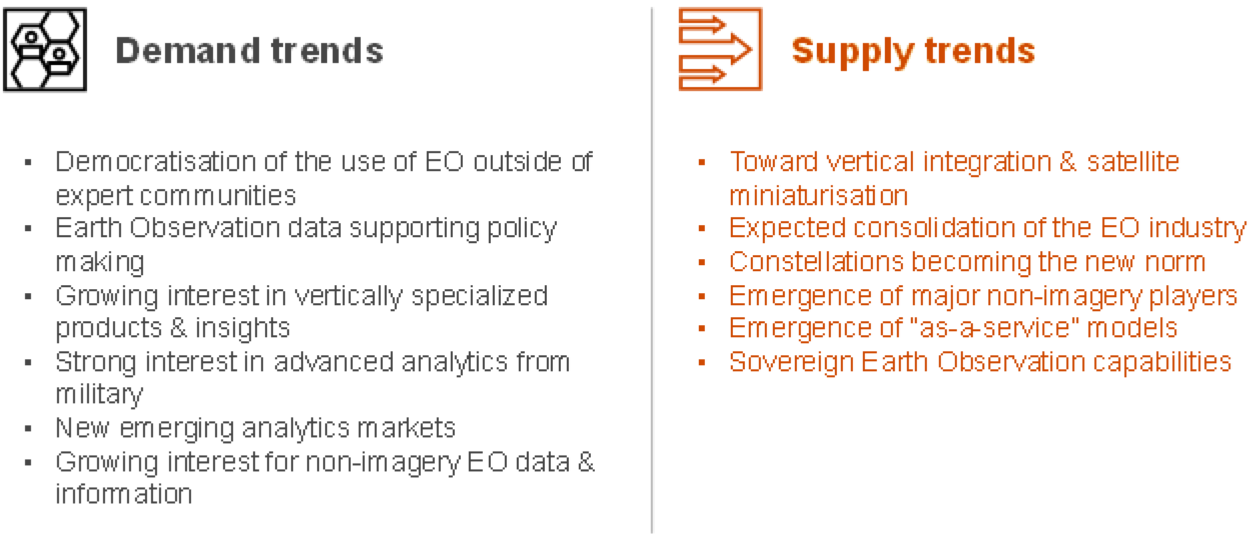

Figure 7: Summary of the main demand and supply trends in the EO domain

Technological progress will revolutionize the satellite imaging industry, notably with the increased use of SAR and InSAR systems offering high-resolution 3D images of Earth. These will be pivotal for mapping landscapes, infrastructures, and monitoring land movements. EUSPA has identified 16 growth areas for EO applications by 2031, such as agriculture, aviation, climate services, emergency management, and more. Notably, the insurance and finance sector will experience rapid growth due to its high innovation adoption rate. The rise of smart cities, utilizing technologies like IoT and satellite imagery, focuses on enhancing the quality of life and reducing environmental impacts. Satellite imagery aids in urban planning and the delivery of public services. Urban planning now depends on efficient remote sensing systems for high-quality, cost-effective data. The EC and ESA have prioritized urbanization among other key areas like food security and climate

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

change for future Sentinel missions. Data from these missions will support initiatives like the European Green Deal and the 2030 Agenda for Sustainable Development.

Satellite Communication

The Satellite Communication (satcom) value chain consists of three main segments: upstream, midstream, and downstream. The upstream phase centers on the design and manufacturing of communication satellites tailored for distinct orbital regimes, namely LEO, MEO, and GEO. This segment is responsible for the development of innovative payloads, such as High Throughput Satellites (HTS) and Very High Throughput Satellites (VHTS). It also focuses on creating innovative systems like inter-satellite communication and optical communication links, in addition to developing ground equipment for Earth stations, gateways, and both fixed and mobile end-user terminals. In the midstream segment, the value chain encompasses the roles of network operators, teleport facilities, and gateway operators. While network operators oversee the network's overall performance and traffic flow, teleport facilities facilitate the essential communication connections between the Earth and satellites. Meanwhile, gateway operators are in charge of the specialized infrastructure linking the satellite network to terrestrial networks. The downstream segment concentrates on providing raw satellite capacity across various frequency bands, such as Ka-band, Ku-band, L-band, and C-band. Beyond this primary provision, the segment also delivers a range of value-added services, including management network services and cybersecurity and encryption solutions. These specialized services cater to the diverse requirements of particular sectors, with industries like Oil & Gas, maritime, and aviation being prime examples.

The global satcom market is forecasted to grow from **$12.1B in 2021** to **$30B by 2031**, with a **CAGR of 9.5%**. Video applications such as Direct-to-Home (DTH) and Distribution, which historically anchored the FSS market, are predicted to experience decreased revenues in the coming decade. This decrease, attributed to the rise of telecommunications bundled packages and a shift towards OTT platforms, will see Distribution revenues drop from $2.4B to $1.5B and DTH from $2.3B to $1.4B by 2031. On the other hand, data-focused segments like Backhaul & Trunking and Broadband Access are expected to thrive. Backhaul & Trunking revenues are forecasted to surge from $1.9B to $6.1B by 2031, thanks to increasing data demands and the spread of 5G. The satcom industry is adapting to this by adopting terrestrial standards and enhancing their services. Broadband Access's potential is even higher, with projections estimating a growth from $1.4B to $10B within the same timeframe. The success of Starlink serves as a testament to this growth. Commercial Mobility also has optimistic projections, with expectations to rise from $0.9B to $5B by 2031, although the 2021 figures were impacted by COVID restrictions. With the pandemic's effects waning and travel resuming, the market is likely to rebound. The Government and Military sector is set for significant growth, from $0.7B to $3B by 2031, driven by geopolitical tensions and nations prioritizing strategic autonomy. From a regional perspective, North America and Asia are projected to grow robustly, reaching $6.8B and $6.6B respectively by 2031. In contrast, Europe shows a modest growth trajectory, with revenues increasing from $3.3B to $4.8B by 2031.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Demand trends

- Starlink enabling greater demand for consumer broadband
- Declining demand for video services more pronounced in Western Europe
- Optical communication links and adoption of 5G standards fuelling demand

Supply trends

- Oversupply of GEO and Non-GEO HTS capacity in the European Markets
- Resurgence of institutionalised satcom programmes
- Market under consolidation

Figure 8: Summary of the main demand and supply trends in the Satellite Communication domain

In the rapidly evolving satcom domain, several innovative technologies, applications, and services are anticipated to emerge, reshaping the future of satellite communication:

Within the upstream segment, several new concepts are emerging: Advanced optical and inter-satellite communication technologies are gearing up to optimize space and ground networks, enhance consumer broadband, and uplift in-flight entertainment & connectivity (IFEC), maritime infrastructure, and data-relay services. The introduction of electronically steered antennas offers more refined mobile connectivity across various sectors and promises better aeronautical and maritime connectivity services. Flexible satellites with innovative capabilities such as independent beam steering and digital channelizers are set to redefine services like flexible traffic landing, crisis communication, and versatile government/military communication. Very High Throughput Satellites (VHTS) are set to expand broadband and mobile connectivity solutions, while Quantum Key Distribution (QKD)-based satellites aim to revolutionize secure and encrypted communications.

In the Midstream segment there is an interest in optimized video software solutions to deliver high-precision, compressed, geo-tagged live video content over satellites, fostering services like ISR, remote inspection, and drone operations. DVB-S2 and HEVC standards are expected to enhance video applications, such as Satellite TV with the transmission of ultra-high-definition channels. With the advent of 5g Non-Terrestrial Networks (NTN) and OFDM, the integration of terrestrial 5g networks, satellite-enabled devices, and direct-to-device communication is set to get a boost. This transition augments satellite backhaul for 5g, promotes broadband services, and improves network interoperability.

Finally, for the Downstream segment: Multi-carrier satellite gateways are being developed to integrate multimedia support, including OTT, with facilities for multi-stream reception and transmission, aiming to refine DTH and DTT video delivery. Edge computing, both in space and on the ground, is being explored for in-orbit data processing and real-time communication link identification, aiming to provide comprehensive managed network services across various market segments.

Satellite Navigation

The value chain of the global navigation satellite system (GNSS) domain is divided into upstream, midstream, and downstream. The upstream sector includes actors contributing to an operational navigation space system. The midstream sector includes all activities related to the operation of GNSS to ensure ultimately the delivery of Positioning, Navigation, Timing (PNT) service, typically executed by satellite operators and GNSS service providers. The downstream sector includes all actors involved in the exploitation of GNSS service and delivering related value-added products and services to the final users. This includes for instance

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

the manufacturers of GNSS receivers and Personal Navigation Devices (PND) integrated systems (e.g., for car, aircrafts, vessels, precision farming) as well as smartphones applications, software applications and value-added services. Finally, GNSS end-users include a very wide range of institutions, companies and individuals using GNSS for their daily activities.

Several GNSS constellations and satellite-based augmentation systems provide navigation capabilities around the globe. At present, there are four main systems providing service globally: Global Positioning System (GPS) by the US, Global Orbiting Navigation Satellite System (GLONASS) by Russia, Galileo by the EU, and BeiDou by China.

The GNSS market spans various sectors where GNSS-driven positioning, navigation, and timing are essential in facilitating different capabilities. Revenues in this market are sourced both from device sales and from the suite of services enhancing or leveraging GNSS technology. Augmentation services include software offerings, digital mapping, and GNSS subscriptions, while value-added services capture earnings from data used for location apps over mobile networks, GNSS-enabled smartphone apps, fleet management subscriptions, and proceeds from drone services in various sectors. The European Union Space Agency (EUSPA) predicts a robust growth in GNSS demand over the upcoming decade, both in the European Union and internationally. Specifically, in the EU from 2021-2031, device-related revenues are forecasted to grow from 12.1 billion euros to 21.6 billion euros, and service revenues from 27.4 billion euros to 53.7 billion euros. Globally, device revenues are projected to rise from 48.4 billion euros in 2021 to 87.0 billion euros by 2031, while service revenues might jump from 150.5 billion euros to a staggering 405.2 billion euros. This trajectory showcases the integral nature of GNSS tech across numerous sectors and its sustained significance in years to come.

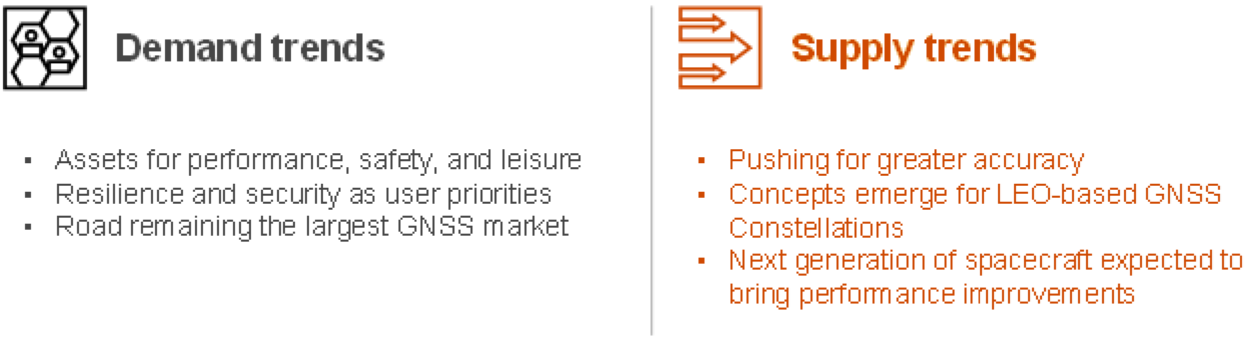

Figure 9: Summary of the main demand and supply trends in the Satellite Navigation domain

In the Satellite Navigation domain, several breakthrough technologies, applications, and services are surfacing across the value chain:

In the Upstream segment dual frequency (L1/L5 and E1/E5a) GPS + Galileo receivers are paving the way for enhanced navigation capabilities. This technology leads to services providing positioning integrity essential for safety-critical sectors. With the use of 6 atomic clocks, the Galileo Second Generation offers enhanced civil satellite navigation. Dual frequency smart GNSS receivers aim to achieve positioning accuracy right down to the centimetre level. This technology ushers in low-cost, high positioning accuracy services, particularly beneficial for land surveying.

Moving to the Midstream segment, GBAS Approach Service Type F (GAST F) enhances robustness against ionosphere and radio disturbances in a multifrequency GNSS setting. This is key for aircraft precision approach operations. The introduction of L1C facilitates GPS interoperability with other GNSS constellations

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

and is instrumental for high-precision surveying. M-Code GPS signal is an encrypted signal tailored for military receivers, introducing a more secure cryptography architecture.

In the Downstream segment, GNSS-blockchain integration is a novel approach in geolocation software. Platforms leveraging this integration provide automated verification of data trustworthiness. GNSS chip-equipped smartphones are revolutionizing emergency alert transmission through the Emergency Warning Satellite Service. For the railway sector, a certifiable on-board localization unit combined with GNSS-based multi-sensor fusion architecture offers a robust train control system.

Access to Space

Access to space is a key enabler of the whole sector and is itself an indispensable element in the overall space value chain. The Launcher Development segment Involves research and technological initiatives to create and enhance launchers. Key European contributors include ArianeGroup, Avio, MT Aerospace, and various space and research agencies. The Launcher Manufacturing segment, managed by “prime integrators” like ArianeGroup and Avio, this phase covers the production of launch vehicles, aided by suppliers providing components, raw materials, and sub-systems such as engines. At last, the Launch Operations segment entails activities that span from transporting launchers to their sites to ensuring satellites reach their intended orbits. Operations are chiefly overseen by ArianeGroup, Avio, ESA, and CNES in Europe.

The market for space launch services has expanded significantly in recent years. The need for better communication, navigation, and Earth observation tools, as well as for scientific study and exploration, is likely to push the demand for spacecraft launches to keep rising. Thus, the size of the global market for space launch services, which was estimated to be worth **$13.9 billion in 2022**, is expected to increase to **$47.3 billion by 2032**, rising at a **CAGR of 13.4%** between 2023 and 2032.[1]

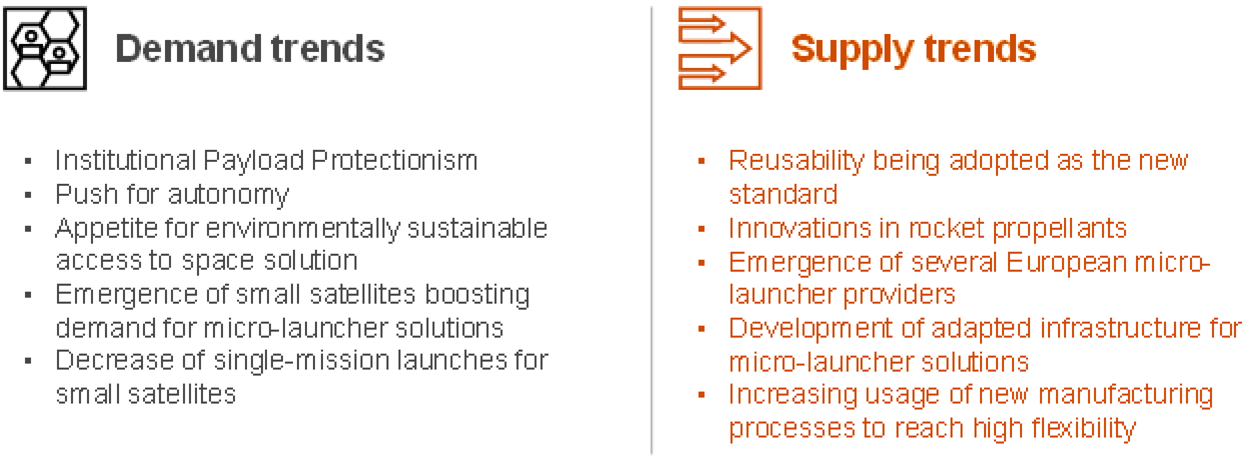

Figure 10: Summary of the main demand and supply trends in the Access to Space domain

In the realm of space exploration and satellite launches, the industry is witnessing dynamic innovations. At the forefront of these advancements is the launcher supply segment, where technologies like super heavy launch vehicles are coming to the fore. With providers like SpaceX and NASA leading the charge, these vehicles are instrumental in orbital and planetary launches, offering increased volume and capacity. The demand is driven by the requirement to launch satellite constellations in flocks and to facilitate planetary missions. Another noteworthy technology is the kinetic launch system, championed by SpinLaunch. Its main application is to provide launches to low Earth orbit (LEO), presenting a cost-effective and environmentally

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

sustainable approach. Furthermore, Ariane 6, from Arianespace, offers commercial, institutional, and exploration missions, catering to the European need for autonomy in space exploration. Reusability is a significant trend. Concepts revolving around reusability are being devised and tested to allow orbital launches with increased frequency and reduced cost. A host of providers, including SpaceX, Rocket Lab, Maia Space, Skyrora, Ceres Aerospace, SALTO, and RRTB, are making strides in this domain, focusing on sustainability and cost-efficiency. 3D printing is carving its niche by aiding in the development and manufacturing of launcher structures. Companies like Relativity Space, Orbex Prime, RocketLab, Additive Space Technologies, and AgniKul Cosmos leverage this technology to accelerate the development phase of their projects. Moreover, stratospheric balloons are emerging as an alternative for rocket launches, operating from a “near-space” environment, with providers like Zero 2 Infinity (Bloostar) and Stratobooster aiming to reduce operational costs. Polaris is introducing the hypersonic spaceplane, which holds promise in defense, cargo, ultra-high-speed transportation, and suborbital flight with their model, AURORA. There is also a focus on achieving routine access to space. Technologies like aerospike engines, associated with providers such as Pangea Aerospace and Polaris, are central to single-stage-to-orbit launch vehicles, increasing payload capacity while simultaneously decreasing rocket mass. Advancements in propellants are evident with methalox propellant, which is being used for reusable rocket propulsion. Its high energy density and clean combustion products are its main selling points, and companies like ULA, SpaceX, Relativity Space, Blue Origin, and Rocket Lab are its primary proponents. NASA is also in the mix, bringing the rotating detonation rocket engine into the spotlight to lighten a rocket's upper stage. This technology aims for enhanced propulsion efficiency with reduced fuel consumption. Other significant innovations include the reusable rocket engine, being developed for European launch vehicles by the European Space Agency (ESA), and the carbon-fiber-reinforced plastic technology for rocket tank manufacturing. ESA, Rocket Lab, and Firefly are tapping into this material's potential for significant weight reduction of rockets.

Space safety

The global value chain for Space Situational Awareness activities follows data gathering, processing and provision logic. The collection of space related data is performed with different sets of observation capabilities by sensors which may combine several sources of information (optical/radar/laser) in a multi-layer fashion. The processing and storage of data aims at producing SSA information products. These activities rely on data repository and processing capabilities. This segment also includes activities covering the creation and maintenance of a catalogue of space objects. Once the data is processed and stored, it is analysed to identify relevant information related to multiple aspects of space safety, such as, for instance, the positioning velocity and attitude of the observed and tracked objects. The service provision ensures that the distribution of SSA data is done in a timely and secured manner to support spacecraft operators in their decision-making process and national security entities in their intelligence needs.

The domain of Space Safety is witnessing a burgeoning market and economy, particularly in the area of space situational awareness. As the number of satellites and space debris increases, the demand for accurate and real-time data for tracking and management is growing exponentially. This uptick in demand is creating new economic opportunities for companies specializing in data access and management, thereby shaping a promising market landscape in Space Safety.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Demand trends

- Growing amount of space debris raising general concerns for and beyond mitigation actions
- Need for automation to deal with large volumes of data
- Rising partnership among countries

Supply trends

- Implementation of new technologies
- Growth of commercial SSA services
- Governance challenges

Figure 11: Summary of the main demand and supply trends in the Space Safety domain

The space safety domain is undergoing a transformation with the advent of numerous groundbreaking technologies and services. One standout innovation is the tow truck spacecraft equipped with vision-based AI. This AI enhancement allows the spacecraft to have an improved capturing mechanism targeting uncooperative space objects, providing a service in active debris removal. This significantly reduces the risk of collisions in space. Spacecraft battery standards are also being reevaluated, leading to advanced design standards that minimize the risk of onboard battery malfunctions. As a result, debris is mitigated, thus promoting the longevity and safety of spacecrafts. The marriage of Space Situational Awareness (SSA) software with spacecraft propulsion control has resulted in a unified platform. This platform offers situational awareness combined with instantaneous response, culminating in an integrated space mobility subscription service that streamlines space traffic management.

Through the use of AI/ML, there is now an advanced system for prioritizing and classifying alerts. By discerning threat levels for potential collisions, this 'Smart' Space Traffic Management (STM) system enables more precise and efficient management of space traffic.

Advanced radar and telescope systems are also being introduced, offering superior tracking abilities. With global coverage and real-time updates, this results in the Autonomous EU Space Surveillance and Tracking (SST) service, which significantly improves the detection and monitoring of space objects. Incorporating multi-agent deep reinforcement learning, collaborative AI agents are now optimizing sensing strategies for object detection. This ensures comprehensive and efficient object tracking through space sensor tasking.

For non-contact debris management, space and ground-based laser nudge technology offer precise nudging mechanisms to safely redirect the trajectories of space debris, providing another active debris removal solution. The tethered-net removal technology, flexible and adaptive, is suitable for capturing various space debris sizes, presenting a scalable solution for debris management. Furthermore, the removal docking plate bus equipment, a modular platform, facilitates easy attachment and de-orbiting procedures, thus standardizing de-orbiting operations. Lastly, the introduction of an extra-vehicular general-purpose robotic arm and hand has added another layer of versatility. This multi-purpose robotic mechanism, highly adaptable, serves as an active debris removal tool. Beyond that, it's also apt for other in-orbit servicing requirements.

3.1 Introduction and scope

This report provides an in-depth analysis of the space services and businesses sector, focusing on key domains that are integral to the industry's growth and sustainability. The objective is to offer a factual, straightforward assessment of current trends, market dynamics, and emerging technologies in Earth

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Observation, Satellite Communication, Satellite Navigation, Access to Space and Launch Systems, and Space Safety.

The report is organised into five main sections, each focusing on a critical domain within the space industry.

The first section delves into Earth Observation, offering a presentation of the value chain and an overview of key programmes such as Copernicus, EO4SD, and LANDSAT. It also examines market dynamics, including both demand and supply trends, and assesses emerging and future downstream activities. Additionally, this section maps out emerging technologies, services, and applications in Earth Observation.

The second section is dedicated to Satellite Communication. It presents the value chain and provides an overview of European institutional programmes such ARTES, GOVSATCOM, and IRIS2. Market dynamics and trends are analysed, along with an assessment of emerging and future downstream activities. The section also maps out emerging technologies, services, and applications in Satellite Communication.

The third section focuses on Satellite Navigation, presenting its value chain and offering overviews Galileo and EGNOS. It explores market dynamics, including demand and supply trends, and assesses emerging and future downstream activities. The section concludes by mapping out emerging technologies, services, and applications in Satellite Navigation.

The fourth section, Access to Space and Launch Systems, outlines the value chain and gives an overview of European landscape of launchers. It scrutinises market dynamics, including demand and supply trends, and assesses emerging and future activities. The section also maps out emerging technologies in the field of launch systems.

The fifth and final section focuses on Space Safety. It presents the value chain of data related to space objects and provides an overview of Space Safety programmes. Market dynamics, including demand and supply trends, are explored, and an assessment of emerging and future downstream activities is provided. The section concludes by mapping out emerging technologies, services, and applications in Space Safety.

3.2 Earth Observation

Earth Observation (EO) is a rapidly evolving domain that leverages satellite technology to monitor and collect data about the Earth's surface, atmosphere, and oceans. This field plays a critical role in a wide range of applications, from environmental monitoring and disaster management to urban planning and agricultural development. With the advent of advanced satellite systems and sensors, the granularity and accuracy of data have improved significantly, enabling more precise analyses and actionable insights.

One of the most noteworthy aspects of the Earth Observation domain is its diverse development landscape, which includes both institutional programmes and private actors. Key programmes such as Copernicus, EO4SD, and LANDSAT, backed by governmental or international organizations, have become cornerstones in the Earth Observation landscape. These programmes provide a multitude of data sets that include temperature, humidity, land use, and even air quality.

Simultaneously, the private sector has become increasingly active in Earth Observation, launching their own satellites and offering specialised services. Companies are innovating in data analytics, machine learning models, and real-time monitoring services, thereby complementing the data and services provided by institutional programs. This synergy between public and private entities is enriching the EO ecosystem, making it more dynamic and responsive to market needs.

The market dynamics in the Earth Observation domain are complex yet promising. On one hand, there is a growing demand for real-time, high-resolution and high-quality data for various applications. On the other hand, there is a surge in the supply side with more satellites being launched and more companies entering

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

the EO services market. This interplay between supply and demand is supporting innovation and investment, making Earth Observation a pivotal domain with significant economic and societal impact.

3.2.1 Presentation of the value chain

The Earth Observation value chain is composed of four segments: upstream, midstream, downstream, and end users. The EO value chain is characterised by the sequential flow of these segments, ensuring acquisition, processing, and utilisation of satellite-based data by end users. These users are predominantly satellite operators, data analytics provides, and government institutions. A visual representation of each segment and interconnections is provided in the figure below.

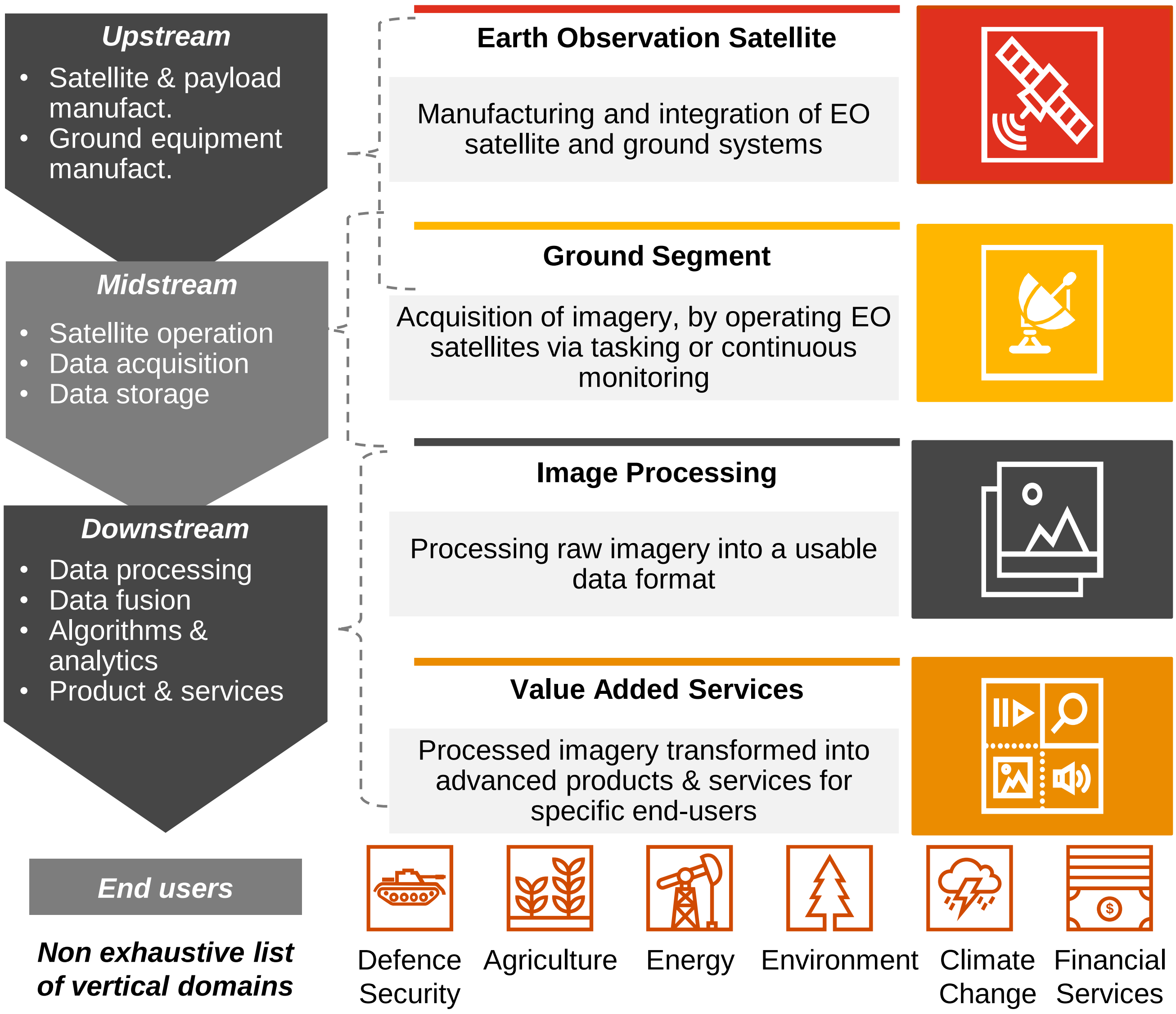

Figure 12: Earth Observation Value Chain.

The operations that make up the value chain of the data obtained via Earth Observation capabilities can be divided into four categories as represented on Figure 2: data acquisition and storage, value-added services, information products, and big data analytics.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Data acquisition and storage: obtaining EO data from a source (optical or SAR sensors), is the first step in EO data exploitation. Due to the increased number of satellites deployed over the past ten years, there has been a growth in the volume of data produced, with a high pace of production of diversified data.

Value-Added Services: this category consists of actions designed to improve the raw satellite data and turn it into Value-Added Products (VAP) or Value-Added Services (VAS). This is accomplished by adding a layer of processing to the data files acquired from the satellite. Most data-acquiring organizations naturally advance to this additional layer of processing in response to the demands of their customers.

Information Products: at this stage, VAP/VAS data is combined with layers of external data files. This allows to develop a product that provides imagery embedded with information relevant to the end-user.

Big data analytics: this process refers to the concept of processing of a large volume of high rate produced data, both structured and unstructured. For instance, the Copernicus Data and Information Access Services (DIAS) was introduced by the European Commission to assist users in obtaining Sentinel satellite data and information without having to download and store it locally. The DIAS serves as a cloud-based one-stop shop that offers third parties scalable computing and storage environments along with limitless, free, and comprehensive access to Copernicus data. Commercial EO satellite operators are shifting away from merely gathering imagery and toward analysing the data for useful insight, particularly with AI-driven data analytics.

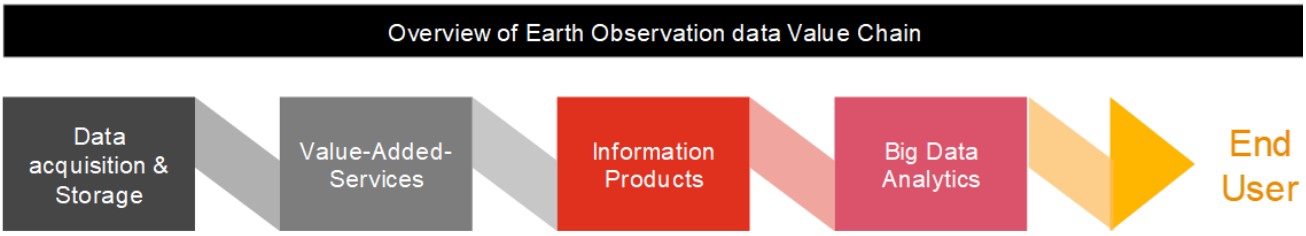

Figure 13: Earth Observation Data Value Chain

3.2.2 Overview of the Earth Observation programmes

3.2.2.1 Copernicus

3.2.2.1.1 Overall presentation of Copernicus

The Copernicus programme is one of the largest EO programmes ever created in terms of satellites and in terms of data generated. It is directed by the European Union, through the European Commission and is implemented in partnership with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan.

Launched firstly as the Global Monitoring for Environment and Security (GMES) in 1998, the programme completed its design phase in 2008 with the official launch of the three pre-operational services (Fast Track Services (FTS) and Pilot services). The pre-operational phase ended in 2011 with the initial operations. In 2012, GMES was renamed Copernicus. Since 2014, Copernicus entered its fully operational phase with the continuous development of its capabilities through the launch of new satellites meant to complete the constellation and of the provision of new products based on Copernicus data.

Table 3: Cost of Copernicus Programme Over 2014 - 2027 Period

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Cost for 2014 - 2020	Cost for 2021 - 2027	Cost over 2014 - 2027
EUR 4,3 billion	EUR 5,421 billion	EUR 9,7 billion

The development costs of the space and service components of the Copernicus programme are shared between the European Union and ESA.

Data collection approach

Satellite and in situ observations are the data sources of the Copernicus Programme.

The EO satellites providing the Copernicus data are split into two groups of missions:

- The Sentinels, which are developed for the specific needs of the Copernicus programme;
- The Contributing Missions, which are operated by National, European or International organisations.

The Sentinel-1, Sentinel-2, Sentinel-5P, and Sentinel-3 land missions are all operated by the European Space Agency (ESA), which is also in charge of developing the Copernicus program's space segment.

EUMETSAT oversees operations of the Sentinel-3 satellites, completing the marine mission, and operating and delivering the Sentinel-4, Sentinel-5, and Sentinel-6 satellites' instruments.[9]

List of current Sentinel satellites

- Sentinel-1A and 1B (launched on the 2014 and 2016) provide all-weather, day and night radar imagery for land and ocean services;
- Sentinel-2A and 2B (launched in 2015 and 2017) have a multi spectral optical sensor for land services;
- Sentinel-3A and 3B (launched in 2016 and 2018) carry a suite of optical, radar, and altimetry instruments for land and marine applications;
- Sentinel-4 is a payload devoted to atmospheric monitoring that will be embarked upon a Meteosat Third Generation-Sounder (MTG-S) satellite in geostationary orbit;
- Sentinel-5 Precursor or Sentinel-5P (launched in 2017) is the forerunner of Sentinel-5 to provide timely data on a multitude of trace gases for atmospheric service;
- Sentinel-5 is a payload that monitors the atmosphere from polar orbit aboard a MetOp Second Generation satellite;
- Sentinel-6 carries a radar altimeter to measure global sea-surface height, primarily for operational oceanography and for climate studies.[10]

The following table provides a high level summary of main features of the Sentinel satellites:

Table 4. Sentinel Satellites Description.

[9] Source: Copernicus https://www.copernicus.eu/en/about-copernicus/infrastructure-overview

[10] Source: Copernicus https://www.copernicus.eu/en/about-copernicus/infrastructure-overview/discover-our-satellites

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

ID	Status	Launch Date	Manufacturer	Mission type
Sentinel 1A	Active	03/04/2014	Thales Alenia Space	Radar
Sentinel 1B	Out of service since December 2021	25/04/2026	Thales Alenia Space	Radar
Sentinel 2A	Active	23/06/2015	Airbus Defence and Space GmbH (Friedrichshafen)	Optical - Imaging (<5m res)
Sentinel 2B	Active	07/03/2017	Airbus Defence and Space GmbH (Friedrichshafen)	Optical - Imaging (<5m res)
Sentinel 3A	Active	16/02/2016	Thales Alenia Space	Ocean Monitoring
Sentinel 3B	Active	25/04/2018	Thales Alenia Space	Ocean Monitoring
Sentinel 4	Planned	2024	Airbus Defence and Space	Atmosphere Monitoring
Sentinel 5P	Active	13/10/2017	Airbus Defence and Space (Stevenage)	Optical - Imaging (<5m res)
Sentinel 6/Jason-CS	Active	21/11/2020	Airbus Defence and Space GmbH (Friedrichshafen)	Ocean Surveillance

In-Situ data sources

All ground-based, air-borne, and ship/buoy-based observations and measurements are part of the Copernicus in-situ component. In-situ data is assimilated into forecasting models, provide calibration and validation of space-based information, and contribute to analysis or filling gaps not available from space sources.

3.2.2.1.2 The Copernicus service areas

The responsibility of the management of these six core services has been delegated from the European Commission to several organisations - the European Entrusted Entities, which thus oversee of the development and supply of Copernicus derived products and services, the “Copernicus Core Products”.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

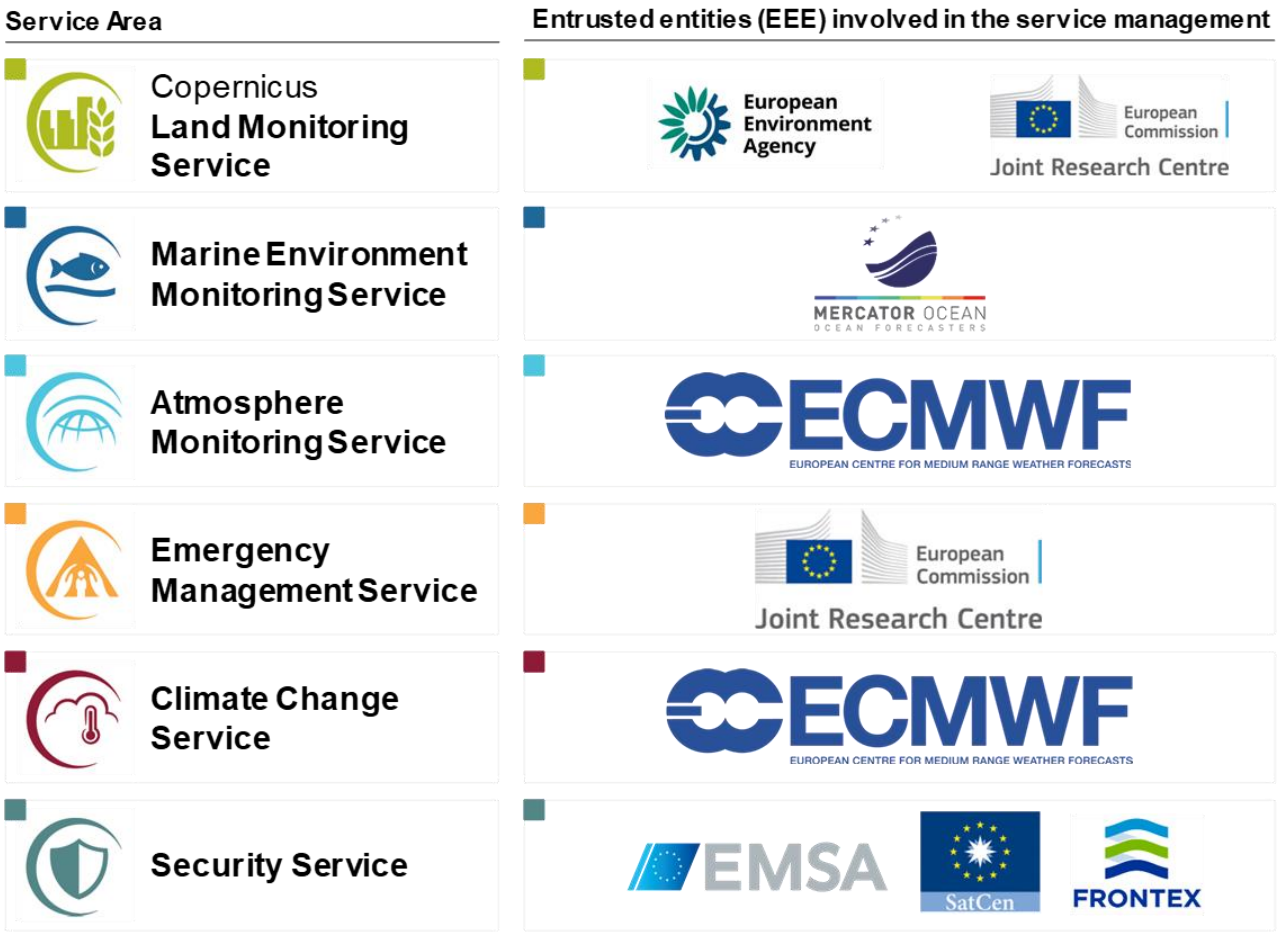

Figure 14: Copernicus Services and Responsible Bodies.

The Copernicus Land Monitoring Service

The Copernicus Land Monitoring Service (CLMS) provides geographical information as well as information on vegetation state and the water cycle. Those products are used by public organisations in their decision-making processes as well as for statistical analysis. The products of the Land service are also used by research centres and by service providers to create value-added products in downstream markets. The Copernicus data from the land monitoring service is provided free of charge and under an open access regime. Accessed via the URL: http://land.copernicus.eu.

The Marine Environment Monitoring Service

The Copernicus Marine Environment Monitoring Service (CMEMS) provides regular and systematic information about the physical state and dynamics of the ocean and marine ecosystems, worldwide and in Europe. The data provided can be describing the current situation, as well as constitute a forecast or a retrospective analysis. CMEMS provides data that is useful for a wide range of different policy areas, such as marine safety, marine and coastal environment, marine resources, weather, seasonal forecasting and climate. For the Copernicus Marine environment monitoring service, the data is provided free of charge and under an open access regime. Accessed via the URL: http://marine.copernicus.eu.

The Atmosphere Monitoring Service

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

The Copernicus Atmosphere Monitoring Service (CAMS) provides a set of information-based services that are providing data on the composition of the Earth's atmosphere. The service generates geophysical products which require additional technical processing and various forms of high-level information to support decision makers. The service is able to study the current situation of the atmosphere, predict future situations, and provide past data records. CAMS is organised as a full and open access regime. Data from the Sentinels satellites is also free of charge to users. Accessed via the URL: http://atmosphere.copernicus.eu.

The Emergency Management Service

The Copernicus Emergency Management Service (Copernicus EMS) supports emergency management actors by providing timely and accurate information in relation to different types of disasters, such as meteorological hazards, geophysical hazards, man-made disasters and humanitarian crises. It also supports actors involved in prevention, preparedness and recovery activities. The activation of the service is limited to certain types of users, but general public can be informed of an activation through the web portal. Accessed via the URL: http://emergency.copernicus.eu/.

The Climate Change Service

The Copernicus Climate Change Service (C3S) aims to provide data in respond to the growing environmental and societal challenges associated with climate change. The service gives access to information for monitoring, predicting and attributing climate change covering a wide range of components of the Earth-system (atmosphere, land, ocean, sea-ice and carbon) and timescales spanning decades to centuries. It maximises the use of past, current and future observations in conjunction with modelling, supercomputing and networking capabilities. The C3S is organised as a full and open access regime. Data from the Sentinels satellites are also free of charge to users. Accessed via the URL: https://cds.climate.copernicus.eu/.

The Security Service

The Copernicus Security service's main purpose is to provide information to policy makers to respond to the security challenges Europe is facing. This objective is being achieved through improving crisis prevention, readiness, and response capacities in the three key areas: support to EU External Actions, maritime surveillance, and border surveillance. The Security service data and products are meant to support decision making to authorised users, which are the main actors involved in the context of EU missions and operations: the EEAS (European External Action Service), COM relevant services national institutions, law enforcement entities and international bodies such as UN. Thus, access to the service is restricted to those users.

3.2.2.1.3 Copernicus' ground segment

The ground segment, which is spread geographically, relies on existing infrastructure. It is delivered by international agencies (ESA and EUMETSAT) as well as national public and private facilities. The Copernicus Ground Segment comprises the Core Ground Segment, which is under the responsibility of ESA, complemented by the Sentinel Collaborative Ground Segment and the Contributing Missions Ground Segments. The Core Ground Segment comprises the Sentinel Core Ground Segment and the Coordinated Data Access System. In addition, there are 19 Collaborative Ground Segments with 8 Data Hub Relays. The Collaborative Ground Segments (existing and planned) are found in the following countries: Austria, Belgium, Canada, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, the Netherlands, and the UK.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.2.2.2 The EO4SD Programme

The European Space Agency, operating in the framework of the Earth Observation Science for Society initiative, created the Earth Observation for Sustainable Development (EO4SD) programme to demonstrate the utilisation of Earth Observation services and products in support of the achievement of Sustainable Development Goals, whilst fostering user uptake of Copernicus data. The EO4SD initiative follows a systematic, user-driven approach to meet longer-term, strategic geospatial information needs in the individual developing countries, as well as international and regional development organizations.

Within the initiative, 11 projects are created reflecting main thematic areas: agriculture and rural development; urban development; water resources management; Eastern European region; climate resilience; disaster risk reduction; marine resources; fragility, conflict and security; lab; EO clinic.[11]

The main elements of the EO4SD programme include:

- **Needs Assessment:** The program begins by collaborating with countries to pinpoint their specific needs for EO data as well as any obstacles they might encounter in obtaining and utilizing this data. This process aids in ensuring that the program is tailored to demands of each country.

- **Capacity Building:** The EO4SD programme offers technical assistance and training to assist countries in developing their capacity to obtain, analyse, and utilise EO data. This includes capacity building for data management and analysis as well as training on how to use tools and software.

- **Data Access and Analysis:** The program makes a variety of EO available, including data from the Sentinel satellites. Additionally, the program offers countries technical support so they can capitalise on the data and related processing tools.

- **Application Development:** The EO4SD program collaborates with countries to create tailored uses for Earth observation data across a range of industries. These applications are made to assist countries in overcoming development barriers, such as raising crop yields or lowering flood risk.

3.2.2.3 LANDSAT

The Landsat program is a series of EO satellite missions that were jointly developed by the United States Geological Survey (USGS) and National Aeronautics and Space Administration (NASA). The primary mission of the Landsat program is to collect and provide high-quality, reliable, and consistent data about the Earth's natural resources and the planet’s surface. The Landsat program has been operational since 1972, making it the longest-running program of its kind.

The first Landsat satellite was launched in 1972 and was followed by six more satellites in the years since. The most recent satellite, Landsat 9, was launched on September 27, 2021. The new Landsat mission, with a constellation of three identical EO satellites with enhanced temporal and special resolution, is expected to launch in late 2030.

Each Landsat satellite carries a set of sensors that capture images of the Earth's surface. These sensors include the Operational Land Imager (OLI), the Thermal Infrared Sensor (TIRS), and the Multi-Spectral

[11] Source: ESA https://eo4sd.esa.int/

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Scanner (MSS). These sensors capture images in various spectral bands, which allow for the identification of different types of land cover and surface features.

The data collected by the Landsat satellites is transmitted to ground stations located around the world, where it is processed and archived by the USGS. The USGS makes this data available to the public free of charge, allowing researchers, policymakers, and the general public to access and use it for a wide range of purposes. The data applications include development of information for monitoring and management of forests, water, agricultural land, urban areas, ecosystems, fire, disasters, climate, energy, and human health.

3.2.3 Market Dynamics

The EO market encompasses two primary revenue streams: EO data revenues and value-added service revenues. EO data revenues result from financial transactions between EO data providers and users, while value-added service revenues are generated further along the value chain, involving transactions between EO products and services or information providers and end-users.

To gain insight into the evolving EO market, EUSPA conducted a 10-year projection from 2021 to 2031. Within the European Union, in 2021, data revenue amounted to 82 million euros, while value-added services revenue stood at 342 million euros. Fast-forwarding to 2031, annual data revenue is projected to increase to 117 million euros, while annual value-added services revenue is anticipated to reach 664 million euros, highlighting substantial growth in both segments. On a global scale, 2021 saw data revenue totalling 536 million euros, with value-added services revenue at 2,236 million euros. Looking ahead to 2031, annual data revenue projected to rise to 797 million euros and annual value-added services revenue to 4,662 million euros. These projections underscore the growing significance of EO data and services in meeting the demands of a rapidly evolving world.[12]

The following table highlights the projections for the EO market over the 2021 – 2031 period within the European market:

Table 5: EO European market revenues (yearly)

Revenue streams	2021 revenues	2031 projected
EO data revenues	€82M	€117M
Value-added service revenues	€342M	€664M
Total	€424M	€781M

The following table highlights the projections for the EO market over the 2021 – 2031 period within the Global market:

Table 6: EO Global market revenues (yearly)

Revenue streams	2021 revenues	2031 projected

[12] Source: EUSPA https://www.euspa.europa.eu/sites/default/files/uploads/euspa_market_report_2022.pdf

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

EO data revenues	€536M	€797M
Value-added service revenues	€2236M	€4662M
Total	**€2,77B**	**€5,45B**

Several factors are driving dynamic supply and demand trends in the EO market. The war in Ukraine has piqued the interest of military actors as well as outside specialist communities in the satellite data, highlighting the relevance of situational awareness and intelligence gathering use cases. Additionally, insurers such as AXA Climate, SwissRe, and MunichRe are investing heavily in EO data exploitation to improve risk assessment and mitigation strategies. The agri-food business is likewise interested in EO, notably for boosting transparency and traceability, with an emphasis on the use of chemical fertilisers. Furthermore, the increased need for EO-based solutions in environmental monitoring, sustainability, and emissions tracking is moving the market ahead. Public investment banks are making direct investments in emerging space enterprises, accelerating their expansion. Finally, the transition in business models from perpetual license to subscription-based models has enabled SMEs to exploit big data into their operations, allowing for use case investigation and prototype creation without long-term commitments. These developments shape the dynamic landscape of the EO industry as a whole. A more extensive breakdown of demand and supply trends is provided below.

3.2.3.1 Demand trends

The democratization of Earth Observation (EO) technology is ushering in a new era where both experts and non-experts, from small enterprises to policymakers, are leveraging EO data for diverse applications. As EO technology becomes increasingly user-friendly, its benefits are being recognised across a multitude of fields. This has led to greater engagement from various stakeholders, who are now utilizing EO data for research, decision-making, and societal benefits. The shift towards broader accessibility is not just a technological trend but a societal movement, enabling more precise resource management, community-based research, and informed policymaking.

Democratisation of the use of EO outside of expert communities

There is a growing need for both experts and non-expert users, including small enterprises, citizen scientists, educators, and policymakers, to harness EO data and tools for their requirements as EO technology becomes more approachable and user-friendly. This need reflects a growing understanding of the benefits that EO may have across a range of fields, encouraging greater engagement and enabling multiple stakeholders to use EO data for research, decision-making, and societal benefits.

The shift towards broader accessibility reflects a deeper understanding of the multifaceted benefits that EO technology can offer across different sectors. For instance, small enterprises in agriculture or environmental monitoring can leverage EO data for more precise resource management, thereby enhancing sustainability and operational efficiency. Citizen scientists and educators can use EO tools to engage in community-based research projects or educational programs, fostering a culture of scientific inquiry and environmental stewardship at the grassroots level.

Earth Observation data supporting policy making

Policymakers are increasingly turning to Earth Observation (EO) data as a valuable resource for informed decision-making across a range of critical areas, including urban planning, disaster management, and climate change mitigation. The shift towards incorporating EO data into policy frameworks is driven by the availability of accurate, real-time information that can significantly enhance the quality and effectiveness of various interventions.

In the context of **urban planning**, EO data can provide detailed insights into land use, population density, and environmental factors. This information is crucial for making decisions about infrastructure development, zoning, and resource allocation. For example, satellite imagery can help identify optimal locations for new public parks, transportation routes, or housing developments, taking into account factors like proximity to natural resources or existing urban centres. By leveraging EO data, urban planners can create more sustainable, efficient, and liveable cities.

When it comes to **disaster management**, the importance of real-time, accurate data cannot be overstated. EO technology can provide immediate information on natural disasters such as hurricanes, wildfires, or floods, allowing for quicker and more targeted response efforts. This can range from the efficient allocation of emergency services to the timely evacuation of at-risk populations. Post-disaster, EO data can also be used for damage assessment and recovery planning, helping communities rebuild more resiliently.

In the fight against **climate change**, EO data offers a powerful tool for monitoring environmental changes and assessing the effectiveness of mitigation strategies. Policymakers can use this data to track deforestation rates, melting ice caps, or rising sea levels, thereby gaining a clearer understanding of the current state of the planet. This information can inform the creation or adjustment of policies aimed at reducing carbon emissions, conserving natural habitats, or transitioning to renewable energy sources.

Growing interest in vertically specialised products & insights

As Earth Observation (EO) technology becomes increasingly sophisticated, there is a growing trend towards the development of vertically specialised products and insights tailored to specific industries and applications. Users are no longer content with generic EO data; instead, they are seeking more targeted and actionable information that directly addresses the unique challenges and opportunities within their respective sectors. This shift signifies a move towards customised EO solutions that offer more than just raw data, providing actionable insights that can drive decision-making and operational efficiency.

In agriculture, for example, specialised EO products can offer insights into soil health, crop conditions, and irrigation needs. These tailored solutions can help farmers optimise resource use, improve yields, and enhance sustainability. Advanced EO data can even predict potential pest infestations or disease outbreaks, allowing for proactive interventions.

In the forestry sector, customised EO solutions can monitor deforestation rates, track illegal logging activities, and assess the health of forest ecosystems. These insights are invaluable for both conservation efforts and sustainable resource management, helping stakeholders balance economic gains with environmental protection.

For urban planners, vertically specialised EO products can provide detailed data on land use, population density, and traffic patterns. This information is crucial for making informed decisions on infrastructure development, zoning regulations, and public transportation networks. The availability of such targeted insights can significantly improve the quality of life in urban areas, contributing to more sustainable and efficient cities.

In the energy sector, specialised EO data can be used to identify optimal locations for renewable energy installations like wind farms or solar panels. It can also monitor the environmental impact of existing energy production facilities, aiding in regulatory compliance and sustainability efforts.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

The increasing demand for these vertically specialised EO products indicates a maturing market where users are recognizing the value of high-quality, targeted data. As a result, EO companies are investing in developing customised solutions that not only meet the specific needs of different sectors but also provide actionable insights that can directly influence strategy and operations.

Strong interest in advanced analytics from military

Military organizations are increasingly turning their attention towards advanced analytics capabilities in Earth Observation (EO) technology, recognizing its strategic importance in today's complex geopolitical landscape. The utilisation of EO data goes beyond mere surveillance; it has become a critical component in the realm of geospatial intelligence, offering a range of applications that significantly enhance military operations.

In the context of mission planning, advanced analytics applied to EO data can provide detailed insights into terrain features, enemy positions, and other critical factors. This enables military strategists to plan more effective and safer routes for troop movements, aerial missions, and naval deployments. For example, EO data can help identify concealed enemy bases or natural obstacles, allowing for more informed decisions that can be the difference between mission success and failure.

Situational awareness is another area where advanced EO analytics are proving invaluable. Real-time EO data can offer a dynamic view of the battlefield, providing commanders with up-to-the-minute information on troop positions, enemy movements, and environmental conditions. This real-time intelligence is crucial for making quick, informed decisions in the heat of combat, thereby increasing the chances of operational success and minimizing risks to personnel.

Advanced analytics also play a role in broader defence and security strategies. EO data can be used for border surveillance, monitoring of restricted airspace, and maritime security. For instance, satellite imagery can detect unauthorised vessels approaching territorial waters, allowing for timely interception. Similarly, EO data can be used to monitor activity in conflict zones or areas of strategic interest, providing early warning signs of potential threats.

It is worth noting that the value of advanced EO analytics in military applications is often maximised when integrated with other technologies, such as Artificial Intelligence (AI) and Machine Learning (ML). These technologies can automate the analysis of large datasets, identify patterns or anomalies, and even predict future events based on historical data, thereby further enhancing the military's decision-making capabilities.

New emerging analytics markets

The Earth Observation (EO) sector is witnessing the emergence of new analytics markets, fuelled by advancements in Artificial Intelligence (AI), computing technology, and the increasing availability of abundant, affordable EO data. These developments are not only improving the accuracy of insights derived from EO data but are also opening up new avenues for innovation and application across various industries.

The integration of AI and advanced computing algorithms has significantly enhanced the capabilities of EO analytics. Machine learning models can now sift through massive datasets to identify patterns, anomalies, or trends that would be impossible or highly time-consuming for human analysts to detect. These advancements are particularly beneficial for complex tasks such as climate modelling, natural resource management, and disaster prediction.

Big Data analytics is poised to be a game-changer within the EO sector. The ability to analyse vast and diverse datasets—from satellite imagery to sensor data—allows for the development of more robust and accurate forecasting models. For instance, in agriculture, Big Data analytics can predict yield outcomes based

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

on a variety of factors like soil quality, weather patterns, and crop health. Similarly, in urban planning, analytics can help in simulating various scenarios for infrastructure development, thereby aiding in more informed decision-making.

The use of advanced analytics enables the creation of enhanced forecasting models that can predict a wide range of phenomena, from weather patterns to economic trends. These models are becoming increasingly sophisticated, incorporating multiple data sources and utilizing machine learning algorithms to improve accuracy over time. Such forecasting models are invaluable in sectors like emergency response, where predicting natural disasters can save lives, or in financial markets, where accurate forecasts can have significant economic implications.

One of the factors contributing to the increased trust in EO analytics is the improvement in data privacy and security measures. As analytics tools become more sophisticated, so do the encryption and security protocols that protect the data. This is particularly important in sensitive applications such as national security or healthcare, where data privacy is a paramount concern.

The new analytics markets are not limited to any single industry. From healthcare and transportation to energy and environmental conservation, the applications are as diverse as they are impactful. The ability to derive actionable insights from EO data is revolutionizing how industries operate, offering efficiencies and advantages that were previously unattainable.

Growing interest for non-imagery EO data & information

While imagery data has traditionally dominated the Earth Observation (EO) landscape, there is a burgeoning interest in other types of data, such as radar, LiDAR, hyperspectral imaging, and more. This shift reflects a growing recognition of the diverse and unique insights that these alternative data types can provide into various Earth phenomena. The inclusion of these data types is enriching the analytical capabilities of EO, enabling more comprehensive analyses, sophisticated modelling, and improved decision-making across a multitude of industries.

Radar data, for instance, offers the ability to penetrate cloud cover and capture information in various weather conditions, making it invaluable for applications like meteorology and disaster management. It can also be used for monitoring ocean currents and wind patterns, providing critical data for both environmental studies and maritime operations.

LiDAR (Light Detection and Ranging) technology is increasingly being used for high-resolution mapping of terrestrial features. It is particularly useful in forestry for calculating biomass and in urban planning for creating detailed 3D models of cityscapes. LiDAR can also be employed in archaeological studies to uncover hidden structures or features beneath dense vegetation.

Hyperspectral imaging captures data across a wide range of the electromagnetic spectrum, providing highly detailed information about the composition of materials. This is particularly useful in sectors like agriculture for soil analysis, in mining for mineral identification, and in environmental monitoring for assessing water quality or pollution levels.

The integration of these diverse data types allows for a more holistic understanding of Earth phenomena. For example, combining radar and hyperspectral data can offer unprecedented insights into ecosystem health, enabling more effective conservation efforts. Similarly, the use of LiDAR and radar data in tandem can significantly improve the accuracy of flood prediction models.

The availability of these varied data types is revolutionizing decision-making processes across industries. In healthcare, for example, EO data can help track the spread of diseases; in transportation, it can assist in

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

route optimization; and in energy, it can aid in identifying optimal locations for renewable energy installations.

Regulation and reporting requirements

The introduction of the Corporate Sustainability Reporting Directive (CSRD) by the European Union, which came into effect on January 5, 2023, marks a significant milestone in the realm of corporate accountability and transparency. The directive mandates that public companies must now include climate risk and Environmental, Social, and Governance (ESG) analysis in their quarterly and annual financial reports. This regulatory development is expected to have a substantial impact on the demand for Earth Observation (EO) and satellite data, particularly in the area of supply chain tracking.

The CSRD aims to provide stakeholders, including investors and regulators, with a more comprehensive view of a company's performance by integrating financial metrics with sustainability indicators. This requires companies to gather extensive data on various aspects of their operations, from carbon emissions to labour practices, to demonstrate compliance with ESG standards.

One of the key areas where satellite data can offer invaluable insights is in supply chain tracking. Companies can use Earth Observation data to monitor the environmental impact of their supply chain activities, such as deforestation rates associated with raw material sourcing or emissions from transportation. This data can be crucial for companies to assess their climate risks and to provide accurate ESG reporting.

Given the new reporting requirements, there is likely to be a surge in demand for specialised Earth Observation services that can provide the necessary data for compliance. This includes services like real-time monitoring of supply chain activities, environmental impact assessments, and even predictive analytics to forecast potential future risks.

The impact of the CSRD is not limited to any specific industry; it has cross-sectoral implications. Whether it's manufacturing, agriculture, energy, or retail, companies across various sectors will need to rely on accurate and timely EO data to meet the new reporting standards. This is likely to drive innovation and competition among EO service providers, leading to more advanced and tailored solutions.

The long-term market dynamics are also expected to shift, with an increasing number of companies integrating EO data into their regular business operations, beyond just compliance. As organizations recognise the value of this data in enhancing sustainability and operational efficiency, Earth Observation is likely to become a standard business practice, rather than an optional extra.

3.2.3.2 Supply trends

Toward vertical integration & satellite miniaturisation

Vertical integration is the process of combining different elements of the EO value chain, such as the production of satellites, data collection, processing, and value-added services, into a single organization. Delivering end-to-end EO solutions is now more efficient and under greater control owing to this trend. At the same time, with the development of smaller, lighter satellites, there is a shift toward satellite miniaturization. These compact satellites provide flexible and affordable platforms for gathering EO data, allowing for more frequent revisits. Vertical integration and satellite miniaturization together increase the amount of accessible and varied EO data available, creating new opportunities for services and products across industries.

Constellations are the new norm for most players

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Constellations, which are arrays of multiple satellites cooperating to gather data, are being adopted by many EO market players. Satellite constellations have a number of benefits, including a higher revisit frequency, global coverage, and enhanced data collection abilities. With this approach, EO providers can increase the amount of data they are able to provide, allowing for comprehensive observations of the Earth's surface, better monitoring of dynamic events, and improved data continuity for a variety of applications.

Expected consolidation of the EO industry, notably due to SPACs

In 2021, prominent EO players such as Spire, BlackSky, Planet, and Satellogic announced SPAC deals, allowing them to capture significant market shares. SPACs enable these businesses to expand their operations via buying promising EO starts-up to access excellent capacity at low cost and boost revenues. This consolidation trend indicates that the industry is maturing, as key players seek strategic partnerships and acquisitions to strengthen their positions, drive innovation, and capitalise on the growing demand for EO data and services.

Emergence of major non-imagery players

While imagery data has traditionally dominated, non-imagery data (hyperspectral, thermal infrared, radio occultation, automatic identification services, radiofrequency monitoring, microwave sensing) is gaining traction. Such companies provide specialised services and data products to supplement and enhance traditional imagery-based offerings. Consequently, the market for EO has become more diversified as evidenced by current investments in such businesses, which also increases the variety of solutions and capabilities on offer.

The emergence of the ‘as-a-service’ models

'Space-as-a-service' models allow governments to contribute to the EO mission by supplying the critical payload while essentially 'outsourcing' the rest of the space segment to commercial companies, which are responsible for payload integration, assembly, and testing, launch service agreements, and satellite operation. This concept enables governments to obtain premade satellites from manufacturers but guaranteeing that the assets are wholly owned by clients such as themselves. It should be noted, however, that traditional satellite manufacturing contracts are not going away anytime soon.

Commercial weather satellites

The commercial weather sector, which is included under the EO industry, will play a significant role in the development of climate adaptation and resilience technologies as climate change enters the everyday narrative. As some private companies (Spire, GeoOptics, Acme AltronOmatic and others) have started offering solutions in this regard, the development of improved sensors, modelling, processing, and transmission of weather data will be largely dependent on the private sector.

Sovereign Earth Observation

As part of their national space strategies, some countries are investing in EO constellations (most recent examples include Australia and UAE) and plans from commercial EO companies to contribute to their respective governments' EO data policies, such as LatConnect60 in Australia and Nara Space Technology in South Korea. This is motivated by changing geopolitics, strategic interests in data independence, and the

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

socioeconomic reason for EO sector development, which also ensures skills progression for the local population as well as job opportunities.[13]

3.2.4 Assessment of emerging and future downstream activities

Technological advancements are projected to shape the future of the satellite imaging industry, including greater deployment of SAR (synthetic aperture radar) systems, as well as InSAR (interferometric synthetic aperture radar), producing very high-resolution three-dimensional pictures of the Earth's surface. It will be utilised more widely for mapping landscapes, infrastructures, buildings, and structures, as well as monitoring land subsidence, deformation, and ground motions.[14]

In terms of application developments, EUSPA highlighted 16 areas where EO downstream applications will be gradually growing and generating revenue by 2031: Agriculture, Aviation and Drones, Biodiversity, Ecosystems, and Natural Capital, Climate Services, Consumer Solutions, Tourism, and Health, Emergency Management and Humanitarian Aid, Energy and Raw Materials, Environmental Monitoring, Fisheries and Aquaculture, Forestry, Infrastructure, Insurance and Finance, Maritime and Inland Waterways, Rail, Road, and Automotive, Urban Development, and Cultural Heritage. Remarkably, the Insurance and Financial sector is anticipated to increase the quickest over the next decade, as it is one of the fast-growing industries with higher rates of innovation adoption.[15]

At the same time, the growth of smart city projects is another attractive and quickly increasing domain. Smart cities gather and analyse data using technologies such as the Internet of Things and satellite images, with the goal of improving inhabitants' quality of life while minimizing environmental impacts. Satellite imagery is critical in these efforts because it provides precise information on the built environment while also enhancing urban planning, public services, transportation, pollution, preparation for extreme weather events and natural catastrophes. Increasing amount of urban site planning projects rely on multi-source remote sensing systems to ensure high-quality data across large areas. Thus, modern urban planning systems require least time-consuming approaches to provide the greatest product quality at the lowest possible cost.[16]

The EC and ESA have also listed urbanization as one of the "High Priority Candidate Missions" that will necessitate further Sentinel missions. Other priority domains include food security, rising sea levels, diminishing polar ice, natural disasters, and climate change.[17]

Finally, the information gathered by Sentinel missions will ultimately be used in relation to the European Green Deal, the European Digital Strategy, and the 2030 Agenda for Sustainable Development.

[13] Source: Geospatial World https://www.geospatialworld.net/prime/business-and-industry-trends/top-five-trends-earth-observation/
[14] Source: Mordor intelligence. Report : Global Commercial Satellite Imaging Market (2023-2028)
[15] Source: EUSPA https://www.euspa.europa.eu/sites/default/files/uploads/euspa_market_report_2022.pdf
[16] Source: Mordor intelligence. Report : Global Commercial Satellite Imaging Market (2023-2028)
[17] Source: ESA https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_High_Priority_Candidates

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.2.5 Mapping of EO emerging technologies, services, and applications

Following the discussion above describing potential areas for emerging downstream applications within the EO domain, the subsequent table maps specific projects focusing on innovative technologies, applications, and services across each segment of the EO value chain. In summary, the table shows a variety of cutting-edge EO technologies and applications in the upstream, midstream, and downstream segments of the EO value chain. Sentinel-4, Sentinel-5, and hyperspectral imagery represent upstream developments that promise improved data collection capabilities. Data processing and analysis are being shaped in the midstream by innovations like the Copernicus Marine Data Store and AI-driven tools like generative adversarial networks. The diverse range of downstream applications—which include improving agriculture to assisting the European Green Deal—illustrates the crucial role that EO plays in tackling today's challenges in a variety of fields. These developments highlight the growing significance of EO in responding to global and regional needs.

Table 7. EO Emerging Technologies, Applications, Services

Value chain segment	Technologies	Applications	Services
Upstream	Meteosat Third Generation Sounder (MTG-S) satellite (Sentinel-4)	Hourly data on tropospheric constituents over Europe for air quality	Weather and atmosphere monitoring
	46 MPixels sensors with video acquisition	High resolution video of an extremely wide scene	Video observation
	32 small satellites fleet constellation	Very high resolution and rapid revisit	Real-time commercial data products
	Hyperspectral imagery	Broad spectral range and narrow sampling	Multipurpose hyperspectral data
Midstream	Bicubic-downsampled low-resolution image-guided generative	Super resolution imagery	Remote sensing image enhancement solutions

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

	adversarial network[18]		
	Efficient hybrid conditional diffusion model[19]	Super resolution imagery	Remote sensing image enhancement solutions
	Onboard AI	Data processing onboard spacecraft	Efficient data transmission with reduced ground-based processing
Downstream	Integrated AI, cloud, and EO capabilities	Digital model of the Earth	Climate monitoring and change prediction
	Geo-augmented reality	Mobile display tools	Advanced situational awareness and location information
	Copernicus Marine Data Store	Cloud-based open access Sentinels data storage	Free marine data and metadata tools, downloads, and post-processing
	Sentinel Hub QGIS plugin	Graphical interface within Copernicus browser	Sentinel data search, integration, and visualisation

[18] Source: Remote Sensing Journal https://www.mdpi.com/2072-4292/15/13/3309
[19] Source: Remote Sensing Journal https://www.mdpi.com/2072-4292/15/13/3452

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.3 Satellite Communication

This section of the report aims to offer an in-depth analysis of the satellite communication (SATCOM) ecosystem. It will also outline the primary goals and driving factors of major European institutional initiatives. Furthermore, it will also investigate the main supply, demand, and pricing dynamics in the European SATCOM market.

3.3.1 Presentation of the value chain

The satcom value chain is composed of three key segments -upstream, midstream & downstream. Each of these phases plays a significant role in the development, delivery, and optimisation of satellite communication services to end users. The figure illustrated below depicts this value-chain.

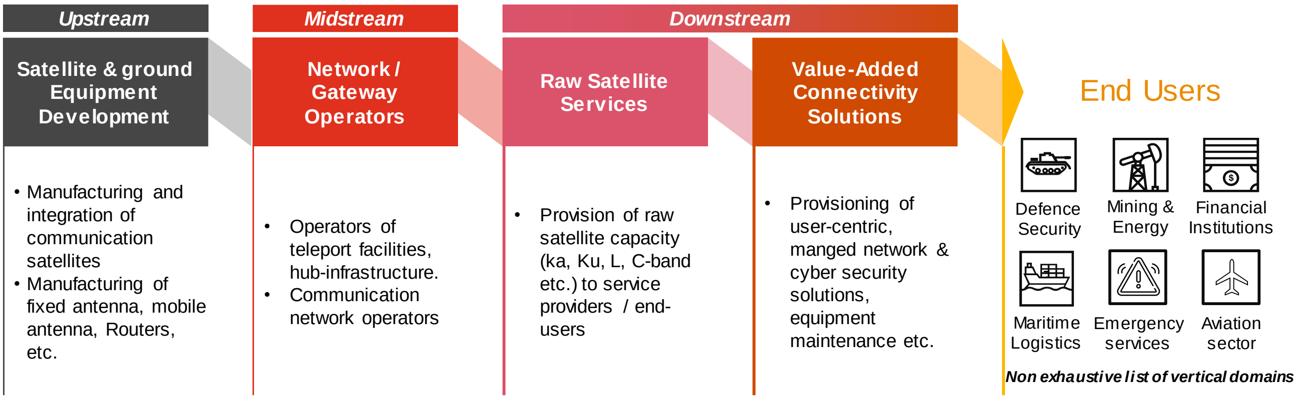

Figure 15: Satcom Value Chain

The **upstream** segment of the value chain involves designing and manufacturing communication satellites that are suitable for specific orbital regimes in LEO, MEO and GEO. Including the development of novel payloads such as High throughput Satellites (HTS) or Very High Throughput Satellites (VHTS), as well as novel sub-systems such as inter-satellite communication/ optical communication links. Additionally, this segment also includes the development of ground equipment for Earth stations, gateways, as well as end-user terminals (fixed and mobile).

The **midstream** segment of the value chain is composed of network operators, teleport facilities and gateway operators. Network operators manage the performance and traffic of the entire network. Teleport facilities provide necessary communication links to and from satellites. Lastly, gateway operators manage the specific infrastructure that connects the satellite network to the backbone of the terrestrial networks.

The **downstream** segment of the value chain involved the provisioning of raw satellite capacity in various bands such as Ka-band, Ku-band, L-band, C-band etc. In addition to this, this segment also involves the provisioning of value-added services such as management network services, cyber security /encryption solutions. These value-added services typically offer tailored solutions catering to the unique needs of specific end-users, including sectors like Oil & Gas (O&G), maritime, aviation, and others.

3.3.2 Overview of Satellite Communication programmes

The European institutional satcom framework is anchored by three critical programmes: the Advanced Research in Telecommunication Systems (ARTES), the Government Satellite Communication (GOVSATCOM),

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

and the Infrastructure for Resilience, Interconnectivity, and Security by Satellite (IRIS[2]). Each catering to distinct motives and objectives.

3.3.2.1 Advanced Research in Telecommunications Systems (ARTES)

The ARTES programme, led by ESA, came to fruition during the ministerial council in 1992, as a successor to the Payload and Spacecraft Development and Experimentation Programme (PSDE) and Advanced Systems and Technology Programme (ASTP) programme.

3.3.2.1.1 Overview of ARTES 4.0 generic and strategic programme lines

Currently, the ARTES programme has evolved into ARTES 4.0, overseen by the ESA's Telecommunications and Integrated Applications (TIA) directorate. A detailed breakdown of ARTES 4.0 is shown in the figure below, highlighting four generic program lines as well as the three strategic programmes lines. [20]

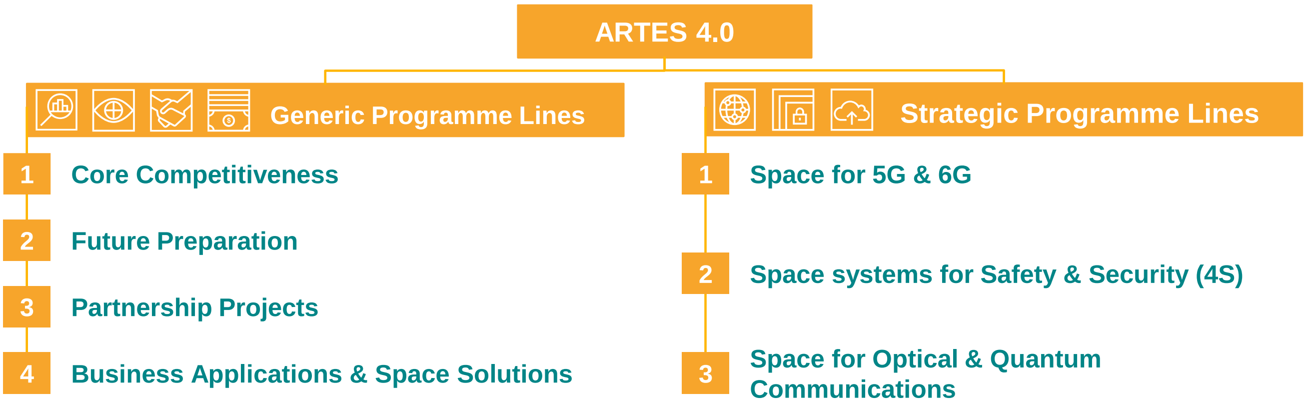

Figure 16: Overview of ARTES 4.0 Programme Lines.

The four generic programme lines highlight the broad long-term goals targeting collective strategic objectives of the participating member states (ESA members, including Canada). Each of these programme lines is described below.

- **Core Competitiveness:** This programme line focuses on both market pull and technology push initiatives. The market pull Focus aims to support technologies and products tailored to current market needs, with proposals originating from the industry. Conversely, the Technology Push Focus is dedicated to endorsing products and solutions addressing future market requirements, with ESA initiating these activities based on insights from academia, industry, and its internal resources.
- **Future preparation:** The primary goal through this program line is to identify upcoming technologies and their associated market opportunities across the satcom value-chain, understand the needs for their implementation, including spectrum usage, and establish standards to promote their adoption. Thereby leading to the development of a workplan that focuses on realising these future opportunities in the mid to long term timeframe.
- **Partnership projects:** Central to this line is creating an enabling environment for the satcom industry to roll out innovative commercial solutions, and foster collaboration for large scale programmes with both the private and public sector entities. Moreover, this programme line provides support

[20] Source: Canadian Space Agency https://www.asc-csa.gc.ca/pdf/eng/funding-programs/canada-esa/notice-artes-v2.pdf

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

throughout the technology development process, from initial inception through to product or service realisation.

- **Business Applications & Space Solutions (BASS):** This programme line supports a wide range of businesses, including start-ups and SMEs, by offering access to tools like ESA Business Incubation Centres, which assist in product realisation. It also grants access to ESA technology brokers, enabling the transition of space solutions into terrestrial market.

The Strategic Program Lines offer a structure that optimises the contribution of satellite communications and space applications to participating countries' strategic agenda on national and European level. Each of these programme lines is described below.

- **Space for 5G and 6G:** This strategic initiative focuses on harmonizing terrestrial networks, both existing and emerging, with space-based communication systems. The approach involves either integrating terrestrial standards into satellite communication networks or collaboratively developing new standards with terrestrial networks. The ultimate goal is to ensure resilient, secure, and robust communication across various applications.
- **Space Systems for Safety & Security (4S):** Through this program line, ESA promotes the creation of secure satellite communication systems compatible with public and private terrestrial networks. In doing so, it strengthens the defence of ESA member states against challenges ranging from cyber threats to natural disasters, enhancing the safety in vital sectors like energy, transportation, and border control.
- **Space for Optical & Quantum Communications:** Through this programme line ESA strives to remain at the forefront by pioneering the development and integration of disruptive technologies. This includes optical communications that amplify network throughput and the advancement of quantum communication technologies, which significantly enhances security measures.

The four generic and three strategic programme lines ensure that ESA member states, including Canada remain ahead of the curve by developing novel solutions that can be commercialised.

3.3.2.1.2 ESA's ARTES Programme and TIA Budgetary Analysis

ARTES has consistently supported a diverse array of notable initiatives. Noteworthy contributions include the design of the General Flexible Payload (GFP), designed to enhance spectrum allocation for smallGEO satellites, and the ESAIL microsatellite launch, a premier tool for maritime activity tracking. Moreover, in July 2021, a significant milestone was achieved with the Eutelsat Quantum satellite's launch, a reprogrammable satellite.

Additionally, the impact assessment study of the ARTES programme suggests that for every EUR 1M invested by Member States in ARTES, EUR 3.4M is realised in industry sales. This multiplier is projected to escalate to nearly 9.8 times by 2025. Moreover, it is estimated that approximately EUR 1B in private investment was catalysed through co-funding activities between 2018 and 2021. Furthermore, the strategic programme lines yielded EUR 3.45B in industry sales, EUR4.8B in added value, and 4,000 jobs.[21]

[21] Source: ESA https://connectivity.esa.int/news/esa-historical-timeline

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

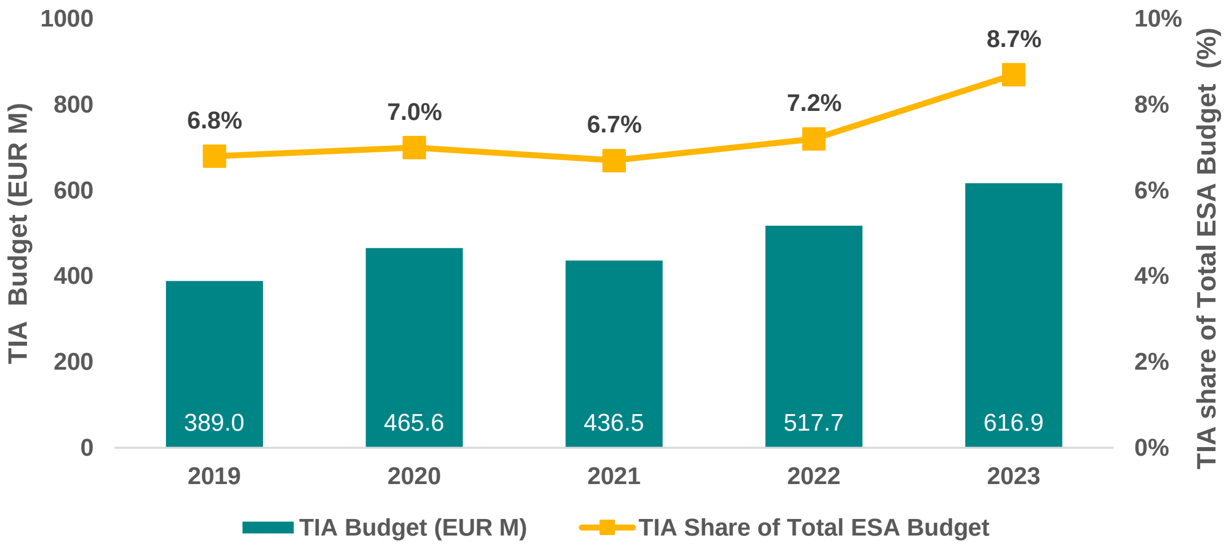

Figure 17: TIA's Budgetary Evolution and Its Share of ESA's Total Budget: 2019-2023

Considering these remarkable achievements, the budget for TIA has expanded at a CAGR of 12%, growing from EUR 389M in 2019 to EUR 617M in 2023. Similarly, the portion of the total ESA budget allocated to TIA has also increased, going from 6.8% in 2019 to 8.7% in 2023. This is depicted in the figure above.

3.3.2.2 GOVSATCOM

In December 2013, the European Council highlighted satellite communication as a priority during its first thematic defence debate. They urged collaboration among Member States, the European Commission, and the European Space Agency for the next-gen Governmental Satellite Communication. Starting 2014, the European Commission spearheaded the EU GOVSATCOM program to ensure European autonomy in satellite communications. This effort continues, and the 2021-2027 EU Space Programme has incorporated EU GOVSATCOM as one of its four main elements.[22]

The GOVSATCOM initiative is built on three key objectives. Firstly, address the fragmentation of European governmental satellite systems by creating a unified pool of capabilities, services, and users. Secondly, ensure Europe's strategic independence in technology and services, enhancing the effectiveness of humanitarian and civil protection efforts both regionally and globally. Thirdly, develop cost-effective communication solutions for EU defence and government users, ensuring timely access, and protection against unauthorised access. Building on these foundational objectives, the broader implications of GOVSATCOM initiative are expected to be instrumental in various EU policy areas, notably the EU Arctic Policy, and the EU Cyber Defence Policy Framework, as well as the EU Maritime Security Strategy.

3.3.2.2.1 Opertational Framework and Applications of GOVSATCOM

Given the recent extension of the GOVSATCOM initiative until November 2025, the initiative plans to leverage existing national space assets and engage with accredited private operators via interconnected operational hubs. [23] These hubs are designed to act as streamlined networking nodes, directing traffic among

[22] Source: ESA https://connectivity.esa.int/sites/default/files/GOVSATCOMAnnoucementofOpportunity110316.pdf
[23] Source: European Defence Agency https://eda.europa.eu/what-we-do/all-activities/activities-search/governmental-satellite-communications-(govsatcom)

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

them to guarantee secure and reliable communication that satisfies end-user Quality of Service (QoS) requirements. Furthermore, in remote areas lacking terrestrial systems or in scenarios where such systems are compromised due to natural disasters or malicious acts, these hubs will be crucial in maintaining secure communication links. Thus, facilitating the three main applications as outlined further.

Crisis Management Operations

The application will serve a variety of users like civil protection teams, military forces, humanitarian aid responders, local EU and national delegations amongst others. While its primary focus is on Europe and its immediate neighbours, its services are global, facilitating coverage in any crisis area (1000 km diameter) within 48 hours or even 12 hours if first responders are present. The communication services offered are vast, encompassing everything from voice communication to specialised applications like telemedicine and asset tracking. A notable feature is its ability to support the operation of Remotely Piloted Aircraft Systems (RPAS), ensuring seamless control and data retrieval through a secure satellite link.

Border Surveillance and Maritime Surveillance Operations

This application shall benefit the end-users such as civilian security actors and military forces by offering continuous and near-real-time connectivity to platforms and sensors that gather intelligence for decision-making. Particular emphasis shall be placed on specific regions that have a high concentration of surveillance assets. Notably, the Mediterranean Sea, the Black Sea, both the North and South Atlantic, and the Baltic area. The growing maritime activities in the Arctic are also on the radar. To facilitate these efforts, EU GOVSATCOM will equip surveillance actors with a diverse range of communication services, from voice communication to the transmission of high-resolution imagery and secure access to specific data systems.

Key infrastructure management and diplomatic communication networks

This application will support a broad range of stakeholders and end-users across key infrastructures including aviation, rail, and land transport. It will also relay sensor-based data from infrastructure elements such as dams, bridges, and power plants through its secure channels. Additionally, it will amplify the EU and Member States' diplomatic communication capabilities, ensuring they have access to reliable satellite communication services globally, independent of the hosting states' communication infrastructure.

3.3.2.3 Infrastructure for Resilience, Interconnectivity, and Security by Satellite (IRIS^2) programme

IRIS^2 is the most recent programme announced by the European commission, the objectives of which are two-fold, first to curb competition arriving from non-European commercial LEO constellations such as OneWeb, Starlink, Telesat, and Project Kuiper, as well as institutional constellations such as China's Guowang and the United States' Proliferated Warfighter Space Architecture (PWSA). Secondly, to ensure sovereign global access to secure, reliable and resilient communication links. This second aspect is more so crucial and has been under discussion for almost a decade.

Events leading up to the formation of IRIS^2

The discussion around European strategic autonomy gradually evolved over the decade. The year 2013 marked the first official use of the term ‘strategic autonomy’ within the context of strengthening Europe’s defence industry. By 2016, the ambition expanded to include space and space-based services under the “global strategy for the EU’s foreign and security policy” aiming to promote autonomy and security across the full spectrum of land, air, space, and maritime capabilities. By 2019, focus on European interests in a challenging global environment began taking shape mainly influenced by the UK's departure from the EU, a

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

change in the American administration marked by unconventional strategies, and China's rising dominance. By 2020, focus was placed on economic and supply chain dependencies which were brought into light following the COVID-19 pandemic. By 2021, the focus further broadened and got to a stage where it addressed all major policy areas beyond defence and security and placed emphasis on the EU's ability to making independent decisions across all major policy sector. By 2022, a more aggressive push towards realising and implementing the aspects of European strategic autonomy began to take shape, especially led by the geopolitical conflict between Russia and Ukraine, and the lack of European capabilities to support Ukraine's secure communication needs further added to the sentiment of developing European autonomous capabilities. The importance of this event is exemplified by the Swift decision making on IRIS², which was approved in record time of 9 months compared to other space-based EU programmes.[24] Additionally, the comments from Director (Catherine KAVVADA) of the IRIS² programme during IRIS² industry information day specifically pointed out that "*IRIS² is first and foremost a governmental constellation with security and defence applications. Our approach will therefore be structured by those cardinal considerations*".

Current Status of IRIS2 & its evolution

The programme has already completed its first phase towards the formation of an open consortium, governed by Airbus Defence and Space, Eutelsat, Hispasat, SES and Thales Alenia Space. While also relying on core expertise from companies such as Deutsche Telekom, OHB, Orange, Hisdesat, Telespazio, and Thales. This consortium is expected to design a multi-orbital satellite constellation, with interoperable features linking the terrestrial networks too. Moreover, the consortium is also expected develop relationships and partnerships with the greater satcom and telco community, that is composed of start-ups and SME's.

Currently the programme is under phase 2, whereby the consortium members submit their preliminary proposals. These proposals include details regarding the project design, cost, schedule as well as gauging the financial involvement of the private sector. Additionally, phase 2 also aims to comprehend the supply chain that shall be necessary to deliver the constellation, including the involvement of start-ups and SMEs. Overall this phase is expected to be completed by 2024.

The implementation of IRIS2 will follow an incremental approach with the ambition to deliver initial services in 2025 to reach full operational capability by mid-2027.[25] It is noteworthy to mention its EUR 2.4B of EU funding over several years is about 1% compared to the $50B annually of public space funding for security and defence globally. [26]

3.3.3 Market dynamics

This section of the report provides an overview of the global satcom market, with a particular focus on Europe's current and prospective standings within this global landscape. Additionally, this section delves into the prevailing trends in satellite capacity pricing specific to Europe and evaluates the region's supply and demand dynamics.

[24] Source: Copernicus https://www.copernicus.eu/en/news/news/observer-copernicus-gets-sibling-iris2-new-eu-secure-communication-constellation#:~:text=A%20major%20outcome%20of%20the,launch%20Europe's%20newest%20satellite%20constellation.
[25] Source: European Commission https://defence-industry-space.ec.europa.eu/system/files/2023-03/IRIS%C2%B2_Factsheet%20%28EN%29.pdf
[26] Source: European Space Policy Institute https://www.espi.or.at/wp-content/uploads/2023/02/ESPI-Perspectives-January-2023.pdf

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.3.3.1.1 Evolution of the global satcom market

The global satcom market is anticipated to grow at a CAGR of 9.5%, increasing from $12.1B in 2021 to an estimated $30B by 2031, as illustrated in the figure below. This overall growth, however, varies dramatically across verticals.

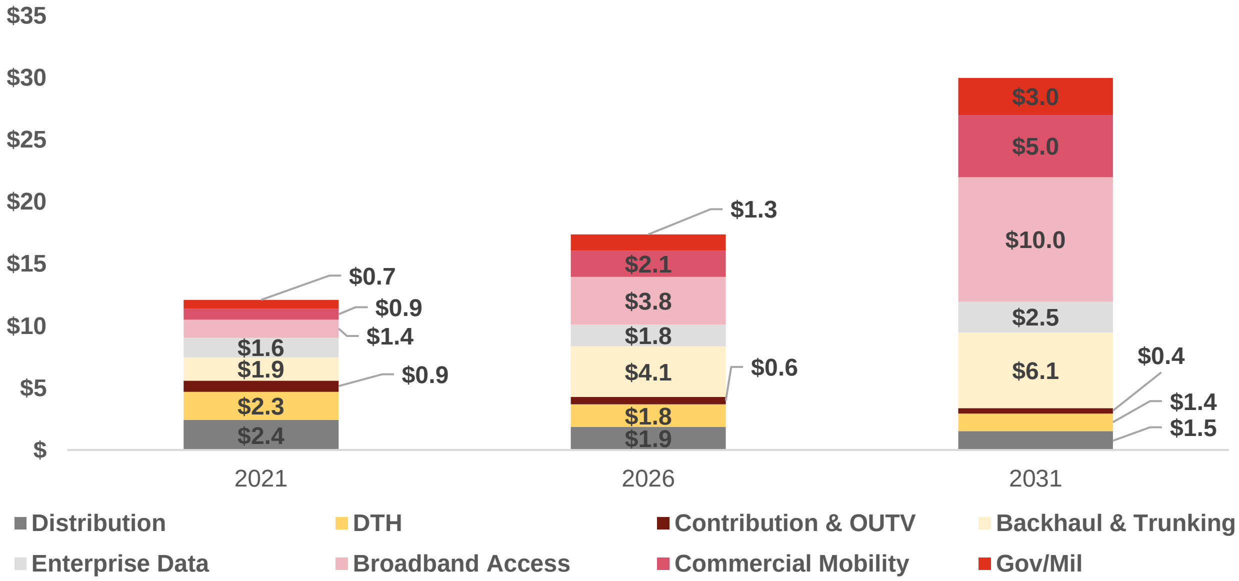

Figure 18: Vertical Segmentation of Global Satcom Market (in $B), projected for 2021-2031.

Video applications like Direct-to-Home (DTH) and Distribution, which have traditionally anchored the FSS market are anticipated to see a downturn in revenues over the next decade. Specifically, Distribution is expected to decline from $2.4B in 2021 to $1.5B by 2031, and DTH from $2.3B to $1.4B. One key factor contributing to this decline is the growing prevalence of bundled packages from telecommunications companies, along with shifting consumer behaviour towards over-the-top (OTT) content consumption platforms.

Conversely, segments focused on data, such as Backhaul & Trunking and Broadband Access, are anticipated to experience significant growth. Revenue projections for Backhaul & Trunking indicate a more than threefold increase, growing from $1.9 billion in 2021 to an estimated $6.1 billion by 2031. This upward trend is primarily driven by the increasing demand for data and bandwidth by Mobile Network Operators (MNOs), especially considering the accelerating adoption of 5G. In alignment with this trend, satcom providers are increasingly adopting terrestrial standards and introducing value-added services, including network traffic management. Furthermore, MNOs are becoming increasingly aware of the distinct advantages offered by satellite communication, notably by non-GEO operators, such as reduced latency and data throughput in par with terrestrial networks.

Broadband Access shows even more promise, with a projected growth from $1.4B in 2021 to $10B by 2031. It is anticipated that a large portion of this market shall be captured by existing and upcoming non-GEO operators who offer the advantages of high bandwidth coupled with low latency. For example, Starlink has already demonstrated the market potential since its beta-testing phase, expanding its global active subscriber base to over 1.5 million[27].

[27] Souce: The New York Times https://www.nytimes.com/interactive/2023/07/28/business/starlink.html

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Verticals such as Commercial Mobility show strong growth prospects as well. For example, the commercial mobility market is expected to see its revenues grow from $0.9B in 2021 to $5B by 2031. It's important to note, however, that the 2021 figures reflect a constrained market led by the ongoing COVID restrictions in certain regions, which limited revenue generation for that year. Now that the pandemic has subsided and travel activities are picking up again, the market is anticipated to return to its pre-pandemic performance.

The Government and Military (Gov/Mil) sector is also projected to experience robust growth, with an anticipated CAGR of 15%, moving from $0.7B in 2021 to $3B by 2031. Contributing factors to this growth include rising geopolitical tensions in Europe, the Middle East, and Asia. As nations within these regions increasingly focus on strategic autonomy, there is a corresponding increase in the procurement of capacity to protect national interests.

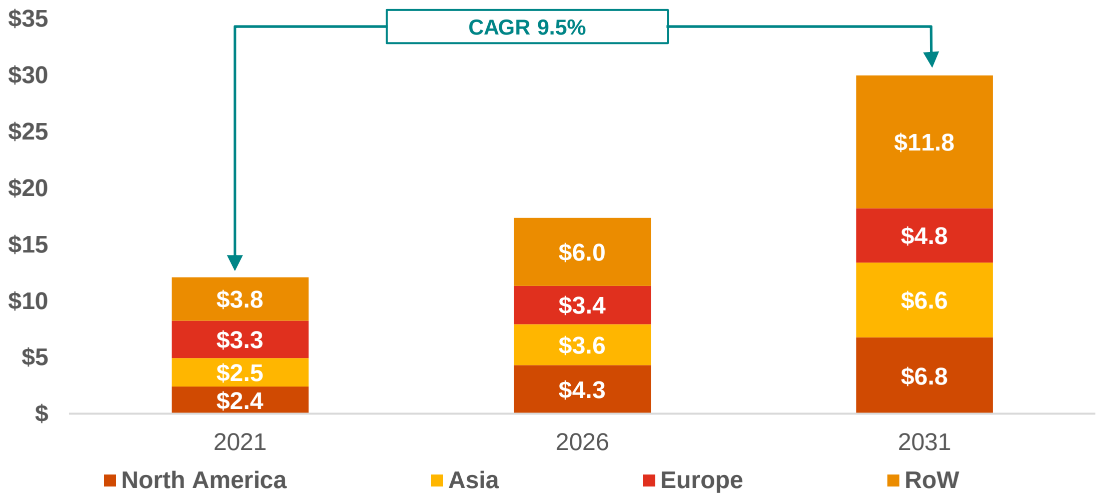

Figure 19: Geographic Breakdown of Global Satcom Market Share ($B), projected for 2021-2031.

Moreover, looking at the market from a geographical perspective, North America, is projected to growth from $2.4B in 2021 to $6.8B in 2031 corresponds to a CAGR of approximately 10.9%. Similarly, Asia is expected to grow from $2.5B to $6.6B at a CAGR of 10.2%. However, Europe exhibits moderate growth, with revenues rising from $3.3B in 2021 to $4.8B by 2031, generating a CAGR of 3.1%

3.3.3.1.2 Evolution of satcom capacity pricing

Much like the global landscape, the European market is experiencing widespread erosion in capacity prices. This trend spans both High Throughput Satellite (HTS) and Fixed Satellite Services (FSS) solutions and is visible across all verticals.

Evolution of GEO HTS & Non-GEO HTS Capacity Pricing in Europe

Currently, Non-GEO constellations such as SES (O3B), and especially Starlink have significantly disrupted the market by offering solutions that are on an average 2.6 times more cost effective than those offered by GEO HTS operators with the widest gap emerging in the Commercial Mobility vertical, where non-GEO HTS operators are almost 3.5 times less expensive than GEO HTS operators.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

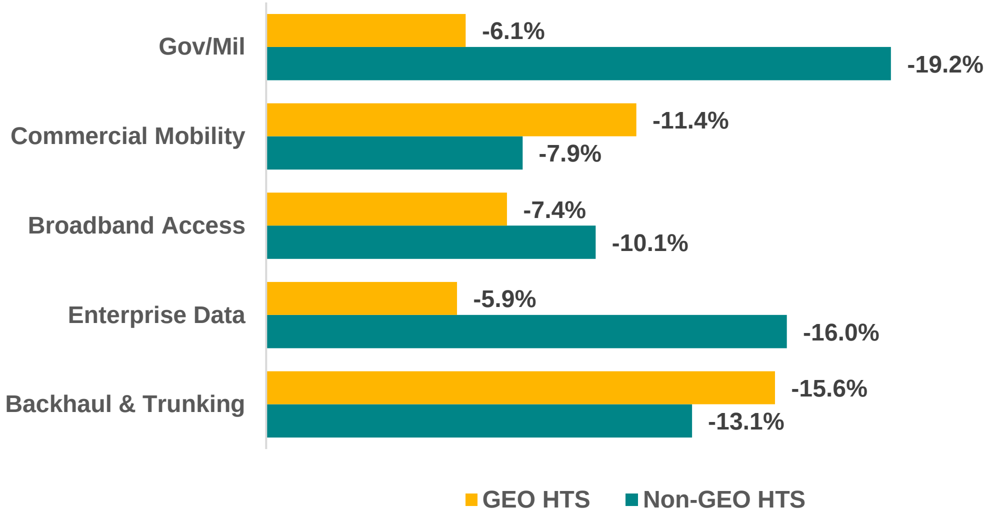

Figure 20: GEO HTS & Non-GEO HTS European Capacity Pricing CAGR, 2021-2031.

By 2031, the price differential is expected to widen even further for specific verticals. For the Government/Military (Gov/Mil) and Enterprise Data segments, non-GEO HTS offerings are projected to be nearly 10 times and 4.5 times more economic, respectively, compared to GEO HTS services. In addition, for other sectors like Commercial Mobility, Backhaul & Trunking, and Broadband Access, Non-GEO HTS is anticipated to continue its cost advantage, being 2.1 times, 1.4 times, and 1.1 times less expensive than the GEO HTS options.

One of the core reasons leading to this wide price gap between the GEO HTS and non-GEO HTS capacity, can be attributed to a couple of distinct but interconnected elements. Firstly, global architecture of non-GEO HTS constellations inherently leads them to over supply the market. Second, Non-GEO HTS operators exhibit a propensity for adopting a more aggressive customer acquisition strategy that include subsidizing end-user terminals[28].

This anticipated excess supply is seen as placing pressure on prices in the market. A detailed analysis of the supply trends is undertaken in section **Error! Reference source not found.**

Evolution of Ku-band, C-band & Wide-beam Ka-band Capacity Pricing in Europe

Similarly, in the context of traditional bandwidth capacities like Ku-band, C-band, and Wide-beam Ka-band, pricing pressures are also manifesting.

[28] Source: TechCrunch https://techcrunch.com/2021/06/29/spacex-is-losing-money-on-its-starlink-terminals-but-sees-lower-costs-ahead/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAZwsmcjCtU3CMc2v5dClgjTXREy-s7aFT-ZCqeHh2nzLYLyx9k3j2jmSfoG63IDvRqzXQ_q_WtV1z2Ge2SwhpZzE6Sn7Vl74hdw9ETDjNoD8odM2TUwvyY3Qgo7ZCB9xlj5l4uL4Y3jRh_xXgaiLSc2Bl-jDMhzVE41JaPdVHIw

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

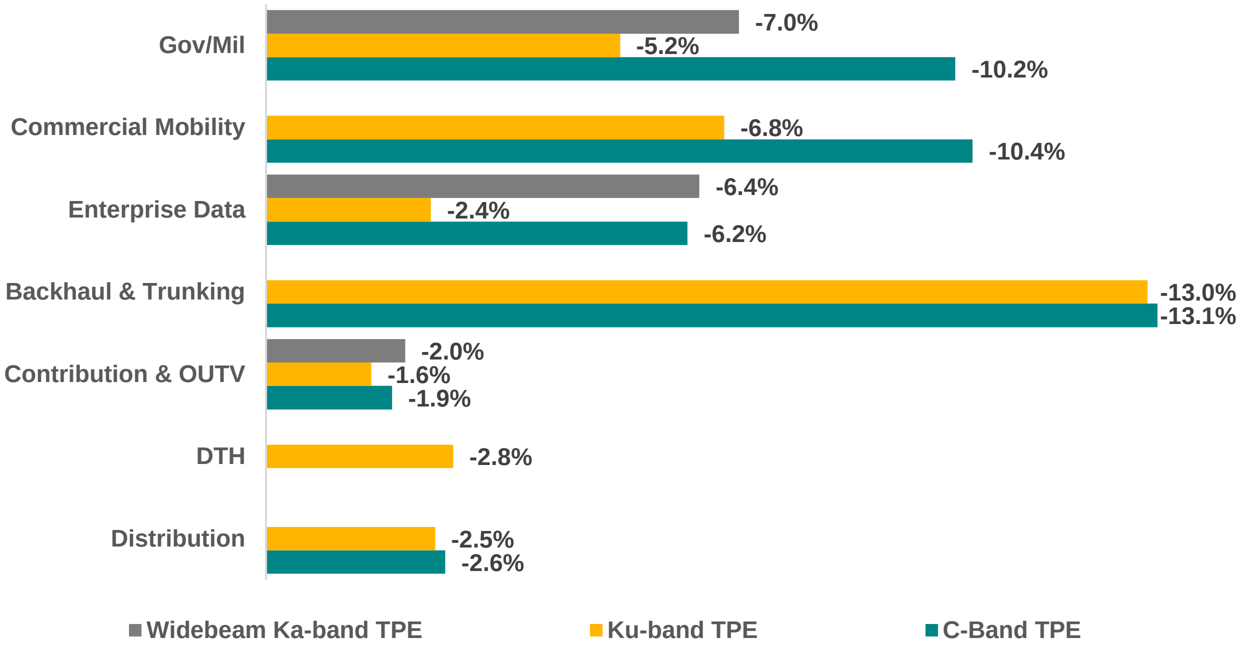

Figure 21: Ku-band, C-band & Wide Beam Ka-band European Capacity Pricing CAGR, 2021-2031.

Backhaul & Trunking sector exhibits a steep CAGR of approximately -13% for both Ku-band and C-band. The core reasons leading to the price decline is directly linked to value proposition provided by HTS solutions, and more recently non-GEO HTS solutions. Given that these solutions are more apt to aid terrestrial network operators in expanding their coverage, providing required bandwidth, and meeting the latency requirements of the on-going 5G deployment, as well as facilitating the existing 4G network across many European geographies.

The Government/Military sector, which predominantly relies on C-band, Ku-band and Ka-band FSS capabilities is projected to experience a significant downturn at a CAGR of -10.2, -7% and -5.2% respectively. Hereto traditional solutions offered by FSS operators are being overshadowed by non-GEO HTS operators, particularly due to the credibility gained by Starlink in the conflict of Ukraine. Furthermore, the influence of IRIS^2 is the coming years is also anticipated to play a role in re-shaping the price points at which capacity is offered to civil government and military institutions. Likewise, Starlink's recent expansion into the mobility markets (Land, maritime and aeronautical mobility), along with the potential entry of other satellite constellations like Project Kuiper, OneWeb, and Telesat, is projected to exert downward pressure on price. Specifically, prices for Ku-band are expected to decline at a CAGR of -6.8%, while Ka-band prices are predicted to decrease at a CAGR of -10.4%

The Enterprise data sector predominantly relies on FSS Ku-band for VSAT applications, particularly in the energy industry. Given the sector's complex requirements, especially for remote operations, there's a growing preference for more dependable connectivity solutions, steering the trend toward GEO HTS options. While there is potential for Non-GEO adoption, this is likely to occur only after thorough network testing. It's also worth noting that the failure of Viasat-3 removes 1Tbps of capacity from Europe, slightly mitigating the impact on FSS capacity pricing. However, the overall pricing for Ka-band, C-band, and Ku-band is anticipated to decrease at a CAGR of -6.4%, -6.2%, and -2.4%, respectively. [29]

For Video applications, which include Distribution, DTH, and Contribution & OUTV, the situation mirrors other sectors in that prices are falling. Specifically, the CAGR for DTH pricing per TPE is projected to drop by 2.8%. For Distribution, the expected decline is -2.5% in Ku-band and 2.6% in C-band, while Contribution & OUTV is anticipated to see an average CAGR decrease of -1.8% across the Ku, C, and Ka-bands.

3.3.3.2 Demand trends

Starlink enabling greater demand for consumer broadband

Traditional broadband packages from established providers usually tie consumers into service agreements that last for a minimum of two years. These plans are marketed as unlimited, but in practice, data speeds are significantly reduced once certain data caps are reached. Therefore, are comparatively considered as being inflexible. In contrast, Starlink has disrupted the traditional model by offering services without mandatory long-term commitments, delivering data speeds ranging from 100-220 Mbps, and giving users options when it comes to acquiring or renting terminals.[30] Starlink also supports roaming and mobility features at highly competitive prices. For example, as of 2023, Starlink's standard services in Europe are priced at EUR 40/month.[31] The option to buy a user terminal is available for EUR 450—a cost believed to be significantly subsidised—or customers can choose to rent the equipment for EUR 10/month. Additionally, global mobility can be added for an extra EUR 190 per month, on top of the standard subscription.[32] Starlink's blend of flexibility, affordability, high-speed connectivity, and low latency has dramatically broadened consumer broadband demand in Europe.

Declining demand for video services more pronounced in Western Europe

The demand for video services are dropping as they face fierce competition from terrestrial alternatives. Established providers like Deutsche Telekom, Sky UK, and Sky Italia are faced with severe competition from Over-The-Top (OTT) platforms, including Netflix and Amazon Prime, among others. On the Contribution and OUTV front, clients are increasingly opting for terrestrial solutions, with fibre gaining ground over satellite for distribution. This trend signals a decrease in dependency on satellite technology for content dissemination, and this is expected to continue especially in the Western Europe. Conversely, the decrease in video application demand is less pronounced in Central and Eastern Europe.

Optical communication links and adoption of 5G standards fuelling demand

The integration of innovative technologies in the space segment, including inter-satellite communication links and the implementation of telecommunications standards, is set to enhance network optimization and simplify the adoption of space-based solutions for MNOs. This advancement is anticipated to stimulate an increase in demand across all key data-centric verticals, whether fixed or mobile.

3.3.3.3 Supply trends

Oversupply of GEO and Non-GEO HTS capacity in the European Markets

[29] Source: Viasat https://www.viasat.com/about/viasat-3/capacity/
[30] Source: Starlink https://www.starlink.com/legal/documents/DOC-1042-35310-55?regionCode=FR
[31] Source: Starlink https://www.starlink.com/orders/?processorToken=6931cdbf-3dc4-4261-a6b8-4f001ab2316d
[32] Source: Starlink https://www.starlink.com/orders/?processorToken=84b9680c-785c-4c2d-ba37-0118a5ec4a9c

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

A robust influx of capacity from both GEO HTS and non-GEO HTS satellites is anticipated to penetrate the European market. The capacity is projected to grow at a CAGR of 61%, expanding from an initial 321 Gbps in 2021 to an estimated 34 Tbps by the year 2031. Notably, this growth in capacity is predominantly attributed to non-GEO HTS constellations, such as Oneweb, Starlink, mPower (SES), and Project Kuiper. It's worth highlighting that in 2021, non-GEO HTS contributed a mere 2% to the overall capacity available in Europe. This proportion experienced a dramatic surge, constituting 82% of the total supply by 2022, and is forecasted to account for 92% of the entire supply by 2031. However, despite this influx of supply (GEO HTS & non-GEO HTS), the total capacity fill rates remain considerably low throughout the period, peaking to merely 10% by 2031.

Resurgence of institutionalised satcom programmes

The last decade has been marked by COMSATCOM, whereby several players entered the market with novel business models, especially leveraging small satellites, in GEO and LEO orbits. However, this era of pure COMSATCOM dominance is gradually diminishing, at least in terms of supplying services to civil government and military institutions. A renewed emphasis on state-led initiatives is becoming evident worldwide, including China's Guowang LEO small satellite constellation and the United States' Proliferated Warfighter Space Architecture (PWSA). Europe has also entered this race with initiatives like GOVSATCOM & IRIS². The re-emergence of these government-backed satellite constellations is anticipated to further exacerbate supply imbalances in the market.

Market under consolidation

Since 2020 the satcom market has seen a strong wave of highly strategic mergers and acquisitions, encompassing both vertical and horizontal strategies. In terms of vertical M&A activities, there is a strong motivation to acquire service providers, for instance, Kymeta acquired LEPTON to enter the defense market, Eutelsat acquired bigblu to provide end-to end broadband solutions across Europe, Intelsat acquired gogo to directly reach its end-users within the In-Flight Connectivity market, and Viasat acquired Rignet to strongly position itself within the energy market. In the realm of horizontal M&A, one of the most substantial deals in over two decades was Viasat's acquisition of Inmarsat for an estimated $7.3 billion USD.[33] Additionally, in 2023, SES and Intelsat engaged in three months of merger discussions with the objective of creating a group worth $4 billion; although this union ultimately did not materialise.[34] These events suggest that the industry could see even more M&A activity in the near future, especially as Low Earth Orbit (LEO) constellations continue to strengthen their market presence.

3.3.4 Assessment of emerging and future downstream activities

In the 1990s and early 2000s, the satellite communications (satcom) industry experienced its first wave of Low Earth Orbit (LEO) constellations with the emergence of Globalstar, ICO Global Communications, and Iridium. These early ventures primarily targeted voice and mobile telephony services, aiming to offer cost-effective global voice coverage with economically priced handsets. The idea was to replicate the Direct-To-Home (DTH) model in voice and mobile telephony, capitalizing on the coverage gaps that terrestrial networks could not fill. However, these ambitions faced setbacks due to the high capital expenditures (CAPEX) involved in manufacturing and launching a global satellite constellation, as well as the operational costs (OPEX) of maintaining ground networks. Added to this were the challenges of poor indoor reception and failure to develop lightweight, affordable handsets. These obstacles, coupled with a gross

[33] Source: Via Satellite https://www.satellitetoday.com/business/2023/05/31/viasat-closes-inmarsat-acquisition/
[34] Source: SpaceNews https://spacenews.com/intelsat-walks-away-from-ses-merger-talks/

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

overestimation of the market—approximately 8.7 times its actual size—led to the bankruptcy of companies like ICO Global and Iridium.

Today this downstream application is experiencing a resurgence, with the rise of small satellites in LEO orbits. This revival has stimulated interest among major corporations, leading to significant partnerships in 2022 between cell phone manufacturers and Mobile Network Operators (MNOs). These partnerships aim to extend global coverage through, particularly leveraging modern LEO SATCOM providers. For instance,

- SpaceX and T-Mobile: companies joined forces to utilise SpaceX's Starlink LEO satellites for nationwide SATCOM services, targeting especially remote and rural areas.
- Apple and Globalstar: developed a partnership to provide new iPhones with emergency SOS messaging services via satellite.
- Huawei: Their latest flagship, the Mate 50 series, incorporates satellite communications through China's BeiDou system for messaging and navigation.
- Bullitt Group and MediaTek: Built a collaboration to introduce satellite-enabled chips in Bullitt’s new smartphone model for enhanced connectivity.
- Iridium and Qualcomm: Announced Snapdragon Satellite, aimed at enabling two-way messaging on smartphones using Qualcomm's Snapdragon 8 Gen 2 mobile platform.
- Amazon and Verizon: They are collaboratively working under Project Kuiper to create satellite-enabled mobile connectivity services.

As the market matures, its financial structure is evolving as well. Contractual relationships between MNOs and satellite service providers are becoming the norm. While some MNOs, like T-Mobile, are providing satellite services as free add-ons, others are exploring specialised pricing packages. The industry is also considering subscription-based models as technological advancements promise to expand the range of available services beyond basic two-way messaging.

Although still in its infancy, the satellite-to-mobile service market is poised to be a cornerstone in the future of telecommunications. The initial focus on emergency communications is likely to expand to encompass messaging, voice, and broadband services. The industry, however, has to surmount several technological and regulatory challenges. A region-specific strategy will also be crucial as the service is likely to find its largest consumer base in developing countries.

3.3.5 Mapping of Satcom emerging technologies, services, and applications

Table 8: Satcom Emerging Technologies, Applications, Services

Value Chain segment	**Technologies**	**Applications**	**Services**
Upstream	Optical communication/inter-satellite communication	Space & ground network optimization (example: managing/diverting traffic between network nodes)	Consumer broadband In-flight entertainment & connectivity (IFEC) Maritime infrastructure & crew connectivity Data-relay

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

	Electronically steered antenna	Mobile connectivity (commercial, civil government & military assets)	Communication on the move (COTM) Aeronautical connectivity (passenger jets, business jets, etc.) Maritime connectivity (merchant vessels, fishing vessels, cruise ships etc.)
	Flexible satellites	Independent beam steering, digital channeliser, alter beam characteristics and power/spectrum profile	Communication on the move (COTM) Flexible landing of traffic (backhaul, cloud services, etc.) Crisis management (offer communications during momentary traffic burst events, example, natural disasters) Government/military communication services (flexibility to support different service level agreements (SLAs))
	Very High Throughput Satellites (VHTS)	Broadband and mobile connectivity	Broadband access Commercial mobility Enterprise data Government/military mobility Backhaul & trunking
	Satellites based on Quantum Key Distribution (QKD)	Secure & encrypted communications Quantum communication network	Cryptographic key delivery services Secure data centric services (broadband access, enterprise data, etc.) Secure managed network services
Midstream	Optimised video software solutions	High-precision, high compression, geo-tagged live video content & streaming over satellite	Fixed & mobile services: intelligence, surveillance, and reconnaissance (ISR), search & rescue, remote

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

			inspection, drone services
	DVB-S2 (Digital Video Broadcasting -Satellite)[35] and HEVC standards (High Efficiency Video Coding)	Video applications (DTH, broadcasting, OUTV)	Satellite TV (transmission of UHD channels, and live UHD channels)
	5g Non-Terrestrial Network (NTN) & Orthogonal Frequency Division multiplexing (OFDM)	Interconnectivity with terrestrial 5g networks Satellite-enabled devices Direct-to-device communication	Satellite backhaul for 5g Satellite broadband services Interoperability and roaming between networks
Downstream	Multi carrier satellite gateway	End-to-End multimedia integrated support, including OTT integration Multi-stream reception and transmission	Direct To-Home (DTH) video delivery Direct-To-Tower (DTT) video & audio delivery live, on-demand OTT distribution
	Edge computing both in-space & on ground	In-orbit data processing Real-time and autonomous identification of efficient/best-fit communication links across multiple-orbits, & terrestrial networks	End-to-End managed network services for enterprise, consumer broadband, & mobility market

3.4 Satellite Navigation

Satellite navigation is used in various sectors beyond its original military purpose. It is now common in cars, smartphones, as well as in farming and shipping. The market for these systems is growing, driven by both public and private sectors. It's not just about the physical devices; services like mapping and real-time tracking are also in demand.

New technologies like the Internet of Things (IoT) and 5G are expected to increase the need for more advanced navigation systems. However, the market faces challenges such as data privacy concerns, signal interference, and the complexity of international regulations. This section will provide a detailed look at the current state and future trends of the satellite navigation market.

[35] Old technology but still relevant for transmitting UHD channels

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.4.1 Presentation of the value chain

The value chain of the global navigation satellite system (GNSS) domain is divided into upstream, midstream, and downstream. As presented on the chart below, the upstream sector includes actors contributing to an operational navigation space system. The midstream sector includes all activities related to the operation of GNSS to ensure ultimately the delivery of Positioning, Navigation, Timing (PNT) service, typically executed by satellite operators and GNSS service providers. The downstream sector includes all actors involved in the exploitation of GNSS service and delivering related value-added products and services to the final users. This includes for instance the manufacturers of GNSS receivers and Personal Navigation Devices (PND) integrated systems (e.g., for car, aircrafts, vessels, precision farming) as well as smartphones applications, software applications and value-added services. Finally, GNSS end-users include a very wide range of institutions, companies and individuals using GNSS for their daily activities.

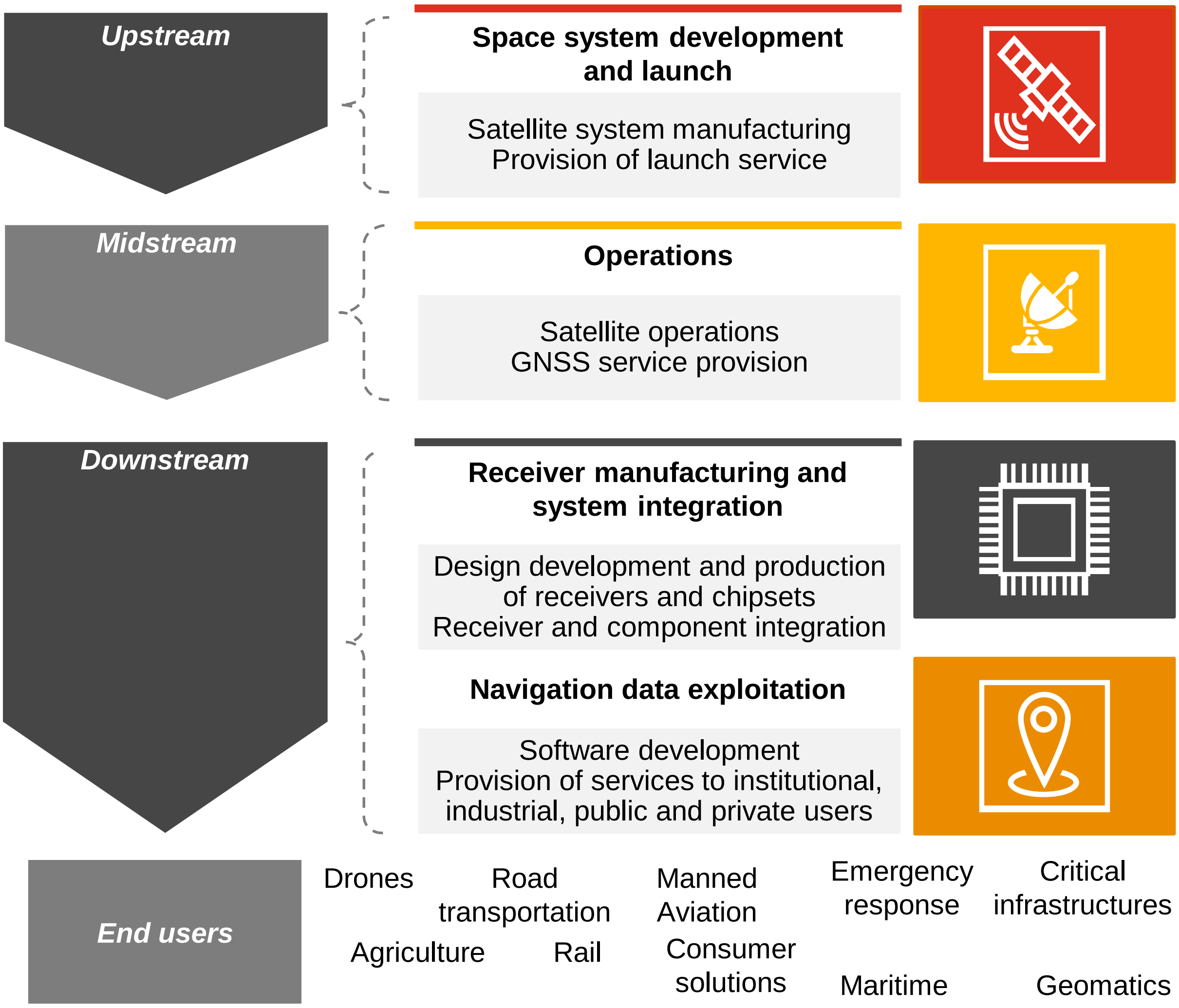

Figure 22: Satellite Navigation Value Chain.

3.4.2 Overview of the Satellite Navigation programmes

Several GNSS constellations and satellite-based augmentation systems provide navigation capabilities around the globe. At present, there are four main systems providing service globally: Global Positioning System (GPS) by the US, Global Orbiting Navigation Satellite System (GLONASS) by Russia, Galileo by the EU,

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

and BeiDou by China. General GNSS constellations and satellite-based augmentation systems around the globe are listed on the Figure below.

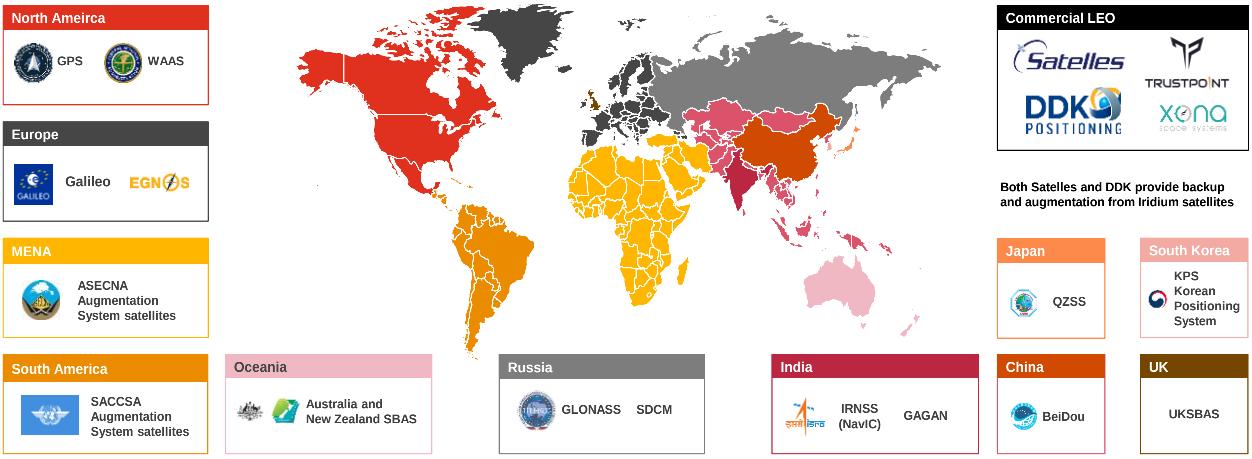

Figure 23: Main GNSS and Augmentation Systems Across the Globe.

3.4.2.1 EU programme

The European Global Navigation Satellite System (GNSS) consists of two elements: Galileo and the European Geostationary Navigation Overlay Service (EGNOS).

Galileo

Galileo is Europe's GNSS civil programme, providing a highly accurate, guaranteed, global positioning service for the public and private use of European and global entities. Moreover, the programme is compatible and interoperable with GPS, GLONASS and BeiDou. It was created to answer Europe's strategic need of a reliable European satellite navigation signal, and to foster the development of economic and societal benefits. ESA leads the design and development of the space and ground systems, as well as procuring launches. EUSPA acts as the service provider of Galileo, overseeing the market and application needs and closing the loop with users.

Currently, there are 28 satellites in orbit and 10 further Galileo satellites due to be launched, after which the first of the Galileo Second Generation (G2) satellites with enhanced capabilities are expected to be added in coming years.

Four services are provided by Galileo:

- Open service (free of charge to users, providing positioning and synchronization information for navigation applications);
- High accuracy service (more secured and precise service delivered through encrypted signal);
- Public regulated service (restricted to government-authorised users, for sensitive applications requiring a high level of service continuity, free of charge for European institutions and the Member States);

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

- Search and rescue services (offers alert informing the sender that their distress message has been received).[36]

EGNOS

The European Geostationary Navigation Overlay Service (EGNOS) is Europe's regional satellite-based augmentation system (SBAS) that is used to improve accuracy of GNSS, while also ensuring continuity and availability of a signal.

Three services are provided by EGNOS:

- Open Service (free and open to the public for common user applications);
- Safety of Life Service (targets a range of safety-critical transport applications such as aviation, maritime, rail and road; more applications are expected in inland waters and agricultural domains);
- EGNOS Data Access Service (provides a controlled ground access through the Internet to customers requiring enhanced performance for professional use).[37]

3.4.2.2 ESA programme

ESA has an increasing funding for satellite navigation programs, and currently has three running initiatives which will be described below.

FutureNAV

The FutureNAV programme will be composed of several missions to adequately respond to the rapidly growing navigation needs. The first mission consists of an initial in-orbit demonstration, small constellation of LEO-PNT satellites complimenting Galileo MEO satellites. Thus, the mission will test a new multi-level 'system of systems' approach in delivering navigation service. The next mission will map the contours of planet Earth more accurately than ever before, thus contributing to the precision improvement of multiple navigation and Earth science applications. The mission also includes creation of a combined single platform satellite navigation with laser and radio-ranging, as well as very long baseline interferometry.

NAVISP

NAVISP is ESA's Navigation Innovation and Support Programme, which facilitates development of new technologies in PNT, and has supported already more than 200 innovative projects by opening a set of tenders offering funding, consultancy, and network opportunities for developers.[38] Further calls within the programme are expected to focus on the applications for green and digital mobility on land and on sea.

Moonlight

Moonlight initiative aims to extend satellite navigation and telecommunications coverage to the Moon and its orbit ensuring sustainable earth-lunar connectivity.[39] The first receiver to operate in lunar orbit was

[36] Source: ESA https://www.esa.int/Applications/Navigation/Galileo_Second_Generation_enters_full_development_phase
[37] Source: EUSPA https://www.euspa.europa.eu/2022-market-report
[38] Source: ESA https://navisp.esa.int/
[39] Source: ESA https://www.esa.int/Applications/Navigation/ESA_Navigation_portfolio_expanded_and_diversified_by_Ministerial_Council

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

already delivered to the UK company Surrey which will further integrate it in the ESA Lunar Pathfinder relay satellite, which is expected to be launched in late 2025.[40]

3.4.3 Market dynamics

The GNSS market encompasses a wide array of activities where GNSS-based positioning, navigation, and timing play a pivotal role in enabling various functionalities. This market includes both device revenues and revenues derived from augmentation and additional value-added services attributed to GNSS technology. Augmentation services comprise software products, digital maps, and GNSS augmentation subscriptions, while added-value services cover revenue generated from data transmitted over cellular networks for location-based applications, income from smartphone apps with GNSS functionality, subscriptions for fleet management services, and earnings from drone services across diverse industries, among other sources. Over the next decade, GNSS demand is projected by EUSPA to exhibit significant growth, both within the European Union and globally. In the European Union, from 2021 to 2031, device revenues are expected to increase from 12.1 billion euros to 21.6 billion euros, while services revenue is anticipated to rise from 27.4 billion euros to 53.7 billion euros. On a global scale, the GNSS market is set to expand considerably, with device revenues projected to grow from 48.4 billion euros in 2021 to 87.0 billion euros in 2031, and services revenue surging from 150.5 billion euros to 405.2 billion euros over the same period. This outlook emphasises the fundamental role GNSS technology plays in a wide range of industries and underscores its enduring importance in the foreseeable future. With a foundational understanding of the market dynamics in place, the following sections will describe the demand and supply trends within the GNSS domain.

The following tables summarise the market growth of the GNSS market over the next decade.

Table 9. European GNSS Market Growth 2021-2031

Revenue streams	**2021 revenues**	**2031 projected**
GNSS devices revenues	€12,1B	€21,6B
GNSS services revenues	€27,4B	€53,7B
Total	€39,5B	€75,3B

Table 10. Global GNSS Market Growth 2021-2031

Revenue streams	**2021 revenues**	**2031 projected**
GNSS devices revenues	€48,4B	€87B
GNSS services revenues	€150,5B	€405,2B
Total	€198,9B	€492,2B

[40] Source: ESA https://www.esa.int/ESA_Multimedia/Images/2023/06/Satnav_from_Earth_to_the_Moon

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.4.3.1 Demand trends

This section provides an overview of the evolving demand trends in the Global Navigation Satellite Systems (GNSS) market. It highlights how location-based services are becoming indispensable for both emergency response and everyday activities. The increasing need for resilient and secure GNSS solutions in military applications is also examined. Additionally, the road sector's role as the largest consumer of GNSS technologies is discussed, especially in the context of digital transformation and legislative mandates. These trends collectively influence the future of GNSS, presenting both challenges and opportunities.

Asset for performance, safety, and leisure

Today, GNSS is used by an extremely wide range of users in every sector, and it drives significant economic activity. Currently there is tendency for location-based services (LBSs), which use real time geo-data through internet capable devices to provide information about current location. LBSs help during flood, rescue events, natural calamities, and for weather forecasting to develop future programs to simplify the situational events. Therefore, most of the countries mandate the use of LBSs as they help in decision making for civil operations. In addition, there is an increase of adoption of LBSs uses by the general public through various internet capable devices (smartphones, digital cameras fitness devices, etc.) as well as various mobile applications for business, communication, gaming, health & wellness apps.[41]

Beyond emergency response, LBSs are increasingly being utilised for more routine decision-making processes in civil operations. Whether it is urban planning, traffic management, or weather forecasting, real-time geospatial data aids in making more informed and timely decisions. This has led to the development of various programs aimed at simplifying complex situational events, thereby enhancing overall efficiency and effectiveness. These programmes include traffic management systems, disaster response programmes, agricultural precision timing, public health initiatives, environmental monitoring, retail and marketing optimization, etc.

The general public has also embraced the use of LBSs, facilitated by the proliferation of internet-capable devices such as smartphones, digital cameras, and fitness trackers. These services have found applications in a wide range of areas, from business and communication to gaming and health & wellness apps. The convenience and utility offered by LBSs have led to their integration into daily lives activities by bringing value added solutions simplifying complex tasks.

Resilience and security drivers

The military's increasing reliance on Global Navigation Satellite Systems (GNSS) has amplified the need for resilient and secure navigation solutions. This is particularly true for safety and liability-critical operations, where the stakes are high and the margin for error is minimal. As a result, the demand for robust GNSS systems has been on the rise, prompting significant advancements in satellite technology and infrastructure. To meet this growing demand, new generations of satellites are being designed with enhanced resistance to various forms of interference and vulnerabilities. These include features such as anti-jamming capabilities, secure communication channels, and advanced encryption methods. The aim is to ensure that the GNSS systems remain operational and accurate even in hostile environments or during electronic warfare scenarios.

Recognizing the need for collaborative efforts to improve GNSS resilience, the geodetic community has recently formed the Open Positioning, Navigation, and Timing (PNT) Alliance. This alliance brings together

[41] Source: Allied Market Research https://www.alliedmarketresearch.com/navigation-satellite-market-A10439

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

experts from academia, industry, and government agencies with the goal of developing redundancies and alternative solutions to institutional GNSS systems. By doing so, the alliance aims to create a more robust and reliable navigation ecosystem that can withstand various challenges, ranging from natural disasters to deliberate attacks on the infrastructure.

One of the key objectives of the Open PNT Alliance is to develop redundant systems that can serve as backups to conventional GNSS. These could include terrestrial-based navigation systems, inertial navigation systems, and even emerging technologies like quantum navigation. The idea is to have a multi-layered approach to navigation, ensuring that if one system fails or is compromised, another can take over to maintain operational integrity.

As the military continues to integrate GNSS into its operations, the focus on resilience and security is expected to intensify. This will likely lead to further innovations in satellite technology and the broader adoption of redundant systems. Moreover, the collaborative efforts of organizations like the Open PNT Alliance are set to play a crucial role in shaping the future landscape of secure and resilient satellite navigation.

Road remains the largest GNSS market

The road sector continues to be the largest market for Global Navigation Satellite Systems (GNSS), and its influence is only growing as highways and vehicles become increasingly digitalised. One of the most prominent shifts in this sector is the transition from traditional toll booths to GNSS-based road tolling systems.

The move to GNSS-based tolling capitalises on the benefits of digital implementation, offering several advantages over older, physical or microwave-based methods. For instance, GNSS-based tolling allows for more efficient and fluid traffic flow as vehicles reduce their necessity to have to stop or slow down at toll booths. It also enables dynamic pricing models, where toll rates can be adjusted in real-time based on traffic conditions, thereby optimizing road usage. Additionally, the system provides more accurate and detailed data collection, which can be used for traffic analysis and infrastructure planning.

In Europe, the adoption of GNSS in the road sector is expected to accelerate due to legislative measures. The European Union has issued a Directive on road safety and emergency services that mandates the use of the Galileo satellite system (Commission Delegated Regulation (EU) 2019/320[42]). This EU Directive aims to enhance road safety by requiring vehicles to be equipped with advanced navigation and emergency call systems that are compatible with Galileo. The move is expected to standardise safety features across the EU, making roads safer while also boosting the market for GNSS technologies.

3.4.3.2 Supply trends

Pushing for greater accuracy

The push for greater accuracy in Global Navigation Satellite Systems (GNSS) is a key trend shaping the industry. One significant development fuelling this trend is the advent of multi-constellation receivers. These advanced devices are designed to be compatible with multiple GNSS signals, thereby offering users a more reliable and accurate navigation experience. The expectation is that these multi-constellation receivers will not only gain rapid adoption among end-users but also elevate the performance metrics, specifically in terms of accuracy and integrity.

[42] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0320&rid=1

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

In a notable milestone, the Galileo High Accuracy Service (HAS) commenced operations in 2023. This service is poised to be a game-changer, particularly in sectors that require high-precision location data. It is anticipated that Galileo HAS will catalyse the development of innovative applications across a diverse range of industries. For instance, in transportation, it could lead to more efficient route planning and traffic management. In agriculture, high-precision data could enable more effective use of resources like water and fertilisers. The geodesy sector could benefit from more accurate land surveys, while the entertainment industry might see the rise of location-based interactive experiences.

Concepts emerge for LEO-based GNSS Constellations

The landscape of Global Navigation Satellite Systems (GNSS) is witnessing a surge in innovative concepts, particularly in the realm of Low Earth Orbit (LEO) constellations. Several players in the industry are proposing commercial LEO constellations as either backups or alternatives to traditional, institutional GNSS systems. Companies like Xona and TrustPoint are at the forefront of this movement, developing LEO-based solutions aimed at enhancing the reliability and versatility of satellite navigation.

In addition to these firms, DDK Positioning and Satelles are offering Positioning, Navigation, and Timing (PNT) services using Iridium spacecraft. These services are designed to provide an additional layer of accuracy and reliability, especially in challenging environments where traditional GNSS signals may be compromised or unavailable. Notably, China's BeiDou GNSS is also reportedly exploring the possibility of adding a complementary LEO constellation to its existing Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO) spacecraft. This move could potentially offer a more robust and versatile navigation solution, not just for China but for global users who rely on multiple GNSS systems for various applications.

The emergence of these LEO-based concepts signifies a shift in the GNSS industry towards more diversified and resilient satellite navigation options. It also opens up new avenues for technological advancements and commercial opportunities, as these LEO constellations could serve a wide range of sectors, from aviation and maritime navigation to emergency response and geospatial analysis.

Next generation of spacecraft brings performance improvements

The next generation of Global Navigation Satellite Systems (GNSS) spacecraft is ushering in a range of performance improvements across various features. One of the most significant advancements is in the area of spoofing and jamming resistance. The Galileo system has incorporated Open Service Navigation Message Authentication (OSNMA), a data authentication function that enhances the security of the navigation messages. This feature assures receivers that the incoming message is genuinely from the Galileo system and has not been tampered with. Since its testing phase in 2021, OSNMA has proven to be a robust solution for mitigating spoofing and jamming attacks, thereby increasing the reliability of the system.

Security enhancements are not limited to the Galileo system alone. The European Geostationary Navigation Overlay Service (EGNOS) has also seen significant upgrades, particularly with the introduction of its next-generation overlay system, known as EGNOS V3. This new version brings improved accuracy and integrity, making it more reliable for critical applications like aviation and maritime navigation.

In addition to security and accuracy, search and rescue capabilities have seen marked improvements. Both the Galileo system and the BeiDou Satellite Navigation System's (BDS) Return Link have enhanced their search and rescue functions since they began operations in 2021. These upgrades allow for quicker response times and more precise location tracking, which can be life-saving in emergency situations.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.4.4 Assessment of emerging and future downstream activities

The Global Navigation Satellite Systems (GNSS) market is poised for significant expansion, particularly in downstream activities that encompass a wide array of sectors.

One of the most anticipated areas for growth in the GNSS domain comes from added-value service revenues. These services encompass a wide range of applications, including data downloaded through cellular networks to run Location-Based Services (LBS), subscription fees from fleet management services, and drone service revenues. Drones equipped with GNSS, for instance, are finding applications across various industries, including agriculture for crop monitoring, real estate for property surveys, and emergency response for rapid situation assessment.

Expanding role of GNSS in the consumer solutions sector

The Consumer Solutions sector stands out as one of the most promising areas for the growth of Global Navigation Satellite Systems (GNSS) technologies. This sector encompasses a wide range of everyday devices that are becoming integral parts of our lives, such as smartphones, wearables like smartwatches and fitness trackers, and smart home systems including voice-activated assistants and home security devices. As these consumer devices come equipped with increasingly advanced GNSS receivers, they unlock new possibilities for more accurate and personalised location-based services (LBS). For instance, smartphones with enhanced GNSS capabilities can provide real-time traffic updates that are not just general advisories but tailored to the user's specific route. This level of customization could significantly reduce commute times and enhance the overall driving experience.

Wearables, another growing category in the Consumer Solutions sector, could benefit from GNSS in unique ways. For example, fitness trackers could use precise location data to offer more accurate measurements of outdoor activities like running or cycling. This could lead to more personalised fitness programs and goals, thereby enhancing the user's health and wellness journey. In the realm of smart home systems, GNSS could play a role in automating various household functions based on the homeowner's location. For example, a smart thermostat could adjust the home's temperature as the resident approaches, ensuring a comfortable environment upon arrival.

Smart security systems could arm or disarm based on the location data from the homeowner's smartphone, adding an extra layer of convenience and security. The retail sector is another area where personalised LBS could revolutionise the consumer experience. The expected level of personalisation could not only enhance the consumer experience but also drive increased sales and customer loyalty for retailers.

The Tourism sector is another area where GNSS applications are expected to flourish. Advanced GNSS-enabled devices can offer tourists more interactive and informative experiences, such as augmented reality tours that provide historical or cultural context based on the user's location. This not only enhances the visitor experience but also opens up new revenue streams for tourism-related businesses.

A growing influence of GNSS technology in Healthcare

Healthcare is emerging as a significant sector where Global Navigation Satellite Systems (GNSS) technologies are gaining traction and offering transformative solutions. One of the most immediate applications is in the realm of emergency services. GNSS-enabled tracking systems can monitor the real-time movements of ambulances and other emergency vehicles, ensuring they take the most efficient routes to reach patients or hospitals. This can be particularly vital in life-threatening situations where every second counts, thereby improving service delivery and potentially saving lives.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Another critical area where GNSS is making a difference is in the care of patients with cognitive impairments, such as Alzheimer's or dementia. Wearable devices equipped with GNSS can help caregivers and medical professionals monitor the location of these patients. This technology provides an added layer of safety, allowing for quick intervention if a patient wanders off or finds themselves in a hazardous situation. As wearable health technology continues to advance, the potential applications of GNSS in healthcare are expanding. For example, fitness trackers and smartwatches could incorporate GNSS to provide more accurate data on an individual's physical activity. This could range from the distance covered during a run to the elevation climbed during a hike, offering a more comprehensive view of one's physical health. Such precise data could be invaluable for healthcare providers in creating personalised fitness or rehabilitation programs. GNSS could also find applications in telemedicine and remote patient monitoring. For instance, GNSS data could help healthcare providers ensure that patients are adhering to prescribed treatments or routines, such as visiting rehabilitation centres or attending regular check-ups. This could be especially useful for managing chronic conditions or post-operative care, where consistent monitoring is crucial for optimal outcomes. Moreover, GNSS technologies could be integrated into larger healthcare systems to improve hospital operations. For example, tracking the location of medical equipment or even healthcare staff within a hospital could optimise workflows and resource allocation, leading to more efficient healthcare delivery.

Expanding GNSS applications in Agriculture, Urban Development and Cultural Heritage

Beyond the more commonly discussed sectors like consumer solutions and healthcare, Global Navigation Satellite Systems (GNSS) are also making significant inroads into Agriculture, Urban Development, and Cultural Heritage, each with its unique set of applications and benefits.

In the agricultural sector, GNSS technologies are enabling what is commonly referred to as precision farming. This involves the use of GNSS-enabled devices to optimise the application of resources such as water, fertilisers, and pesticides. By doing so, farmers can achieve higher yields while reducing waste and environmental impact. This not only contributes to sustainability but also has the potential to revolutionise food production methods, thereby contributing significantly to GNSS revenues.

In the realm of urban development, GNSS technologies are becoming indispensable tools for land surveying and infrastructure planning. Accurate GNSS data can assist city planners and architects in creating more efficient and sustainable urban environments. For example, GNSS can help in the precise placement of buildings to maximise natural light or in the layout of transportation networks to optimise traffic flow. These applications not only improve the quality of life for residents but also offer new avenues for revenue generation in the GNSS market.

When it comes to cultural heritage, GNSS technologies offer invaluable support in the mapping and documentation of historical and archaeological sites. Accurate geospatial data can aid in the preservation efforts for these sites, providing detailed records that can be used for restoration or educational purposes. This has the added benefit of attracting tourism and academic interest, further contributing to GNSS-related revenues.

3.4.5 Mapping of Navigation emerging technologies, services, and applications

Following the discussion above describing potential areas for emerging downstream applications within the GNSS domain, the subsequent table maps specific projects focusing on innovative technologies, applications, and services across each segment of the GNSS value chain. The table demonstrates key developments in satellite navigation technology and its downstream applications. Upstream, innovations in DFMC Navigation modes, Galileo Second Generation, and low-cost dual-frequency GNSS systems are set to revolutionise the GNSS capabilities. In the midstream, advancements encompass GBAS services, navigation message authentication, high accuracy services, and cybersecurity measures, ensuring the reliability of satellite navigation systems. Downstream applications span a wide spectrum, including precision agriculture, climate modelling, rail command and control, and disaster management, illustrating the profound impact satellite navigation has on various sectors, enhancing safety, efficiency, and resilience across diverse applications.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Table 11. Satellite Navigation Emerging Technologies, Applications, Services

Value chain segment	Technologies	Applications	Services
Upstream	Dual frequency (L1/L5 and E1/E5a) GPS + Galileo receiver	Enhanced navigation capabilities	Positioning integrity for safety-critical sectors
	Use of 6 atomic clocks	Galileo Second Generation	Enhanced civil satellite navigation
	Dual frequency smart GNSS receivers	Positioning accuracy at the centimetre level	Low-cost high positioning accuracy for land surveying
Midstream	GBAS Approach Service Type F (GAST F)	Robustness against ionosphere and radio disturbances in multifrequency GNSS environment	Aircraft precision approach operations
	L1C	GPS interoperability with other GNSS constellations	High-precision surveying
	M-Code GPS signal	Encrypted signal for military receivers	Secure cryptography architecture
Downstream	GNSS-blockchain integration	Geolocation software	Platforms with automated verification of data trustworthiness
	GNSS chip equipped smartphones	Emergency alert transmission	Emergency Warning Satellite Service
	Certifiable on-board localisation unit in the railway environment	GNSS-based multi-sensor fusion architecture	Train control system

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.5 Access to space and Launch systems

Access to space is a key enabler of the whole sector and is itself an indispensable element in the overall space value chain. To deliver variety of space mission payloads, different types of launchers have been used, such as heavy-lift (>10,000 kg to LEO), medium-lift (4,000-10,000 kg to LEO), light-lift (500-4,000 kg to LEO), and micro-lift (<500 kg to LEO), as per European classification used by Arianespace and ESA for the classification of launch vehicles.

3.5.1 Presentation of the value chain

The value chain of the access to space domain, as presented in the figure below, is usually divided in 3 types of key activities:

- **Launcher development:** includes all activities related to the Research & Innovation actions and technologies initiatives (e.g. demonstrators) supporting the development of future launchers, including continuous incremental upgrades on launch vehicles. In Europe, prime contractors and key-subsystems manufacturers include ArianeGroup, Avio, MT Aerospace, PLD Space, Air Liquide Advanced Technologies. European public entities involved in launchers development include space agencies (ESA, ASI, CNES, DLR), research agencies (ONERA, DGA), academic institutions.
- **Launcher manufacturing:** includes activities from the launch vehicle integrators (also referred to "prime integrators"), components and material suppliers (e.g. raw materials, micro-electronics) and sub-systems suppliers (e.g. engines, faring etc.). Prime contractors in the European region include ArianeGroup, Avio, and Europropulsion (ArianeGroup/Avio joint venture). Sub-systems manufacturers are MT Aerospace, Nammo, RUAG, SABCA.
- **Launch operations:** include all the activities performed during launch campaigns such as the transport of the launcher to the launch site, storage of the satellites in clean rooms prior their integration on top of the launcher, fuelling of the launch vehicle on the pads, monitoring of the launch until the delivery of the satellite for the customer to the right orbit. In Europe, operations are performed by ArianeGroup, Avio, ESA, CNES (safety of the launch site).

Notably, the access to space value chain is using a vertical integration model to cut costs, rationalise the supplier base, and streamline operations. Launch vehicle integrators are creating (or acquiring) internal capabilities to handle a stream of tasks that were previously reserved for their suppliers. For Ariane 5, two organizations, Airbus Defence & Space (formerly EADS Astrium) and Safran, were responsible for manufacturing the vehicle and the engine, which is the primary critical sub-system of a launch vehicle (formerly Snecma). Another organization, Arianespace, which was also partially in charge of the launch operations, promoted the launch services. The manufacturing of a launcher's core (structure and engine) and its launch operations are currently being gradually merged under one organization in Europe, ArianeGroup, a Joint Venture between the main contractors, Airbus and Safran. For the Vega launcher, Avio, which is also the launch vehicle's primary integrator, has been handling launch operations in French Guiana since 2017. As a result, the same entity can cover multiple streams in each of the value chain's three key activities.

The demand for launches is driven by a diverse range of end users spanning various sectors. These customers include public entities such as space agencies, governmental bodies, and international organizations, private companies, and export countries seeking foreign partnerships. The institutional demand for launch vehicles in Europe is primarily characterised by four key actors: the European Union (EU), the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and the individual member states.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

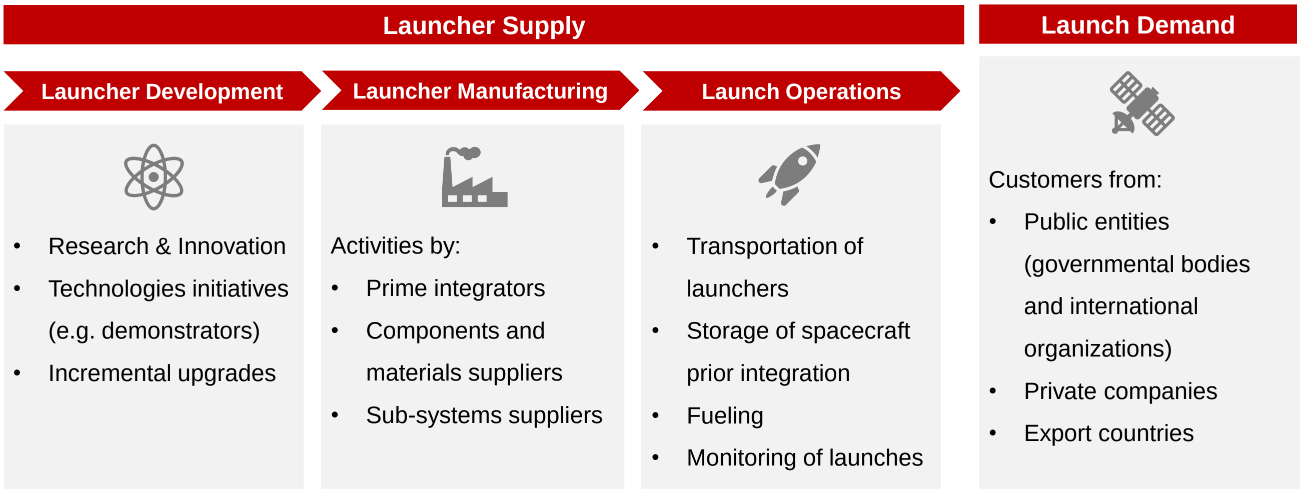

Figure 24: Access to Space Value Chain.

Access to Space operations are supported by development and maintenance of spaceports or launch facilities which provide needed infrastructure. Currently, 5 spaceports are operational in Europe: Guiana Space Centre, Esrange Space Centre, El Arenosillo, Taranto-Grottaglie (suborbital launches), Spaceport Cornwall. A mobile launch platform in off-shore Marseilles, in the Mediterranean, was developed by Zero 2 Infinity. In EU, spaceports are now development in Andøya (Norway), Azores (Portugal), and Canary Islands (Spain), which are planned to be operational by 2025. In the UK, two spaceports are under construction: Sutherland and Shetland.

Figure 25: Map of Spaceports in Europe.

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.5.2 Overview launch system programmes

3.5.2.1 European Union access to space projects

The EU space policy emphasises independent access to space. It makes it possible to deploy crucial space infrastructures like Galileo, Copernicus, and EGNOS as well as upcoming innovations like Secure Connectivity, which are essential for boosting the economy and societal security. According to the Space Strategy for Europe (COM (2016) 705), Europe must guarantee an affordable, flexible, and responsive access to space. The EU industry's efforts to create space access solutions are greatly facilitated by the Horizon Europe (formerly Horizon 2020) Programme. Several organizations, including the Health and Digital Executive Agency (HaDEA), the EU Agency for the Space Programme (EUSPA), the European Space Agency (ESA), and the European Commission itself, oversee managing space research and innovation (R&I) projects within this initiative. One of previous projects under H202 focused on creating a Small Innovative Launcher for Europe. It was designed to give access to space for small satellites up to 50 kg. Another effort, the European Innovation Council (EIC) Horizon Prize for "European Low-Cost Space Launch," aimed to create a European method for launching satellites up to 400 kg. The prize was given to the German company Isar Aerospace in recognition of its accomplishments. In total, 16 projects centred on access to space have received funding from the Horizon Europe program totalling €56.7 million by the year 2022.[43] Finally, according to a recent overview by Ariane Cities, the European space transportation sector employs 11,000 highly skilled individuals in 16 countries.[44]

3.5.2.2 European Space Agency access to space projects

Since 2003, ESA has launched five feasibility studies to find a micro-launcher that is commercially and economically sustainable and operates independently of public funding. In this regard, the Future Launchers Preparatory Programme aims to create "ready-made technical solutions, which can be transferred to new or even existing development projects with minimal cost, effort, and risk".[45] The main objectives are to develop environmentally friendly technology, ensure long-term industry competitiveness, promote technology reusability while lowering development costs, and prepare system competence and technology. The main components of the initiative are the study on the evolution of current launchers and their system concepts, the selection and maturation of technologies, and the definition, development, and testing of integrated demonstrators.[46]

Another currently active project is "Preparation activities of launch services from European privately developed mini/micro launchers". This call's main goal is to increase the competitiveness of the European space transportation industry and determine whether, once privately developed micro and mini launchers are operational, they will be able to meet the ESA's needs for small payloads, in keeping with the commercialisation priority outlined in Agenda 2025. The call was open for small payloads or small payload aggregates (below 500 kg) launch providers. The qualified participants had to launch European payloads from European soil and have a European supply chain. Launch service providers will receive up to €300,000 from ESA as a first step toward demonstrating the maturity of the launch systems that are currently being developed. This may include assistance with testing and access to testing facilities, quality control, a debris

---

[43] Source: European Commission https://defence-industry-space.ec.europa.eu/system/files/2022-09/DEFIS_B2_Comms_kit_factsheet_Access%20to%20space_web.pdf
[44] Source: Ariane Cities https://www.ariane-cities.org/wp-content/uploads/2023/01/en-CVA_3a.pdf
[45] Source: EUCASS https://www.eucass.eu/doi/EUCASS2017-248.pdf
[46] Source: ESA https://www.esa.int/Our_Activities/Space_Transportation/New_Technologies/FLPP_preparing_for_Europe_s_next-generation_launcher

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

mitigation strategy, adherence to national laws and regulations, risk management, and a launch service compatibility analysis.[47]

3.5.2.3 Launchers' overview

Medium and heavy lift

ArianeGroup is a key launch vehicle manufacturer operating in the medium and heavy-lift launch vehicle market. It is a joint venture between Airbus and Safran. It consists of three core arms, i.e., aerospace, defense, and security. The launch vehicles manufactured by the company include the heavy lift Ariane 5 for dual launches to geostationary transfer orbit and the solid-fuelled Vega and Vega-C for lighter payloads. The Vega-C launcher has been upgraded with an improved second stage, a new solid-fuel engine, and a larger fairing to significantly increase payload mass and volume capabilities. This is expected to cater to the propelling Earth observation market, as well as long-term institutional requirements. Ariane 6, a next-generation two-stage launch vehicle, is currently under development, intended to succeed the Ariane 5 rocket. Ariane 5 launch vehicle has been launched over 110 times. Ariane 6 will be offered in two variants that will be capable of carrying a payload between 10,350 and 21,650 kilograms. Notably, the operation of Soyuz launchers as a medium lift alternative has been suspended due to sanctions following the invasion of Ukraine by Russia.

Light lift

There are significant amounts of start-ups, small and dedicated companies developing micro-launchers. The European and international market include a variety of agents creating or running micro-launchers, from start-ups to more versed firms. The necessity for innovative technology and new launching methods evens out the playing field in the development phase, yet funding plays a significant role. As such, several challenges, venture capital firms and other forms of accessing finance remain open for newcomers in the micro-launcher segment. Below is presented the list of companies generating micro-launchers in Europe.

Table 12. Development of Micro-Launchers in Europe

Established Company	Small/Dedicated companies	Start-ups
ArianeGroup	Dawn Aerospace	HyImpulse
MT Aerospace	Zero2Infinity	Rocket Factory Augsburg
Avio	PLD Space	Pangea aerospace
Nammo	Horizon Space Technologies	Smallspark Space Systems
Deimos	Space LS	Sidereus Space Dynamics
Celestia Aerospace	Orbex space	HyPrSpace

[47] Sources: ESA
https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/ESA_supports_the_commercialisation_of_European_micro_and_mini_launchers
https://ideas.esa.int/servlet/hype/IMT?documentTableId=45087150965736746&userAction=Browse&templateName=&documentId=2f6b1701891446045afd2d973ef811e4

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Swedish Space Corporation	Tranquility Aerospace	MaiaSpace
Orbital Access	Isar Aerospace	Skyrora

3.5.3 Market dynamics

The market for space launch services has expanded significantly in recent years. The need for better communication, navigation, and Earth observation tools, as well as for scientific study and exploration, is likely to push the demand for spacecraft launches to keep rising. Thus, the size of the global market for space launch services, which was estimated to be worth $13.9 billion in 2022, is expected to increase to $47.3 billion by 2032, rising at a CAGR of 13.4% between 2023 and 2032.[48] Moreover, a number of start-ups are creating cutting-edge launch technologies and tactics, paving the way for new players to enter the industry. Below is presented further information on trends in supply and demand.

3.5.3.1 Demand trends

Institutional Payload Protectionism

Major space-faring nations such as the US, China, Japan, and Russia have adopted measures to prioritise and protect their domestic space industries. One way they have done this is by implementing regulations that prevent foreign launch service providers from launching their institutional payloads. By imposing such regulations, these countries aim to:

- **Boost domestic industry:** By ensuring that institutional payloads are launched by domestic companies, they provide a steady stream of business for their own space industries.
- **Ensure national security:** Satellites, especially those with strategic purposes, are vital for national security. Launching them using domestic providers minimises the risk of espionage or sabotage.
- **Maintain control:** Using domestic launch providers allows these countries to have better control over the entire process, from production to launch.

Despite the trend seen in other major space nations, Germany, a significant player in the European space scene, has at times opted to use non-European launch service providers. This decision can be based on a variety of reasons:

- **Cost-effectiveness:** Sometimes foreign launch providers might offer more competitive prices.
- **Technological capabilities:** Depending on the specific requirements of a mission, a foreign launch provider might possess a particular technology or capability that is deemed essential.
- **Diplomatic or strategic ties:** International collaboration in space missions can serve as a gesture of goodwill or to strengthen bilateral relations.

In July 2021, Germany and France have agreed to increase funding for the Ariane 6 and support the new European launcher and the smaller Vega for public and institutional missions. This agreement resolves previous disagreements between the two countries, which were not settled in the last European Space Agency (ESA) Member State meeting in mid-July. Both nations have also decided to grant Ariane 6 and the new Vega version a preferential status for public and institutional launches.

[48] Source: Allied Market Research https://www.alliedmarketresearch.com/space-launch-services-market

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

The agreement aims to institutionalise a European preference for launch services. This move is significant for several reasons:

- **Strengthening the European space industry:** By preferring European launch providers, the agreement ensures that the European space industry receives consistent business, fostering growth and development.
- **Political and economic unity:** The agreement represents a desire for a more integrated European approach to space exploration and services, reflecting a broader theme of European unity.
- **Security and autonomy:** Just like other major space-faring nations, Europe would also be keen on ensuring the security of its institutional payloads. Preferring European launch providers could reduce potential vulnerabilities associated with relying on external entities.

The regulations and agreements related to launch service providers are reflective of a country or region's broader goals concerning space exploration, national security, and economic strategy. As the space industry continues to grow and evolve, it's likely that such agreements and regulations will play a pivotal role in shaping the dynamics of international space relations and industry competition.

Push for autonomy

The Ariane 6 is Europe's next-generation heavy-lift vehicle, designed to replace the older Ariane 5. Delays in its development and deployment could impact Europe's capabilities to reliably launch commercial and institutional payloads, making them dependent on foreign launch providers and potentially causing financial losses due to breach of contract.

Vega-C is an evolution of the Vega rocket, tailored for smaller payloads. Any failure in its operations not only poses financial setbacks but also reduces the trust of potential clients, especially if they have alternative, more reliable launch options available. However, the second launch of Europe's Vega C rocket from the Spaceport in Kourou, French Guiana, on December the 20st 2022 did not proceed as expected. While the rocket's first stage, the P120C, performed its role successfully, the second stage, Zefiro 40, experienced a malfunction. The rocket had been assigned to transport two satellites for Airbus' Pléiades Neo Earth-imaging constellation. Following this failure, Arianespace, the launch service provider, in collaboration with the European Space Agency (ESA), which is responsible for the development of the launch system, promptly established an independent inquiry commission to determine the root cause of the mishap. The findings of the investigation were released on March the 4th 2023 and concluded that the mission's failure was attributed to a flawed nozzle throat insert produced by the Ukrainian firm, Yuzhnoye.

The Soyuz, a Russian launch vehicle, has been frequently used from the Guiana Space Centre, providing Europe with an additional medium-lift capability. The operation of the Soyuz launcher from Europe's Spaceport in French Guiana and from Baikonur in Kazakhstan was facilitated by an inter-governmental agreement between France and Russia and a separate agreement between ESA and Roscosmos. While this collaboration has been fruitful since the end of the Soviet Union, it was paused/ended due to Roscosmos' unilateral decision to halt Soyuz launches from Europe's Spaceport following the beginning of the conflict between Russia and Ukraine.

The geopolitical tensions involving Ukraine have wider implications on the space industry. Given that certain components or materials for the space industry may be sourced from this region, conflicts can disrupt supply chains, resulting in delays or the need to find alternative suppliers. Ukraine, with its established aerospace and engineering legacy, has been a significant player in the space industry. Many European launchers rely on components or materials sourced from Ukraine. Any disruption due to geopolitical tensions can halt the production or final assembly of launch vehicles, making it challenging for Europe to meet its launch schedules. Finding alternative suppliers often comes at a premium. New suppliers might have higher costs or might need time to ramp up production to meet European demands. There could also be costs associated with reconfiguring assembly lines or making design changes to accommodate different components. Delays in the production and launch of rockets mean delays in putting satellites into orbit. This can have cascading effects, especially if these satellites are part of critical missions related to Earth observation, communication, or navigation.

The European launcher industry competes on a global stage with other major players such as the United States, China, and Russia. Any disruptions or delays can make European launch services less attractive to potential customers, thereby losing market share to competitors. Space has increasingly become a domain of strategic importance. Dependence on components from a region with geopolitical tensions might pose security concerns. Europe may be compelled to rethink its sourcing strategy to ensure it does not compromise on strategic autonomy. Such disruptions could lead Europe to re-evaluate its partnerships and collaborations. It might lead to increased intra-European collaboration, focusing on indigenization of production and decreasing reliance on external, potentially unstable, suppliers. If the European launcher industry spends time and resources in circumventing supply chain challenges, it might divert attention from innovation and research, which are crucial for the industry's growth and evolution. The geopolitical situation surrounding Ukraine is not just a diplomatic challenge, it also poses substantial operational and strategic challenges for the European launcher industry. Addressing these concerns requires a combination of short-term adaptive measures and long-term strategic planning to ensure the industry remains resilient and competitive.

As more countries look inward to develop their own spaceports and launch systems, existing collaborations or agreements might be reconsidered or reshaped. This could affect launch schedules, partnerships, and economic dynamics, especially if countries prefer their domestic capabilities over previously contracted European launch services.

All these challenges culminate in the broader issue: Europe's disrupted access to space. In an age where space is becoming more commercialised, accessible, and contested, having reliable and autonomous access to space is paramount for Europe's strategic interests. As challenges mount, there is a clear need for strategic decisions to ensure that Europe remains a dominant player in the global launch domain arena. By addressing supply chain vulnerabilities, investing in indigenous capabilities, and fostering collaborations, Europe can navigate these challenges and emerge stronger.

Environmentally sustainable access to space

The growing global focus on sustainability and environmental conservation is increasingly reshaping the space industry. With space access being a critical component of modern technological and defence ecosystems, ensuring its alignment with environmental goals is becoming paramount. Here's a detailed exploration of this shift:

There is a rising emphasis on R&D aimed at ensuring that space access technologies are environmentally friendly. Such projects focus on everything from sustainable rocket propellants to the materials used in spacecraft, aiming to minimise carbon footprints and other forms of environmental impact. As space access becomes a domain of multiple players, including both established space powers and emerging space nations, an emphasis on sustainability can serve as a strategic differentiator. Countries or companies that prioritise green initiatives in their space programmes may attract more global partnerships, investments, and customer trust. While legacy space entities have established technologies and processes, new entrants to the launcher industry are sometimes more agile in adapting to modern requirements. Several of these nascent competitors are embedding sustainability into their foundational ethos, ensuring that their technologies are green from the outset. Countries like the United States, Japan, and France are offering significant subsidies for the development and adoption of renewable rocket fuels. These financial incentives

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

not only level the economic playing field for green technologies, which might initially be more expensive than conventional alternatives, but also catalyse the rate at which the industry shifts towards sustainable practices.

Apart from direct environmental benefits like reduced emissions, focusing on sustainable space access can have ancillary benefits. For instance, research into green rocket propellants could spawn innovations applicable in other sectors, such as clean energy for terrestrial uses. As global environmental consciousness grows, stakeholders – ranging from investors to customers, to regulators – are demanding sustainability. Future regulatory frameworks might even mandate certain green benchmarks, making it crucial for space entities to anticipate and adapt to these shifts.

The momentum towards environmentally friendly space access technologies represents more than just a passing trend. It's indicative of a larger global movement toward sustainability and responsible utilisation of resources. As the space industry continues to grow and evolve, integrating these principles will be vital for its long-term success and relevance.

The emergence of small satellites is creating a new demand for micro-launcher services providers

The landscape of the space sector has undergone significant transformation with the entry of dynamic private players bringing fresh perspectives and innovative techniques to the table. These contemporary approaches manifest in both the methods of manufacturing and the nature of products being developed.

The advent of new-age private enterprises in the space domain has driven a surge in innovative manufacturing solutions. Traditional models, often cumbersome and time-consuming, are being revamped in favour of lean, efficient, and scalable techniques. The usage of cutting-edge technologies like 3D printing, AI-driven design optimization, and digital twinning are just some examples of how manufacturing in the space sector is evolving.

Beyond manufacturing, there's a notable shift in the products themselves. Instead of colossal, singular satellites that necessitate massive budgets and extended timelines, the industry is leaning towards more modular and adaptive solutions. Here, small satellites, often referred to as "smallsats," become pivotal.

Smallsats have surged in popularity due to several inherent advantages:

- **Cost-Efficiency:** They're relatively less expensive to produce and deploy, making space access more democratic and feasible for a wider clientele, from startups to educational institutions.
- **Versatility:** Their design allows them to cater to a diverse array of missions, be it Earth observation, scientific research, or communication relay.
- **Rapid Deployment:** Their smaller size and standardised designs often lead to reduced lead times from concept to launch.

While smallsats offer numerous advantages, their effectiveness hinges on timely and affordable access to space. Thus, smallsat operators are constantly seeking reliable launch services that not only offer competitive pricing but also flexibility in terms of launch schedules. To cater to the burgeoning demand from smallsat operators, a new segment of launch vehicles, termed 'micro-launchers,' has emerged. These launchers are designed specifically to carry lighter payloads to orbit. Micro-launchers often boast a more attractive price-per-kilogram for payload delivery compared to their larger counterparts. One significant advantage of micro-launchers is their ability to offer more tailored launch windows. Instead of waiting for a slot on a larger vehicle that caters to multiple customers, smallsat operators can potentially secure a dedicated launch that aligns closely with their mission timelines.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

The shift towards smaller satellites and the corresponding emergence of micro-launchers epitomises the ongoing transformation in the space sector. With private players spearheading innovations in both manufacturing and product development, the future promises to be even more dynamic, offering unprecedented opportunities for a broader spectrum of participants in the space arena.

Single-mission smallsats launches are expected to decrease

The next decade (2019-2030) is expected to see a downward trend in the number of non-constellation smallsats being launched. This development, while initially surprising given the recent boom in smallsat activities, can be understood by examining a couple of significant factors driving this evolution in the space sector.

The rise in constellations and mega-constellations is expected to overshadow and cannibalise the demand for individual non-constellation smallsats in domains such as Communications and Earth Observation. The term 'cannibalisation' in this context refers to the process where a new product or service drastically reduces the demand for existing ones. With regards to the smallsat domain. As larger projects involving constellations (a group of satellites working in concert) and mega-constellations (even larger groups) emerge, they are poised to dominate certain sectors of space activity, particularly in Communications and Earth Observation. These projects aim to provide comprehensive global coverage, thereby decreasing the need for independent non-constellation smallsats that cater to the same needs. Constellations offer economies of scale, as deploying multiple similar satellites can lead to cost savings, more efficient deployment strategies, and continuous coverage. This makes constellation projects more economically viable and technologically advanced, thereby overshadowing individual non-constellation smallsats in these specific domains.

Technology demonstration smallsats have historically been used to trial and prove new technologies before they're incorporated into larger, more expensive missions. As the space industry progresses, several of the technologies once deemed experimental or new have now been tried, tested, and validated. With constellation projects advancing, there is a growing confidence in the technologies being used, leading to a reduced need for standalone demonstration projects. Instead of launching numerous independent demonstration missions, the focus is shifting towards integrating new technologies directly within constellations. This change streamlines the process, as successful demonstrations can be immediately scaled up within the constellation framework.

While the smallsat sector has undeniably catalysed a range of innovations and expanded access to space, the trends for the next decade highlight the space industry's continuous evolution. The emergence of constellations and the maturation of technologies signal a shift from a scattered approach with numerous individual smallsats to a more coordinated and integrated strategy. This transition is reflective of the industry's growth, underscoring the dynamic nature of space endeavours as they adapt to emerging needs and opportunities.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

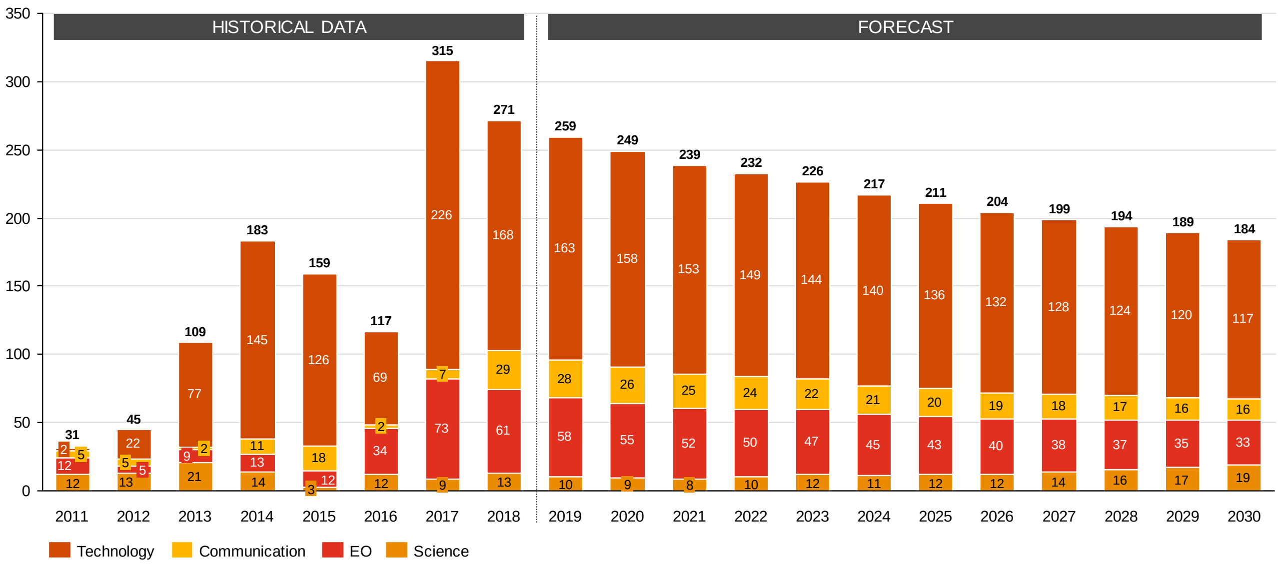

Figure 26: Evolution of the Number of Smallsats (<200 kg) for Single Missions to be launched.

3.5.3.2 Supply trends

The landscape of space launch systems has undergone a transformative shift with the introduction and successful implementation of reusability in rocket technology. Previously, the conventional approach required constructing a new rocket for every launch, contributing to higher costs and extensive material wastage. However, with the advent of reusable rockets, a significant reduction in launch expenses has been observed, making space missions more economically viable and frequent. Concurrently, advancements in propellant technology are also reshaping the industry. Among these is the development of green propellants based on methane. Not only does methane offer a cleaner alternative to traditional fuels, but it also holds the potential for enhanced performance metrics. Collectively, these innovations underscore a dynamic and evolving space industry, poised to make space exploration and satellite deployment more accessible and sustainable than ever before.

New launch systems have mostly adopted reusability

The concept of reusability in the context of space launch systems fundamentally disrupts the once throwaway nature of rocket launches. This paradigm shift is primarily driven by the economic and environmental rationale of reducing the cost per launch and decreasing the waste generated from each mission.

SpaceX is perhaps the most notable proponent of this reusable rocket technology. Their Falcon 9 rockets have successfully been recovered and reflow multiple times. The first stage of the Falcon 9, which carries the majority of the fuel and the main engines, returns to Earth post-launch. Through a series of controlled burns and manoeuvres, it can either land vertically on a ground pad or on a drone ship stationed in the ocean, depending on the mission profile. This pioneering approach has enabled SpaceX to dramatically reduce the cost of putting payloads into orbit.

Another example is **Blue Origin** with its New Shepard suborbital vehicle. While it serves a different purpose than Falcon 9 – primarily space tourism and research – the New Shepard booster is designed to launch, land vertically, and be reused. Blue Origin's approach underlines the company's vision for increasing access to space through sustainable methods.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Rocket Lab, although starting with small rockets, introduced plans to recover and reuse the first stages of their Electron rockets. Their unique approach involves capturing the descending booster mid-air by a helicopter, minimizing the wear and tear from a landing burn and potential saltwater exposure.

The success of these companies, especially SpaceX, has validated the viability of reusability in the aerospace sector. Their milestones have set new standards and expectations for how space missions are conducted and have paved the way for a more cost-effective and frequent access to space. With the trajectory of current advancements, reusability might soon become a norm rather than an exception in space launches.

Innovations in rocket propellants

Research into new and greener propellants is shaping the future of rocket propulsion, responding to both environmental concerns and the quest for enhanced performance. Traditional propellants, while effective, have environmental and handling drawbacks, prompting the industry to explore alternative, more sustainable solutions. Methane (CH_4), being cleaner-burning, has emerged as a promising alternative. SpaceX, for instance, is developing its Starship and Super Heavy rocket system powered by Raptor engines, which utilise methane and liquid oxygen. Beyond methane, there's also a push towards entirely new classes of propellants. AF-M315E, developed with support from NASA and the U.S. Air Force, is a green monopropellant that promises improved performance and reduced environmental impact compared to traditional hydrazine-based propellants. Companies like Aerojet Rocketdyne and Blue Origin have also shown interest in developing propulsion systems that utilise more environmentally-friendly fuels. Such innovations signify an industry trend towards more sustainable and efficient propulsion solutions, essential for the future of space exploration and satellite deployment.

The following table provides an overview of the main launch system developers investigating in the usage of methane:

Company	Launch system	Capacities	Status
LandSpace			
LANDSPACE	**Zuque-2**	• Middle class LOX/LCH4 launcher • Up to 6 tonnes 200 km LEO/4 tonnes 500 km SSO	Successful maiden flight in July 2023
United Launcher Alliance (ULA)			
ULA	**Vulcan**	• Heavy class LOX/LCH4 launcher • Up to 27 tonnes in LEO and 14 tonnes in GTO	Under development (first launch currently planned for late 2023
SpaceX			
SPACEX	**Starship**	Reusable super-heavy launch vehicle - up to 150 tonnes (reusable), up to 250 tonnes (expandable) to low orbit	Under development (first failed orbital launch in April 2023)
Rocket Lab			
ROCKETLAB	**Neutron**	• LOX/LCH4 Partially Reusable Medium Class Launcher - Up to 13 Tons to LEO	Under development (first launch currently planned for 2024)
Relativity Space			
Relativity	**Terran R**	• Heavy class launcher, partially reusable, LOX/LCH4 - Up to 33 tonnes in LEO (non-reusable)	Under development (first launch expected in 2026) - derived from previous version, Terran 1
Avio			
AVIO	• **Moteur M10** • **Moteur M60**	• M10: 10 ton class LOX/LCH4 engine • M60: more powerful version (up to 60 tonnes)	Under development (five successful firing tests in September 2023

Figure 27: Overview of Methane Launchers.

The development of several European micro-launchers

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

The European launcher sector, historically known for its heavyweight contributions like the Ariane family of rockets, has recently witnessed a significant pivot towards the development of micro-launchers. These smaller, nimble rockets are tailored to serve the burgeoning small satellite market, which demands frequent, cost-effective, and dedicated access to space.

In the European market, there is a demand for launching small satellites using micro-launchers. However, this demand is not exclusive to European micro-launchers, and competition among global micro-launcher providers is expected to be high. It may be challenging for European micro-launchers to secure a significant market share within the given timeframe. To improve their position, European micro-launcher programs could receive support from the European Space Agency (ESA) Member States through the procurement of military or governmental smallsats. This support could help sustain the demand for European micro-launchers and make them more viable.

The rise of small satellites and CubeSats in the last decade has necessitated a shift in launch strategies. Traditional large rockets are often seen as overkill for deploying these compact payloads, leading to a global demand for smaller, more efficient launch solutions. The United States, with players like Rocket Lab, took an early lead in this domain, but Europe quickly recognised the potential and began its foray.

Several companies have emerged as front-runners in the European micro-launcher scene:

- **Orbex:** With its Prime launcher, Orbex aims to provide a greener solution to satellite launches, using bio-propane as fuel and targeting a capacity of around 150 kg to Sun-Synchronous Orbit (SSO).
- **PLD Space:** A Spanish startup, PLD Space's Miura 5 aims to offer a reusable micro-launcher solution with a capacity of roughly 300 kg to SSO.
- **ISAR Aerospace:** This German company is developing a launcher to provide competitive access to space
- **ArianeGroup:** While traditionally focused on larger launch vehicles, ArianeGroup is developing the Maia rocket that is expected to be reusable.

European governments and agencies have been proactive in their support for these endeavours. Recognizing the economic potential, several spaceport projects have been announced or repurposed to cater to these micro-launchers. The sounding rocket sites of Esrange in Sweden and Andoya in Norway are notable examples. Additionally, regulatory frameworks are being adapted, with countries entering multilateral cooperation agreements to streamline operations and make Europe an attractive hub for the micro-launcher industry.

While the European micro-launcher market is bustling with activity and promise, challenges lie ahead. The sustainability of business models, the actual global demand for micro-launch services, and the potential oversaturation of facilities and launch providers are concerns that need addressing. However, with the collective momentum of industry players, government support, and the inherent demand for small satellite launches, the European micro-launcher scene is poised for growth and innovation in the coming years.

The following table provides an overview of the European micro-launcher capabilities:

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Company	Launch system	Capacities	Status
Orbex			
	Prime	180 kg to SSO	Maiden flight planned on the 31st of December 2023
PLD Space			
	Miura 5	300 kg to SSO	Maiden flight planned for Q4 2024
MaiaSpace			
	Maia	• 500 kg to SSO • Reusable	First flight scheduled for 2026
ISAR Aerospace			
	Spectrum	• 700 kg to SSO • 1000 kg to LEO	First commercial flight planned for Q4 2023

Figure 28: Overview of European Micro-Launcher Programmes.

Micro-launcher activities require adapted infrastructures for launch operations

The European aerospace arena has seen a surge in micro-launcher initiatives in recent years. These compact, cost-effective rockets, designed to carry smaller payloads into orbit, have become a focal point of interest for many European nations, eager to tap into the growing satellite launch market and foster new economic avenues. Since 2015, the enthusiasm has been palpable, with numerous spaceport projects being announced. Governments are not merely investing in new infrastructure but also considering the repurposing of established rocket launch sites. In particular, the sounding rocket facilities at Esrange in Sweden and Andoya in Norway are under examination for potential adaptability to accommodate these micro-launchers.

This burgeoning industry isn't solely about infrastructure; it's also about ensuring a regulatory framework that fosters growth. Recognizing the need for streamlined operations to make Europe an attractive hub for micro-launcher companies, countries are engaging in multilateral cooperation agreements. These collaborations aim to refine and adapt existing regulations, thereby simplifying processes and reducing bureaucratic hindrances.

However, the long-term viability of such ventures is challenged by several factors. The core concern is whether the global demand for micro-launch services will match the rapid proliferation of facilities across Europe. There's a very real risk that the supply might outstrip demand, casting uncertainty on the sustainability of the business models being pursued. As the industry evolves, balancing infrastructure development with realistic market demands will be crucial to ensure the longevity and success of European micro-launcher projects.

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

New manufacturing processes increasingly being used for higher flexibility

The micro-launcher industry stands at an inflection point, grappling with challenges of cost-efficiency that are paramount to their continued viability in an increasingly competitive market. With slender margins and heightened demand for affordable launch services, these companies are pushed into a race not just to the stars but to the drawing board, innovating and optimizing at every stage.

In this high-stakes arena, technology, particularly in the realm of digitalisation, emerges as both the disruptor and saviour. New-age manufacturing techniques, spurred by digitalisation, offer the potential to significantly reduce both the time and cost involved in the development and production phases. With the adoption of 3D printing technologies, for instance, companies can rapidly prototype and manufacture intricate components, often at a fraction of the cost and time of traditional methods. Further supplementing this is the rise of the Internet of Things (IoT), digital twin technology, and virtualisation. These digital tools allow companies to create digital replicas of physical systems, facilitating real-time monitoring and simulation. Automated production lines, empowered by these technologies, can significantly ramp up the manufacturing pace, ensuring that the production process is not only faster but also more precise. Equally crucial is the data-driven aspect of modern manufacturing. Advanced analytics solutions, when incorporated, can scrutinize the minutiae of production, pinpointing inefficiencies, enhancing quality controls, and predicting potential maintenance requirements. Predictive maintenance, especially, holds the promise of pre-empting disruptions, ensuring the longevity of production assets, and, by extension, guaranteeing a steadier, more reliable production flow. A testament to the transformative potential of these technologies is Relativity Space, a US-based micro-launcher company. They've taken 3D printing to the next level, deploying a dedicated, large-scale 3D printer to churn out major components for their launch vehicles. This not only showcases the feasibility of such a manufacturing approach but also underscores the potential for radical shifts in how rockets are built.

3.5.4 Assessment of emerging and future activities

Next to the current trend of development of new spaceports and micro-launchers, future trends in Europe are dictated by the tendency to build reusable vehicles and use new types of sustainable propulsion.

The SALTO project, funded through the Horizon Europe project in collaboration with ArianeGroup, is accelerating the development of reusable launchers in Europe. To advance to the next stage of the development of the first reusable rocket in Europe, the project consortium brings together the knowledge of the major research institutes, start-ups, and SMEs from across Europe. The project started in December 2022 and is intended to test vertical landing of a reusable launcher stage prototype. Eight ESA Member States are participating in the programme: France, Switzerland, Belgium, Sweden, Spain, Netherlands, Poland and Hungary. SALTO enables perfectly synchronised acceleration of the two ESA programmes Themis reusable stage and Prometheus reusable engine developed by ArianeGroup under contract to ESA.[49] The testing will continue at the end of the year following a successful full ignition in June 2023. The 100-tonne thrust class Prometheus makes extensive use of new materials and manufacturing techniques to cut costs of Ariane 5's Vulcain 2, which is used to power the core stage of Ariane 6 with its upgraded form Vulcain 2.1. Prometheus burns liquid oxygen-liquid methane fuel, and it is also being developed to use liquid hydrogen-liquid oxygen. Themis is a prototype for a reusable rocket stage that is being created concurrently with the Prometheus engine. Later on, this engine-stage combination will try a number of "hop-tests," lifting a few meters above

[49] Source: Space Ref https://spaceref.com/space-commerce/salto-project-will-advance-forward-europes-first-reusable-rocket/

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

the ground to evaluate its capacity to take off and land. Thus, Prometheus and Themis are expected to be common building blocks for a future family of European launchers.[50]

Additionally, ArianeGroup creates a reusable upper stage concept for use with Ariane 6 and the next generation of European launch vehicles. The stage, known as Susie (Smart Upper Stage for Innovative Exploration), will take the place of the launcher's fairing and be able to fly crewed missions with up to five astronauts or function as an automated freighter. Susie can carry out a variety of crucial missions in space, including the towing, inspection, or upgrading of satellites and other payloads as well as the resupply of space stations with supplies like food, fuel, and equipment.[51]

[50] Source: ESA https://www.esa.int/Enabling_Support/Space_Transportation/Full_ignition_for_ESA_s_reusable_rocket_engine
[51] Source: Ariane Group https://www.ariane.group/en/news/susie-the-reusable-space-transporter-european-style/

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

3.5.5 Mapping of Access to Space emerging technologies

A table below provides insights into emerging technologies within the access to space domain, with a specific focus on launch systems. This emphasis on launch systems is strategic, given their pivotal role in the broader sector. The table outlines the latest developments in launch systems, spotlighting technologies and applications currently in the pipeline within the launch supply segment of the value chain. Furthermore, it also underscores the demand for these innovative technologies, reaffirming their critical role in enabling successful space missions.

Table 13. Launch System Emerging Technologies and Demands

Value chain segment	Technologies	Applications	Providers	Demand pulls
Launcher supply	Super heavy launch vehicles	Orbital and planetary launch with increased volume and capacity	Space X, NASA	Launch of flocks of satellites constellations, planetary missions
	Kinetic launch system	LEO launch	SpinLaunch	Cost effective and environmentally sustainable launches
	Ariane 6	Commercial, institutional, exploration missions	Arianespace	European autonomy
	Reusability concepts	Orbital launch with increased frequency and decreased cost	SpaceX, Rocket Lab, Maia Space, Skyrora, Ceres Aerospace, SALTO, RRTB	Sustainability and cost-efficiency
	3D printing	Launcher structures development and manufacturing	Relativity Space, Orbex Prime, RocketLab, Additive Space Technologies, AgniKul Cosmos	Acceleration of the development phase

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

	Stratospheric balloons	Rocket carriers and launches from a "near-space" environment	Zero 2 infinity (Bloostar), Stratobooster	Reduction of operation costs
	Hypersonic spaceplane	Defence, cargo, ultra-hight speed transportation, suborbital flight	Polaris AURORA	Routine access to space
	Aerospike engines	Single-stage-to-orbit launch vehicles	Pangea Aerospace, Polaris	Increasing the payload capacity while decreasing the rocket mass
	Methalox propellant	Reusable rockets propulsion	ULA, SpaceX, Relativity Space, Blue Origin, Rocket Lab	High energy density with clean combustion products
	Rotating detonation rocket engine	Light-weight rocket's upper stage	NASA	Achieve increased propulsion efficiency while reducing fuel consumption
	Reusable rocket engine	European launch vehicles	ESA	Low-cost rocket engine
	Carbon-fiber–reinforced plastic	Rocket tanks manufacturing	ESA, Rocket Lab, Firefly	Rocket weight reduction
Launch demand	Anticipated developments			Higher frequency of launches and dedicated small lift launchers Commercial use of space resources Space tourism

3.6 Space Safety

As of September 2023, there are 8672 satellites in orbit around the Earth[52], overtaking historical rates of the launch traffic in all mass and type classes. The increase in launch traffic and permanence of space debris events in Low Earth orbit leads a significant conjunction risk in the most congested Earth orbits. The extrapolation of the current changing use of orbits and launch traffic, combined with continued fragmentations and limited post mission disposal success rate could lead to a cascade of collision events over the next centuries. To date, more than 30 000 pieces of space debris have been recorded and are regularly tracked by space surveillance networks.[53]

The provision of Space Situational Awareness (SSA) services is the cornerstone of space safety and is a foundation for establishing Space Traffic Management (STM) system which builds on SSA data. Such data encompasses Space Surveillance and Tracking (SST), Space Weather (SWE) and Near Earth Objects (NEO). It refers to the capability of detecting and tracking man-made and natural threats (e.g. space debris, geo-magnetic storms, asteroids), predicting and assessing the involved risks (e.g. collision risk, storm intensity risk) and providing services (e.g. conjunction warnings, storm forecasts and alerts) and related products (e.g. tailoring data and information to the specific type of institutional or commercial users).

Elliptical	36
LEO Below 2,000 km	7 831
MEO Between 2,000 and 36,000 km	148
GEO-GSO/GTO 35,786 km	600
Others Lagrangian, Interplanetary, Translunar	57

8 672
Operating Satellites
(as of September 2023)

Figure 29: Distribution of active and operating satellites (September 2023).

3.6.1 Presentation of the value chain

The overall value chain characterising Space Situational Awareness activities can be broken down into four main activities as depicted in the following figure.

[52] PwC analysis based on Spacetrack Seradata database (15/09/2023)
[53] Source: ESA ESOC https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

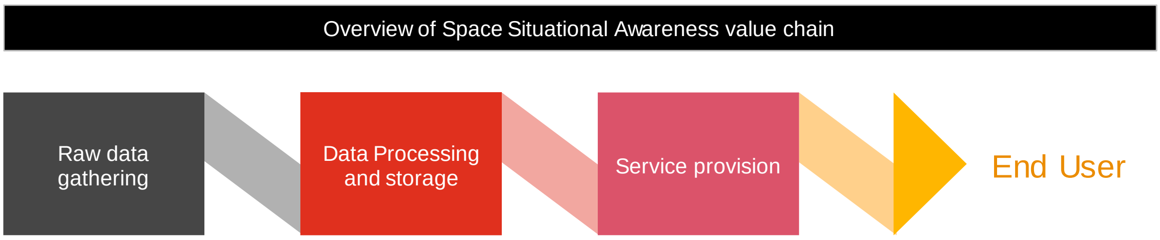

Figure 30: Overview of the Space Situational Awareness Value Chain.

The global value chain for Space Situational Awareness activities follows data gathering, processing and provision logic.

The collection of space related data is performed with different sets of observation capabilities by sensors which may combine several sources of information (optical/radar/laser) in a multi-layer fashion. The processing and storage of data aims at producing SSA information products. These activities rely on data repository and processing capabilities. This segment also includes activities covering the creation and maintenance of a catalogue of space objects.

Once the data is processed and stored, it is analysed to identify relevant information related to multiple aspects of space safety, such as, for instance, the positioning velocity and attitude of the observed and tracked objects. The service provision ensures that the distribution of SSA data is done in a timely and secured manner to support spacecraft operators in their decision-making process and national security entities in their intelligence needs.

3.6.2 Overview Space Safety programmes

EU initiatives

With the adoption of Regulation (EU) 2021/696 of the European Parliament and of the Council, the European Union adopted the Space Surveillance and Tracking (SST) component of the Space Situational Awareness (SSA) component of the EU Space Programme. The European SST Capability is being developed in collaboration with the SST Partnership and the EUSPA. The Partnership's Member States have networked their resources to offer a selection of SST services to all EU Member States, EU institutions, spacecraft owners and operators, as well as other public and private entities, through the SST Service Provision Portal run by EUSPA. The SST services detect and characterise in-orbit fragmentations as well as evaluate the risk of in-orbit collisions and uncontrolled re-entry of space debris into the Earth's atmosphere. The following participating member states of the SST Consortium are responsible for implementing this framework; they are represented by their respective national entities: Austria (FFG), Czech Republic (MDCR), Denmark (RDAF), Finland (FMI), France (CNES), Germany (German Space Agency at DLR), Greece (NOA), Italy (ASI), Latvia (IZM), the Netherlands (EZK), Poland (POLSA), Portugal (PT MoD), Romania (ROSA), Spain (AEE) and Sweden (SNSA).

The SST capability consists of three main functions: sensor (network of sensors to survey and track space objects), processing (a common database), and service provision. The provided services to all EU member, EU institutions, spacecraft owners and operators, and other public and private entities, include:

- Collision Avoidance: provides risk assessment of collision between spacecraft or between spacecraft and space debris and generates collision avoidance alerts; analyses all the available information in order to detect close approaches with different levels of risk

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

- Re-entry Analysis: provides risk assessment of uncontrolled re-entry of man-made space objects into the Earth's atmosphere and generates related information; analyses all the available information regarding the uncontrolled re-entries
- Fragmentation Analysis: provides detection and characterisation of in-orbit fragmentations, break-ups or collisions; analyses all the available information (at short, medium and long term) regarding the object(s) involved in the event.[54]

On STM, there were two initiatives within the Horizon 2020 programme in years 2021-2022.

'European space traffic management for the 21st century' (EUSTM) project joined 18 partners from across Europe that were working on an independent and end-to-end activity that defined the future European space traffic management capability. The main objectives of EUSTM were to define organisational, technological, scientific, policy, regulatory and legal guidelines and standards that would lead European STM efforts in the decades to come. The EUSTM consortium performed research, consulted global stakeholders design detailed specifications and a preliminary roadmap, as also worked to create a dedicated community of experts to ensure the continuation of project activities beyond its initial duration.[55]

'European ways forward for space traffic management' (SPACEWAYS) project joined 17 partners to establish a common understanding of the rules and standards required to develop an STM concept for the EU. The project assessed available and demanded European technical capabilities in the domains of SSA and SST and provide STM best practices and recommendations concerning EU interests. SPACEWAYS analysed policy, legal and economic environment of STM to better understand the STM concept's dynamics on a European and global level, and aims to provide standards supporting related EU policymaking.[56]

ESA initiative

The ESA SSA Programme is being implemented as an optional ESA programme with financial participation by 19 Member States. Funded at a total of approximately EUR 95 Million for the timeframe 2017-2020, it was boosted up to EUR 432 Million for the timeframe 2020-2024 (+354%) following the Space 19+ ESA ministerial in November 2019, highlighting the growing interest from ESA Member States for Safe Space Operations.[57]

ESA SSA Program places focus on R&D to support and improve domestic SSA goals, and enhance European SSA capabilities, directly supporting the EU's motivation towards being an enabler of SST/SSA and STM services through three priority topics: Space Weather, Near Earth Objects and SST.

In addition to its main entities ESRIN, ESTEC, ESAC and ESOC and its own SSA capabilities (the Optical Ground Station in Tenerife, tests telescopes in Spain and Chile), the ESA SSA Programme relies on the collaboration with other European and international organisations and external partners, particularly relying on US Department of Defence for SSA data.[58]

International capabilities

[54] Source: EUSST https://www.eusst.eu/
[55] Source: EUSTM https://eustm.eu/
[56] Source: EC Cordis https://cordis.europa.eu/project/id/101004208
[57] Source: ESA https://www.esa.int/About_Us/Ministerial_Council_2016/Space_Safety_Space_Traffic_Management_Programmes
[58] Source: ISA Science and Technology Policy Institute https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

- **US:** the United States maintains a system known as the Space Surveillance Network (SSN), which includes the most complete catalogue of space objects and a large network of sensors. The data collected by the group of phased array radars, tracking radars, and space-based tracking telescopes, is sent to the Combined Space Operations Center (CSpOC), which oversees a database of orbital trajectories of more than 23,000 space objects larger than 10cm. This database performs various analyses to support services, such as conjunction assessment warnings for satellite operators. Since CSpoC is part of the US Space Force and the system initially has been built to protect the US space assets, it is theoretically not service-oriented. The data is shared with the rest of the world free of charge because benefits from its data aid with dealing with a global issue of debris collision. Therefore, CSpoC service is not designed to meet commercial satellite operators' requirements such as support to avoidance manoeuvres, update of ephemeris, etc.
- **China:** China has recently began developing its network. It is estimated that China maintains the following set of capabilities: two ground-based optical sensors; four ships capable of performing SSA; four large Phased-Array Radar (LPAR) sites dedicated to identifying missile attacks; three telemetry, tracking, and control centres. Additionally, from a data processing standpoint, it is believed that there are some internal capabilities that have been developed China but are still reliant on conjunction warning provided by the US DoD.
- **Russia:** today, Russia operates the second largest SST/SSA network, the Russian Space Surveillance System (SSS). On the civilian front, Russia has developed the Automated Warning System on Hazardous Situations in Outer Space (ASPOS OKP), with the operations of the system being sub-contracted to the Astronomical Scientific Centre (ASC) by the Russian Space Agency (ROSCOSMOS). In addition to that, the Russian federation also leads the International Scientific Optical Network (ISON), which is an international non-governmental project, and provides freely-accessible SSA data and information for civilian purposes, globally. The network possesses the capability of conducting SST activities in Highly Elliptical Orbits, Geostationary Orbit, and Near-Earth Orbits. Moreover, ISON has the second largest non-government owned network of optical sensors.[59] Moreover, in 2017, Russia launched an earth observation satellite, which hosted a smaller satellite that detached from the mother spacecraft. This small satellite is a probe that is capable of approaching and imaging other space objects.[60] In 2022, Russia also launched a satellite for space inspection mission, capable of manoeuvring close to other spacecraft, which is believed to be a spy satellite rather than an SSA mission.

Commercial services

In addition to governmental programmes, the following figure provides an overview of the main private and commercial service providers in the field of SSA and most specifically in SST:

[59] Source: ISA Science and Technology Policy Institute: https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx
[60] Source: Space Flight Now https://spaceflightnow.com/2019/11/25/russia-launches-space-surveillance-satellite/

Funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Data Providers	• ArianeGroup • SDA • ExoAnalytic Solutions • LeoLabs • Share My Space	• Zodiac Aerospace • Vyoma Space • Okapi Orbits • North Star
Database Management Software	• AGI • Applied Analytics Solutions • ArianeGroup • Omitron • Solers • Share My Space • ExoAnalytic Solutions • Schafer	• A.I. Solutions • GMV • Vyoma Space • Okapi Orbis • LeoLabs • Sybilla • Nurjanatech • North Star
Analysis software	• AGI • Applied Analytics Solutions • ArianeGroup • Omitron • Solers • Schafer • A.I. Solutions • Share My Space	• Lockheed Martin • North Star • ExoAnalytic Solutions • Applied Defense Solutions, Inc. • Vyoma Space • Okapi Orbis • Sybilla • Nurjanatech
Service Providers	• AGI • ArianeGroup • Lockheed Martin • Schafer • North Star • LeoLabs • ExoAnalytic Solutions	• Applied Defense Solutions, Inc. • Share MySpace • Vyoma Space • Okapi Orbis • Sybilla • Nurjanatech • Spaceable

Figure 31: Main Private and Commercial Service Providers in the Field of SSA.

3.6.3 Market dynamics

The domain of Space Safety is witnessing a burgeoning market and economy, particularly in the area of space situational awareness. As the number of satellites and space debris increases, the demand for accurate and real-time data for tracking and management is growing exponentially. This uptick in demand is creating new economic opportunities for companies specializing in data access and management, thereby shaping a promising market landscape in Space Safety.

Current space safety market is formed by the following applications and services:

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Table 14. Space Safety Current Applications and Services

Applications	Services	Comments
Solar activity observation *Particles detection* *Coronagraphic imaging*	Space weather forecasts	Space weather forecasts predict solar flares, coronal mass ejections (CMEs), and other solar events that can impact Earth's magnetosphere, ionosphere, and communications systems. These forecasts are vital for protecting spacecraft, satellites, astronauts, and power grids from the adverse effects of space weather.
Radiofrequency monitoring *Spectrum analyse*	Orbit determination Radiofrequency interference RFI notifications	Data on the orbits and movements of objects; notifications about RFI sources allow for the mitigation of interference, ensuring the reliability of satellite communication and navigation systems.
Onboard propulsion *Drag devices*	Disposal/end-of-life support	Facilitate controlled deorbit manoeuvres or reentry into Earth's atmosphere at the end of a spacecraft's operational life, preventing the accumulation of space debris and reduce the risk of collisions in Earth's orbit
Ground-based radar systems *Space-based sensors* *Optical telescopes*	Launch detection Space object identification Breakups and separation detection Space debris tracking Orbit determination Conjunction assessment	Timely notification about launches; provide data on the location, trajectory, and characteristics of debris objects, including those resulting from spacecraft breakups or separations; calculating and predicting the positions of spacecraft, space debris, and other objects in Earth's orbit; calculating the probability of close approaches or collisions
Atmospheric modelling *Radar tracking*	Re-entry forecasts On-orbit conjunction assessment	Precise predictions of re-entry times and impact locations by analysing orbital parameters and atmospheric conditions
Laser ranging	Space objects' precise position measurement	Ground-based observation system using short laser pulses to determine the distance, velocity, and orbit of space objects with millimetre precision
Machine learning *Artificial intelligence*	Predictive analysis Passive space surveillance	Process vast real-time datasets from multiple observation systems

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Table 15. Drivers and Restraints of Space Safety Market

Drivers	Restraints
Safety: STM systems are required to ensure safe operation of spacecraft and collision risks rising due to the congestion of the Earth's orbit	**Regulations:** Lack of international coordination on regulatory level to create enforceable law inhibits the development and testing of STM technologies
National security: Effective STM systems are vital for protection of space assets mitigating possibilities of hostile acts against national space assets	**Politics:** Application of STM system raises concerns on space security and militarization of space, resulting in space nations disagreement on further developments
Sustainability: Effective monitoring of space debris and implementation of relevant guidelines reduce risks to the space environment sustainability	**Costs:** The development, implementation, operation of monitoring systems and satellites are associated with high costs. Moreover, there is a lack of incentives for space companies to participate in such programmes
Economy: The number of launched satellites is increasing due to the rise of commercial space entities and New Space economy, thereby adding to the orbit congestion increasing collision risks	**Technology:** STM requires advanced SSA data management, communication, and tracking systems, entailing high investments in R&D

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Table 16. Drivers and Restraints of Space Safety Market

Drivers	Restraints
Safety: STM systems are required to ensure safe operation of spacecraft and collision risks rising due to the congestion of the Earth's orbit	**Regulations:** Lack of international coordination on regulatory level to create enforceable law inhibits the development and testing of STM technologies
National security: Effective STM systems are vital for protection of space assets mitigating possibilities of hostile acts against national space assets	**Politics:** Application of STM system raises concerns on space security and militarization of space, resulting in space nations disagreement on further developments
Sustainability: Effective monitoring of space debris and implementation of relevant guidelines reduce risks to the space environment sustainability	**Costs:** The development, implementation, operation of monitoring systems and satellites are associated with high costs. Moreover, there is a lack of incentives for space companies to participate in such programmes
Economy: The number of launched satellites is increasing due to the rise of commercial space entities and New Space economy, thereby adding to the orbit congestion increasing collision risks	**Technology:** STM requires advanced SSA data management, communication, and tracking systems, entailing high investments in R&D

3.6.3.1 Demand trends

Growing amount of space debris

The proliferation of space debris in Earth's orbit presents a mounting challenge for satellite operators worldwide. As the density of these defunct satellites, spent rocket stages, and other remnants of space missions continues to increase, so does the potential for catastrophic collisions that could damage or destroy operational satellites and further exacerbate the space debris problem. Consequently, satellite operators are increasingly seeking more accurate and timely data on the trajectories of these debris fragments. Having precise information about potential collisions allows them to make informed decisions about whether to adjust their satellite's course or take other preventive measures. This growing demand emphasises the critical need for enhanced space situational awareness and underscores the importance of investing in advanced tracking and monitoring technologies to safeguard the sustainable use of space.

Need for automation to deal with large volumes of data

Satellite operators are inundated with vast volumes of data pertaining to potential space debris collisions, typically known as Conjunction Data Messages (CDM). Manually sifting through this information is not only time-consuming but also introduces the possibility of human error, making it an inefficient and potentially risky approach. Consequently, there is a burgeoning interest and appetite among these operators to employ automation in analysing and actioning this data. Artificial Intelligence (AI) emerges as a promising solution in this context. With its advanced data processing capabilities, pattern recognition, and predictive analytics, AI can rapidly assess potential collision threats, rank them based on severity, and even suggest optimal manoeuvres to satellite operators. By integrating AI into their operational frameworks, operators can

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

achieve quicker response times, reduce human intervention, and enhance the overall safety and efficiency of satellite operations. As space becomes increasingly congested, leveraging AI's prowess will be pivotal in ensuring the sustainability and safety of space activities.

Rising partnership among countries

Rising international collaboration, especially in the realm of Space Situational Awareness (SSA), has become a defining trend in recent times. The United States, recognizing the shared challenges and mutual interests in space, has taken significant strides in forging new SSA partnerships with countries around the globe. One of the landmark agreements in 2022 was with India, a burgeoning space power. This partnership seeks not only to enhance the flow of critical information between the two nations but also aims to catalyse a collaborative environment for the co-development and co-production endeavours of space manufacturers in both countries. The implications of this are significant. By aligning their technological and manufacturing prowess, the US and India can potentially lead in setting global standards and practices for sustainable space operations.

In the same vein, 2022 also saw the US extending its SSA cooperative framework to nations in the Asia-Pacific region. These collaborations are not merely confined to space but are emblematic of broader and multifaceted relationships. With South Korea, Japan, and the Philippines, the SSA agreements are part of comprehensive packages that encompass security, economic, technological, and educational dimensions. Such broad-spectrum engagements underline the fact that space is now deeply intertwined with geopolitics and global economies. These nations, by partnering with the US on SSA, are not just ensuring the safety and operability of their satellites but are also cementing their positions as stakeholders in the future of space exploration and utilisation. This shared commitment is a testament to the growing understanding that space, as the final frontier, requires collective stewardship, and these collaborations mark a significant step toward that global objective.

3.6.3.2 Supply trends

Implementation of new technologies

The intricacies inherent in the operations of satellite constellations necessitate the utilisation of high-performance computational systems. These systems are capable of processing millions of data points in mere fractions of a second, predicting satellite attributes with heightened accuracy. To further bolster the precision and efficiency of tracking and predicting spatial object movements, an earnest investment in technological innovation is underway, prominently featuring machine learning and artificial intelligence in the realm of Space Situational Awareness (SSA). These cutting-edge technologies offer unparalleled data processing and analytical capabilities, substantially mitigating risks by providing timely and accurate information.

In addition to AI and machine learning, extensive research and development efforts are being channelled into optical, radar, and laser technologies. Enhanced telescope capabilities allow for superior observation and tracking of space objects, including minuscule debris, enabling timely alerts and manoeuvre recommendations. Advancements in radar technology contribute to an enriched and detailed mapping of space debris, substantially augmenting the available data regarding potential collisions. Laser technology, furthermore, holds promise for both tracking and potentially mitigating space debris, offering a multifaceted approach to the ever-escalating challenge of space debris management. The integration of these emergent technologies plays a pivotal role in augmenting the capabilities of SSA systems, providing satellite operators with an advanced, comprehensive, and reliable toolkit to navigate the cluttered expanse of outer space.

Growth of commercial SSA services

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

The burgeoning interest in Space Situational Awareness (SSA) has ushered in a new era marked by the active participation of private enterprises in the domain. Witnessing the rising demand for SSA, a multitude of private companies have seized the opportunity, carving out a niche in the market. This trend of commercialisation has been transformative, diversifying the array of available SSA services with a mix of innovation and adaptability. As these commercial entities play an increasingly prominent role, the traditional contours of space safety are undergoing a remarkable evolution. Their contributions are not only amplifying the overall SSA capabilities but also introducing agile solutions tailored for diverse clientele.

However, with the advent of these commercial offerings comes a unique set of challenges. Given the specificity and nuanced needs of satellite operators, they often seek highly customised information about objects that might intersect or come perilously close to their spacecraft. This specific demand means that while there's a vast array of SSA services, not all of them may align perfectly with the unique requirements of every operator. Consequently, some commercial SSA service providers might find it challenging to secure long-term, significant contracts that ensure consistent revenue streams.

Yet, the landscape is not static. The growing momentum behind the launch of megaconstellations — vast networks of interconnected satellites — brings with it renewed opportunities for these commercial entities. These megaconstellations, given their sheer number and intricate operational patterns, necessitate robust and precise SSA services. Therefore, as the frequency and scale of megaconstellation launches amplify, the market dynamics could tilt favourably towards commercial SSA service providers. Their capacity to offer specialised services might soon become indispensable, paving the way for a prosperous and symbiotic relationship between them and the broader space community.

Governance challenges

It appears that the current regulatory framework around space safety remains relatively timid. At the international level, legally binding obligations on the protection of the outer space environment are quite broad, and existing guidelines on the matter are not binding and are difficult to be enforced for implementation in national laws. STM is now an annual topic at the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) proceedings. However, little agreement exists on what structure international STM should eventually take. At the same time, Space Safety Coalition, ad hoc coalition of companies, organizations, and other government and industry stakeholders actively promoting responsible space safety, has recently prepared a second version of its document “Best Practices for the Sustainability of Space Operations”, focusing on UN and IADC guidelines. By April 2023, 27 stakeholders endorsed the practices and strive to implement them in their space operations. Another recent development came from the US Federal Communication Commission adopting a 5-year rule for deorbiting satellites to address the growing risks of space debris.

3.6.4 Assessment of emerging and future downstream activities

Aiming to prevent the generation of debris in valuable orbits by 2030, the European Space Agency has taken the lead by introducing the Zero Debris approach, which is represented by its Clean Space initiative. This strategy entails several important actions, such as developing space debris mitigation policies, modernizing spacecraft platforms, showcasing trustworthy removal services, and enhancing space operations and traffic coordination.

Zero Debris is a significant component of ESA's Agenda 2025 and the ESA PROTECT accelerator, both of which aim to support global competitiveness of the European space industry. The key component of the ESA Clean Space initiative is collaboration with Swiss start-up ClearSpace, which signed a launch contract with

Arianespace for ClearSpace-1 with for the second half of 2026. This will be the first active debris removal mission that will capture and deorbit a derelict space debris object of more than 100kg.[61]

Another upcoming mission is developed by Astroscale, the market leader in satellite servicing. Based on its demonstration mission (ELSA-d) in 2021-2022 proving magnetic capture in-orbit, Astroscale works on the COSMIC mission – Cleaning Outer Space Mission through Innovative Capture. It will harness Astroscale's Rendezvous and Proximity Operations (RPO) and robotic debris capture capabilities to remove two defunct British satellites currently orbiting Earth by 2026.[62] Astroscale also announced the opening of Astroscale France SAS (Astroscale France) and a contract with the French national space agency, Centre National D'Etudes Spatiales (CNES), showcasing France's investment in space sustainability.[63]

[61] Source: Spacewatch Global https://spacewatch.global/2023/05/clearspace-to-launch-the-first-active-debris-removal-mission-with-arianespace/
[62] Source: Astroscale https://astroscale.com/astroscale-on-course-for-first-uk-national-mission-to-remove-space-debris/
[63] Source: Astroscale https://astroscale.com/astroscale-expands-operations-to-france-and-secures-contract-with-cnes/#:~:text=Astroscale%20France%20is%20incorporated%20in,has%20approximately%20450%20team%20members.

3.6.5 Mapping of Space Safety emerging technologies, services, and applications

Table 17. Space Safety Emerging Technologies, Applications, Services

Technologies	Applications & Features	Services & Benefits
Tow truck spacecraft enabled with vision-based AI	AI-enhanced capturing mechanism targeting uncooperative space objects	Active debris removal; reduces risk of space collisions
Revaluation of spacecraft battery standards	Advanced design standards reducing risk of onboard battery malfunctions	Debris mitigation; promotes longevity and safety of spacecrafts
Combination of SSA software and spacecraft propulsion control	Unified platform for situational awareness and instantaneous response	Integrated space mobility subscription; streamlined space traffic management
Open-Architecture Data Repository (OADR)	Centralised database promoting transparency and seamless data sharing	Warning system for public operators; enhances global coordination
AI/ML-based prioritisation and classification of alerts	Advanced algorithms discerning threat levels for potential collisions	'Smart' STM; enables more precise and efficient space traffic management
Advanced radar and telescope system	Superior tracking with global coverage and real-time updates	Autonomous EU SST; improves detection and monitoring of space objects
Multi-agent deep reinforcement learning	Collaborative AI agents optimizing sensing strategies for object detection	Space sensor tasking; ensures comprehensive and efficient object tracking
Space/ground-based laser nudge	Precise nudging mechanisms to safely redirect space debris trajectories	Active debris removal; offers non-contact means to manage space debris
Tethered-Net Removal	Flexible and adaptive technology suitable for capturing various space debris sizes	Active debris removal; provides a scalable solution to manage different debris sizes

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Removal docking plate bus equipment	Modular platform facilitating easy attachment and de-orbiting procedures	Active debris removal; standardises de-orbiting operations
Extra-vehicular general-purpose robotic arm and hand	Multi-purpose robotic mechanism with high adaptability for various space operations	Active debris removal; versatile tool for both debris management and other in-orbit servicing requirements

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

4. APPENDIX A – LIST OF NATIONAL AND EUROPEAN LEVEL REPORTS USED

Country	Agency	Year	Type, format	Language	Document title/url
Austria	bmvit (Federal Ministry for Transport, Innovation and Technology	2017	Report, pdf	English	Austrian Technology in Space - An Overview of Austrian Space Industry and Research
	bmvit (Federal Ministry for Transport, Innovation and Technology	2014	Report, pdf	English	Strategy of bmvit for Austrian Space Activities
	Federal Ministry Republic of Austria - Climate Action, Environment, Energy, Mobility, Innovation and Technology	2021	Report, pdf	English	People, Climate and Economy - Space is for EVERYONE (Austrian Space Strategy 2030+)
Belgium	Belgian Science Policy office	2023	Website	French	https://www.belspo.be/belspo/space/index_be_en.stm
Bulgaria	ESA (European Space Agency)	2023	Website	English	https://www.esa.int/About_Us/Corporate_news/Bulgaria_becomes_tenth_ESA_European_Cooperating_State
Czech Republic	Ministry of Transport (MD)	2019	Report, pdf	English	National Space Plan 2020-2025
Croatia	ESA (European Space Agency)	2023	Website	English	https://www.esa.int/About_Us/Corporate_news/Croatia_to_become_12th_ESA_European_Cooperating_State
Denmark	The Danish Government	2016	Report, pdf	English	Denmark National Space Strategy
	The Danish Government	2021	Report, pdf	English	Denmark National Space Strategy - Update of strategic objectives
Estonia	Estonian Space Office	2020	Report, pdf	English	Estonian Space Technologies Phone Book - Selection of Estonian Space Technologies and their mapping to the ESA Technology Tree
Finland	Työ-ja elinkeinoministeriö Arbets-och näringsministeriet - Liikenne-Ja Viestintäministerio	2018	Report, pdf	Finnish	Suomi 2025 - Maailman houkuttelevin ja ketterin avaruusliiketoimintaympäristö, josta hyötyvät kaikki täällä toimivat yritykset
France	CNES (Centre national d'études spatiales)	2022	Report, pdf	English	Annual Report 2022
Germany	DLR (Deutsches Zentrum für Luft- und Raumfahrt)	2023	Website	English	https://www.dlr.de/en/

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

Hungary	Department for Space Activities of the Hungarian Ministry of Foreign Affairs and Trade	2021	Report, pdf	English	Hungary Space Strategy
	Department for Space Activities of the Hungarian Ministry of Foreign Affairs and Trade	2022	Report, pdf	English	Hungarian Space Kaleidoscope 2021/2022
	Department for Space Activities of the Hungarian Ministry of Foreign Affairs and Trade	2023	Website	English	https://space.kormany.hu/dear-visitor
Ireland	Government of Ireland	2019	Report, pdf	English	National Space Strategy for Enterprise 2019-2025
Italy	ASI (Agenzia Spaziale Italiana)	2020	Report, pdf	Italian	Documento di Visione Strategica per lo Spazio 2020-2029
Latvia	Republic of Latvia: Ministry of Education and Science - Ministry of Economics	2020	Report, pdf	English	The Space Strategy of Latvia 2021-2027
Luxembourg	The Government of the Grand Duchy of Luxembourg: Ministry of the Economy - Luxembourg Space Agency	2020	Report, pdf	English	National Action Plan 2020-2024 - Space Science and technology
	Luxembourg Space Agency	2023	Website	English	https://space-agency.public.lu/en/agency/mission-vision.html
Malta	Government of Malta: Ministry for Equality, Research and Innovation	2022	Report, pdf	English	Malta National Space Strategy
	Xjenza: The Malta Council for Space and Technology - Ministry for Education and Employment	2017	Report, pdf	English	Malta National Space Policy
Netherlands	State Secretary for Economic Affairs and Climate	2019	Letter, pdf	Dutch	2019 Space Policy Memorandum
	(NSO) Netherlands Space Office	2023	Website	English	https://www.spaceoffice.nl/en/
Poland	POLSA (Polish Space Agency)	2022	Report, pdf	English	Polish Space Sector - Entity Directory 2022
	POLSA (Polish Space Agency)	2020	Report, pdf	English	Polish Space Sector 2020. Analysis of the current state, trends and technologies in the national and international context

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

	POLSA (Polish Space Agency)	2019	Article, pdf	English	Building Polish space sector - from small islands of excellence to a national innovation ecosystem
Portugal	Portugal Space	2021	Report, pdf	English	Overview of the Portuguese Space Community - Portuguese Space Catalogue 2021-2022
Romania	ROSA (Romanian Space Agency)	2022	Report, pdf	Romanian	Raport Annual de Activitate 2022
Slovakia	SARIO (Slovak Investment and Trade Development Agency)	2022	Report, pdf	English	Space Industry in Slovakia
Slovenia	Republika Slovenija - Ministrstvo za Gospodarstvo, Turizem in Šport	2023	Report, pdf	Slovenian	2030 - Slovenska vesoljska strategija 2023-2030
Spain	Gobierno de España	2019	Report, pdf	English	National Aerospace Security Strategy
	Gobierno de España - Ministerio de industria, comercio y turismo	2022	Report, pdf	English	Spain for Aerospace Industry
Sweden	Rymdstyrelsen - Swedish national Space Agency	2019	Report, pdf	English	The Strategy of the Swedish National Space Agency
UK	Department for Business, Energy & Industrial Strategy	2022	Report, pdf	English	UK Severe Space Weather Preparedness Strategy
	HM Government	2021	Report, pdf	English	National Space Strategy
ESA	European Space Agency	2021	Report, pdf	English	ESA Agenda 2025 – Make Space for Europe

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. The statements made herein do not necessarily have the consent or agreement of the ASTRAIOS Consortium. These represent the opinion and findings of the author(s).

OUR PARTNERS

Science Connect – European Science Foundation; AZO Space of Innovation; University of Twente ITC; SME4SPACE; University of Strathclyde Glasgow; EASN TIS; International Space University; Πολυτεχνείο Κρήτης – Technical University of Crete; FDC; Space Skills Alliance

LET'S CONNECT HERE!

01.01.2023 36 months

https://astraios.eu

info@astraios.eu

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement **No. 101082636**

Funded by the European Union