In partnership with

WAY 4 SPACE

On-orbit Servicing, Assembly, and Manufacturing

State of Play and Perspectives on Future Evolutions

ESPI European Space Policy Institute

Report:

Title: "On-orbit servicing, assembly, and manufacturing - Full Report 87"

Published: October 2023

ISSN: 2218-0931 (print) • 2076-6688 (online)

Editor and publisher:

European Space Policy Institute (ESPI)

Schwarzenbergplatz 6 • 1030 Vienna • Austria

Phone: +43 1 718 11 18 -0

E-Mail: office@espi.or.at

Website: www.espi.or.at

Cover design: www.rainfall.ro

Internal layout design: www.copylot.at

Cover page picture credit:

Table of Contents

1 Introduction

1.1 Background and rationale

For most of the space age, the possibility to autonomously upgrade, repair, reposition or refuel a space object in orbit was considered a futuristic endeavour, far from regular, reliable, and profitable applications. While on-orbit servicing and assembly missions are far from being new, they were to a large extent confined to extravehicular missions *conducted* by astronauts.

Most space systems, except for human-tended space stations, are traditionally built to be operational over their entire mission life cycle without human physical intervention. Once they become dysfunctional or reach their end of life, they are discarded, either placed in a graveyard orbit, pushed back into the atmosphere, or left out as orbital debris.

Considering the increasingly intensive use of the Earth's orbits, leading to a congested, competed, and contested orbital environment(s) alongside technological developments, a growing and sustained commercial interest in autonomous and robotic on-orbit servicing, assembly, and manufacturing has emerged.

Since 2020 ESPI's Report on the topic was published, pioneering missions and operations have been performed, alongside newly proposed concepts and new players emerging worldwide, including in Europe. Fuelled for now almost exclusively by public contracts and demonstrations requested by space agencies, many of these new actors hope to develop new orbital capabilities and pave the way for a future space economy, the realisation of which remains uncertain to this day. Alongside this dynamic, the policy and regulatory landscape has also been evolving, as these technologies not only hold commercial promise but also imply security considerations and legal liability that must be considered in the development of technology and the preparation of business plans.

A follow-up study to ESPI's Report on *"In-Orbit Services"* [1]

In 2020, ESPI published a report on on-orbit servicing, assembly, and manufacturing (OSAM).

The report constituted an initial analysis and assessment into this nascent technology. It addressed the historical evolution of OSAM, dwelling into the origins of servicing missions as part of extravehicular missions conducted by astronauts from the United States and the USSR during the Cold War. These then evolved into increasingly robotic and autonomous missions conducted by States as part of national space programmes and later by commercial companies.

The report, drafted right after the MEV mission, which demonstrated the business case for life extension, aimed at providing a comprehensive definition and assessment of the commercial and institutional landscape of on-orbit servicing as well as an overview of the various technological, technical, economic, political, and legal challenges surrounding this technology.

The report demonstrated that OSAM was a representative case of the changing landscape in the global space sector as well as the challenges it faces. It also concluded that most challenges mostly stem from political and legal issues rather than technological ones. At the time of writing, Europe had not defined a clear position on the matter. The report recommended that Europe positions itself as an anchor customer and encourages the development of such services through policy and legal incentives,

[1] *In-orbit services* (2020) *ESPI*. Available at: https://www.espi.or.at/reports/in-orbit-services/ (Accessed: 15 April 2023).

1.2 Objectives

The goal of the study is to provide an **overview of the evolving landscape of on-orbit servicing, assembly, and manufacturing (OSAM) and provide policy recommendations for the future of European ambition in this field.**

The report provides an overview of the current OSAM market, emphasising the changes that took place over the past three years and the issues that remain, including parameters that affect OSAM's development. It includes insights on private investments in European OSAM companies based on ESPI's Space Venture proprietary database.

The report also provides an updated overview of current policy, legal, and capability developments in the field of OSAM, looking into current actors, projects, and publicly expressed priorities of ESA and EU Member States as well as selected spacefaring nations in the rest of the world. The report provides an overview of doctoral research focusing on OSAM in European universities, giving a more detailed understanding of the interests and projects in this domain. In terms of regulatory developments, it focuses on interpretations of international space law surrounding OSAM. Finally, the report provides recommendations to unlock the potential of OSAM in Europe. The study provides a current snapshot of OSAM initiatives and missions being announced, developed, and carried out and their related trends. While OSAM technologies have been developed since the beginning of the Cold War, the report does not aim to go into historical details about OSAM or State capabilities and rather focuses on current policy, technology, and market developments. It is also worth noting that current trends are subject to many assumptions that remain to be confirmed. OSAM activities carry promises for the future, attracting many new players, but it will be essential to observe their development in the coming years to judge their true importance.
Therefore, while taking stock of the history and status of the European OSAM ecosystem as well as the challenges presented in the 2020 study, this report adopts a more forward-looking perspective.

1.3 Methodology

The study was conducted in collaboration with **Way4Space**, a think tank and innovation centre bringing together public policy actors, the space industrial ecosystem and academic structures in political science, economics, and engineering. The research was carried out by ESPI, with the support of Way4Space, in particular for the review process.

The research involved a combination of qualitative and quantitative methodologies based on primary sources such as national policy documents and international treaties. Data presented in the study come from desktop research, proprietary databases, and consultations with experts from space agencies, industry, and academia. Limits to the study pertain to the availability of information online, the availability of information in languages spoken by the ESPI research team, as well as data provided by consulted stakeholders during research interviews.

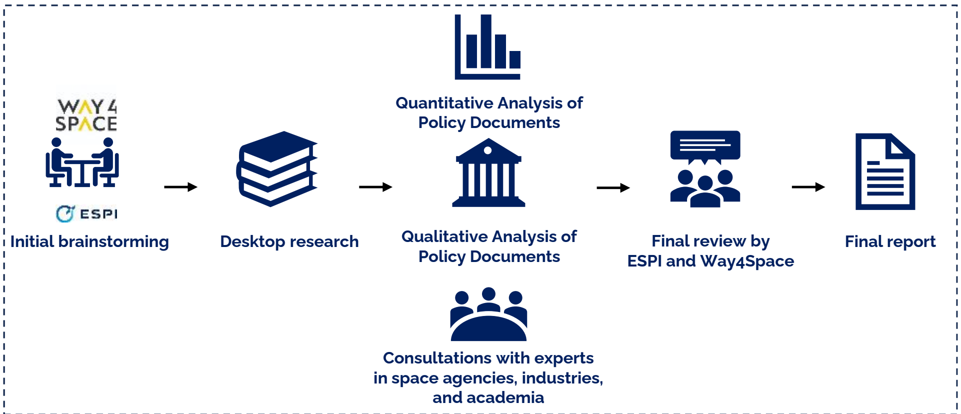

Figure 1: Methodology of the study

2 Defining On-Orbit Servicing, Assembly, Manufacturing

While the use of space for applications on Earth (e.g., Earth Observation, Navigation, Telecommunications, etc.) is widely developed, the **in-space economy** is still emerging. The in-space economy is often referred to as *"the space-to-space economy"*, *"space-for-space economy"*[2], *"the Low Earth Orbit economy"*, *"the on-orbit economy"*, or the *"beyond Earth to space economy"*. These terms translate the idea of the full range of activities and use of resources in space that create value and benefits in space. **This is about *"goods and services produced in space for use in space*"**.[3]

Naturally, assets, components, and technologies of the in-space economy do not function entirely autonomously in outer space as they are launched and operated from Earth and ultimately also provide an added value to the economy on Earth. Yet, **the difference between the space-for-space economy and the space-for-Earth economy is that, in the former, the final end-users or recipients are in outer space.**

On-orbit servicing, assembly, and manufacturing (OSAM) can therefore be considered as part of the in-space economy or the space-for-space economy. However, the in-space economy goes beyond OSAM. Erik Kulu proposed a taxonomy for the in-space economy, which comprises areas of activities such as but not limited to human spaceflight and landers, cargo transportation and landers, surface rovers, space stations and habitats, surface habitats and structures, in-space manufacturing, space resources utilisation and mining, space utilities, in-space transportation.[4]

It is essential to underline that there is no universally accepted definition for OSAM. It is often referred to in various ways, whether it is *"in-orbit servicing"*, *"on-orbit servicing"*, *"in-orbit services"*, *"in-space services"*, etc. There are no specific differences between these terms. For this reason, the term *"On-orbit servicing, assembly, and manufacturing"* (OSAM) will be consistently used throughout the report.

This report will consider that:

- **On-Orbit servicing (OOS)** refers to the provision of support services by a spacecraft (servicer) to another space object (serviced spacecraft) while in orbit, regardless of whether the serviced spacecraft is cooperative or not.
- **On-Orbit Manufacturing (OOM)** involves activities related to the in-orbit transformation of raw materials into usable spacecraft components as well as other objects, artefacts, and materials.
- **On-Orbit Assembly (OOA)** can be defined as the in-orbit aggregation and connection of components to constitute a spacecraft or spacecraft subsystem.

---

[2] Weinzierl. M et al. (2021) Encouraging the Space-for-Space Economy. The New Space Age: Beyond Global Order. University of Pennsylvania. Available at: https://global.upenn.edu/sites/default/files/perry-world-house/Weinzierl_SpaceWorkshop.pdf (Accessed 22 September 2023)
[3] Kulu, E., 2021. In-Space Economy in 2021 - Statistical Overview and Classification of Commercial Entities. In: Proceedings of the 72nd International Astronautical Congress (IAC 2021), 25-29 October 2021, Dubai, United Arab Emirates. IAC-21-D3.3.10.
[4] *Ibid*, p.9-10.

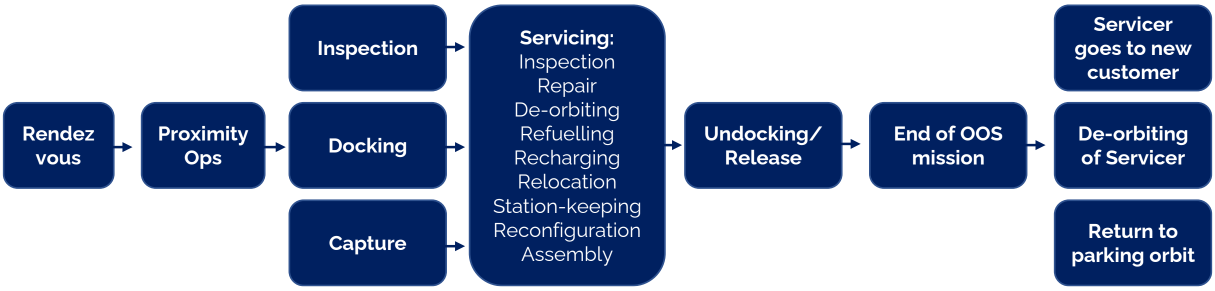

Figure 2: Steps of an on-orbit servicing mission (Source: CONFERS, adapted by ESPI)

On-orbit servicing missions usually involve several steps, which can vary depending on the mission:

- **Step 1 – Rendezvous:** the series of actions taken by the Servicer Spacecraft to transition its orbit from the departure of the previous customer or from its parking orbit to the desired rendezvous orbit by conducting an orbital transfer or manoeuvres to reach the location of the rendezvous.
- **Step 2 – Proximity Operations**: the operations carried out between the servicer and the serviced spacecraft within close vicinity to each other.
- **Step 3:**
  - **Inspection:** the servicer spacecraft does not come in physical contact with the inspected spacecraft but inspects it remotely by coming relatively close to the inspected spacecraft, acquiring data or images, or remotely exchanging data in order to assess the conditions of the space system; or
  - **Docking:** alternatively, the servicer spacecraft can approach and establish physical contact by docking with the serviced spacecraft through a dedicated interface or by using another component in order to provide a service. Docking enables the servicer and the serviced spacecraft to exchange data, power, components, etc. and provide services such as refuelling, repair, reconfiguration, recharging, station-keeping, etc; or
  - **Capture:** alternatively, the service spacecraft can capture a (usually) non-cooperative space object through various techniques such as robotic arms, nets, or harpoons. This often comprises Active Debris Removal missions.
- **Step 4 – Undocking or release:** the operations in which the servicer spacecraft separates from the serviced spacecraft or manoeuvres away from it.
- **Step 5 – End of mission:** once the mission is over, the servicer can either manoeuvre towards another client, move back to its parking orbit, or de-orbit itself by re-entering the atmosphere or repositioning itself in a graveyard orbit when it reaches its own end of life.[5]

Furthermore, OSAM also partially overlaps with the term space logistics, which is linked to activities allowing *"the transportation of cargo and material to, from, and within space as well as the capacity to sustain human-tended and robotic operations"*[6] or services *"provided by autonomous robotic vehicles which are able to: change their orbit and altitude; and perform rendezvous, proximity operations, and docking with customer spacecraft"*[7]. These definitions clearly seem to encompass some on-orbit servicing, assembly, and manufacturing missions as described above, thereby making OSAM one of the components of space logistics. Others consider that space logistics only comprise relocation and last mile delivery services in which spacecraft are transported to their final

[5] Confers on-orbit servicing (OOS) mission phases. Available at: https://www.satelliteconfers.org/wp-content/uploads/2019/10/OOS_Mission_Phases.pdf (Accessed: 14 September 2023).
[6] Space Logistics market size, share, trends, report, analysis (2020) Allied Market Research. Available at: https://www.alliedmarketresearch.com/space-logistics-market-A47401 (Accessed: 14 September 2023).
[7] New Space Economy (2023) Space Logistics - A Quick Overview, New Space Economy. Available at: https://newspaceeconomy.ca/2022/11/25/space-logistics-a-quick-overview/ (Accessed: 14 September 2023).

orbital destination or to different altitudes and orbits using an Orbital Transfer Vehicle (OTV). This definition would therefore include space logistics as one of the on-orbit services.

It can also be considered that **OSAM falls within the realm of in-space transportation**, as the latter includes on-orbit servicing, inspection, OTVs, propellant depots, active debris removal, reusable satellites, and space logistics.[8]

Various taxonomies can be established regarding on-orbit servicing, assembly, and manufacturing (OSAM), with a plethora of studies, market analyses, and forecasts covering OSAM in different ways.

[8] Erik Kulu *Op. Cit*. at p.10.

In this context, the study will consider the following services:

In-orbit refuelling can be defined as the provision and transfer of propellant, fuel pressurants, or coolants from the servicer spacecraft to the serviced one so as to keep the system operational.

In-orbit repair consists of repairing or replacing parts of a space system in orbit in order to extend or maintain the system in operational conditions. Repair may be performed on a cooperative or non-cooperative target.

Active Debris Removal can be defined as the process in which a space system is being captured to relocate it to a graveyard orbit or to accelerate its atmospheric re-entry at the end of the life of the satellite. This involves the capture of a non-cooperative object.

In-orbit inspection can be defined as the process for assessing the physical status and conditions of a satellite to detect anomalies or assess the consequences of a failure, attack, or collision. Inspection may be performed on a cooperative or non-cooperative target.

In-orbit recharging is the provision of electric power to a space system in orbit through power beaming or docking to power the batteries.

Station-keeping can be defined as the process of docking with a satellite to keep it in a particular orbit or altitude.

In-orbit relocation services can be defined as modifying or maintaining the position, orientation, location, or orbital parameters of the space system. It is about moving a spacecraft to another location in the same orbit or in a nearby orbit.

Last Mile Delivery can be defined as the transport of a spacecraft from the separation phase of the launch to the final orbital destination using e.g., an Orbital Transfer Vehicle (OTVs).

In-orbit assembly can be defined as the in-orbit aggregation and connection of components to constitute a spacecraft or spacecraft subsystem.

In-orbit manufacturing involves activities related to the in-orbit transformation of raw materials into usable spacecraft components.

Figure 3: Definitions of types of on-orbit servicing, assembly, and manufacturing

3 Market analysis

This section will provide a market analysis of the current OSAM market, focusing on the developments and changes that took place in the past three years. The market analysis will assess the emerging nature of the market and the business cases for OSAM (3.1), and address current market trends (3.2), the market value and market forecasts (3.3), the state of private investment in European on-orbit servicing companies (3.4) and factors influencing the development of the OSAM market (3.5).

3.1 Creating the market

3.1.1 Expectations vs. Reality: the business case for OSAM since MEV

In 2019, Northrop Grumman (then Orbital ATK) launched **the Mission Extension Vehicle-1 (MEV-1) mission, which was the world's first commercial mission for life extension.**

Following several in-orbit tests, MEV-1 was launched to service Intelsat's IS-901 satellite and provide relocation services.[9] To do so, Intelsat raised the altitude of IS-901 so as to match the one of the MEV-1 servicer. MEV-1 performed a rendezvous and docked with IS-901 by using the liquid apogee engines to grab Intelsat's satellite as it was not initially designed to be serviced. MEV-1 took over the propulsion and altitude control functions of the serviced satellite and relocated it to a graveyard orbit. The demonstration mission was conducted in graveyard orbit to reduce risk of collisions with active satellites in GEO. MEV-1 eventually proceeded to relocate IS-901 to its intended orbital slot in GEO. In 2024, IS-901 is expected to be placed into graveyard orbit after its end of life.[10]

In 2020, Northrop Grumman launched the Mission Extension Vehicle-2 (MEV-2) to service Intelsat's 10-02 satellite. MEV-2 directly docked 10-02 in GEO and will remain docked to the satellite for a period of five years to provide altitude control and station-keeping.[11]

These two missions sparked new hopes in the commercial space sector as it proved the technology to extend the life of satellites that were not originally designed to be serviced and raised awareness about this possibility to extend the lifetime of space systems, and eventually their commercial output and revenues. The economic value of on-orbit servicing was positive for Intelsat as it increased its Return on Investment (RoI) on its existing satellites, saving around $200-400 million for a cost of around $70 million ($13-14 million per year over five years).[12]

In this context, **the sector expected to see a new market emerge with various contracts and missions for life extension services in a short period of** time as the MEV missions proved the business case for life extension. **However, it does not seem that the market really took off. MEV-1 and MEV-2 remain the only two major commercial missions to have taken place since 2020.** As a result, the commercial life extension market is still rather small. **Interests for such services appear to currently come from public actors** such as DLR (e.g., Orbit Solutions to Simplify Injection and Exploration (OSSIE)); DARPA (e.g., MRV/RSGS); or NASA (e.g., OSAM-1). These missions are scheduled to be launched by 2024/2025. **However, they do not necessarily indicate a commercial**

---

[9] *MeV 1, 2, 3 Gunter's Space Page*. Available at: https://space.skyrocket.de/doc_sdat/mev-1.htm (Accessed: 23 May 2023).
[10] *Mev-1: A look back at the groundbreaking journey* (2020) *Intelsat*. Available at: https://tinyurl.com/92z6y6wr (Accessed: 02 June 2023).
[11] *In-orbit services* (2020) *ESPI*. Available at: https://www.espi.or.at/reports/in-orbit-services/ (Accessed: 15 April 2023).

interest or mature market. At the moment, most commercial developments are supported with public funds and seem to have only reached the R&D and, for some, the demonstration phase.

3.1.2 Heterogenous approaches to foster market creation

Several approaches can be observed in the development of this emerging market with clear distinctions between European countries and the United States. These approaches also translate the difficulties in creating the market and underline that to a large extent, the emerging OSAM market is not commercially driven, but that there is a policy push to develop such capabilities and services. However, the nature of this push varies from country to country.

Figure 4: Heterogenous approaches to market creation

For instance, in Europe, several countries have demonstrated an interest in fostering the OSAM market. Both France and Italy have provided funds and contracts to OSAM companies as part of their post COVID-19 Recovery Funds or programmes. However, their approaches seem to vary greatly from one another.

While France awarded numerous low-value contracts and funds through its France 2030 investment plan to various OSAM start-ups in the hope that some of these companies can develop commercial systems and services, Italy awarded a limited amount of high-value contracts to large industrial players (e.g., €235 million contract from ASI to Thales Alenia Space for design, development, and qualification of a spacecraft for OSAM demonstration mission) to conduct major R&D programmes and develop a demonstrator, with the idea that only an established player could develop and prove such technologies.[13]

In addition, **European emerging spacefaring nations or smaller space nations in Europe seem to mostly opt for developing OSAM capabilities through their participation to ESA programmes** to pool resources, benefit from the geographical return policy and be part of major R&D contracts or missions, that may help create the market. These countries have limited capacities and funding and are aware that they cannot develop capabilities or missions entirely on their own but would still like to contribute to fostering the creation of the market at their own level. This seems to be the case of Spain[14], Portugal[15] or Luxembourg.[16]

However, it is important to underline that the amounts invested in this technology in Europe are not comparable in volume to what is being implemented in the United States. The U.S. OSAM landscape

[13] Interview conducted by ESPI on August 29th, 2023.
[14] Interview conducted by ESPI on August 10th, 2023.
[15] +Space in Portugal and Europe with ESA (2019) Portugal Space (the Portuguese Space Agency). Available at: https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=%3D%3DBAAAAB%2BLCAAAAAAABACzNDAyBADs2aI0BAAAAA%3D%3D (Accessed 29 June 2023)
[16] Interview conducted by ESPI on September 7th, 2023.

does not seem market-driven either but is currently being fostered by the allocation of institutional funds and contracts, which are mostly provided by defence actors such as DARPA or the Space Force to both major industrial players (e.g., Northrop Grumman) as well as start-ups.[17] The U.S. Government is supporting the creation of this market by awarding numerous high-value and low-value commercial contracts to private companies to then buy their services for their purposes. The private-to-private OSAM market (e.g., operators paying for OSAM) in the United States remains very limited.[18]

3.2 The current market for OSAM

Looking at the European OSAM market, this slow development appears twofold and may be explained by phenomena taking place on both the demand and the supply side:

- **Supply:** In general, industry primes whose revenues are regularly replenished by orders for new satellites may have been less incentivised to invest or co-fund R&D in areas that could reduce those revenues such as OSAM. Therefore, there may have been more interest from these satellite manufacturers to sell brand new satellites than sell on-orbit servicing. With the emergence of new entrants and the increasing awareness of the space debris and congestions issues by government and industrial actors alike, this situation may evolve in the future. Industry primes are slowly seeing the benefit of entering this market, which can be seen as a complement from satellite manufacturing by generating revenues from maintenance as well.[19]
- **Demand:** the market may have been slow to take off because operators may not necessarily see the need to contract OSAM services. From a sustainability point of view, nothing requires operators to make their systems serviceable or contract ADR services at the end of their systems' lifecycle or should they create debris or lose control of their satellite. Also, as only few commercial missions took place, OSAM missions can be seen as expensive, not yet fully operational, and therefore seen as a potentially risky. The launch of mega-constellations is also a reducing factor as operators benefit from a high redundancy, with a great number of small satellites, which may not prompt operators to contract OSAM missions in case of failure on one of their spacecrafts.

The slower than expected development of the commercial OSAM market also saw various **OSAM companies change or adapt their business models to the current market.** OSAM companies and start-ups seem to have first emerged with the idea to develop on-orbit servicing capabilities, usually focusing on one type of service. However, the difficulties of the commercial market to materialise, the high number of start-ups, and the low expressed demand for OSAM seem to have led many companies to change their initial business models by deciding to develop several types of servicing capabilities instead in order to be profitable; or by turning their target customers from commercial satellite operators to the defence sector, in particular in the U.S. (e.g., Rogue Space Systems).

Despite current revenues being lower than projected by some analysts, the OSAM market has nevertheless evolved in the past three years. Different dynamics between State and industrial actors have emerged. This emerging market can be characterised by the presence of different types of contracts and origins of demand such as:

In the past three years, two new types of models appeared in the OSAM landscape beyond companies looking to service institutional satellites or commercial satellite operators:

[17] Interview conducted by ESPI on August 29th, 2023.
[18] Interview conducted by ESPI on August 29th, 2023.
[19] Interview conducted by ESPI on August 10th, 2023.

- **The emergence of commercial contracts in between OSAM companies.** Instead of satellite operators or governments simply contracting OSAM services, it seems that an increasing number of OSAM companies are signing contracts with other OSAM companies. For example, Orbit Fab (on-orbit refuelling) signed a contract with Astroscale (ADR) to enable the Japanese company to dock its own LEXI satellite servicer to Orbit Fab's fuel depot in order to be refuelled. OrbitFab's RAFTI device is expected to be installed into the LEXI servicer to ensure that refuelling is possible. The contract was considered by the two companies as the *"first on-orbit satellite fuel sale agreement"*. OrbitFab also signed a partnership with ClearSpace to equip ClearSpace's debris-removing satellites with OrbitFab's RAFTI in-orbit refuelling interface.[20] This trend indicates that the market is growing based on circular dependency and that while there is a willingness to create the market by equipping satellites to be serviceable in the future, this market also remains uncertain.
- **Space companies looking to service their own space systems.** Instead of contracting services from other commercial companies, some satellite operators and/or launch providers are looking to develop capabilities to service their own space systems, with limited or even no intention of selling these services to other companies. For instance, SpaceX plans to develop the capabilities to be able to refuel Starship.[21] This trend is heavily influenced by a broader trend of verticalisation in the New Space era, and particularly at SpaceX. While this shows the potential of OSAM for space missions, it does not necessarily contribute to the immediate development of the commercial OSAM market.

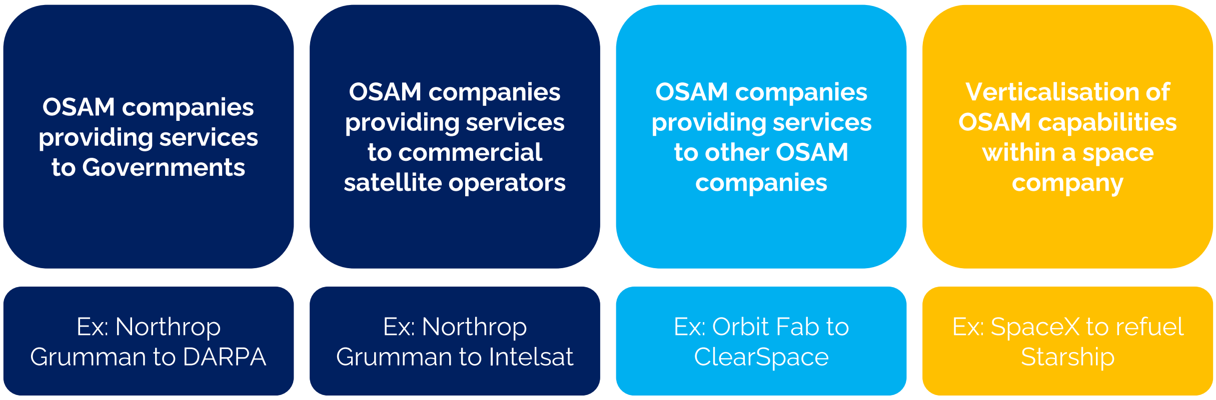

Figure 5: Types of OSAM companies

3.2.1 Growing demand for last mile delivery

Over the past four years, one OSAM market did take off, notably that of Orbital Transfer Vehicles (OTVs). OTVs provide relocation or last mile delivery services, which consist of transporting a spacecraft from the separation phase of the launch to the final orbital destination.

Europe is well-positioned in this emerging market with several companies currently developing or operating OTVs:

[20] *Orbit Fab Part of UK team making debris removal operations sustainable through refuelling* (2022) *Orbit Fab*. Available at: https://www.orbitfab.com/news/clear-mission/ (Accessed: 03 May 2023).
[21] Ralph, E. (2021) *SpaceX's path to refuelling starships in space is clearer than it seems*, *TESLARATI*. Available at: https://www.teslarati.com/spacex-how-to-refuel-starships-in-space/ (Accessed: 16 April 2023).

Country (alphabetical)	Company	System	Status
France	Hybrogines	Hyscab	In development
France	Exotrail	spacevan	In development[22]
France	Dark	*undisclosed*	In development
Germany	Rocket Factory Ausburg	Redshift	In development
Germany	Exolaunch	Reliant	In development
Italy	**D-Orbit**	**ION**	**Operational**
Spain	UARX	Ossie	In development
United Kingdom	Lunasa	VIA	In development
United Kingdom	Skyrora	Space tug	In development
United Kingdom	SmallSpark	S4-SLV OTV	In development

Table 1: List of European OSAM companies

The market leader is the Italian company D-Orbit, which was founded in 2011 and launched its ION Satellite Carrier OTV for the first time in September 2020 on board of a Vega rocket. Since then, **D-Orbit launched 10 missions**, mostly on SpaceX's Falcon 9 rocket, to carry satellites to their distinct final orbital destinations, conduct orbital demonstrations, or carry third party payloads.[23] Yet, the ION Satellite Carrier is the only OTV that is operational in Europe. In 2023 alone, D-Orbit launched its ION Satellite Carrier five times on a Falcon 9 rocket. Other European systems are still in development. **These companies often see Last Mile Delivery as a springboard to develop other capabilities, including servicing. Some companies are also integrating capture mechanisms to their OTV prototypes to provide other OSAM.**

The market for OTVs may be considered as increasingly commercially established as an increasing number of missions takes place each year. However, the market remains volatile as most customers of OTVs are New Space start-ups, with some fears existing as to the financial state and shifting business models of some companies currently generating this demand.[24] In addition, the service only concerns a very specific type of satellite, which are the ones that are not capable to autonomously reach their orbit.

[22] The spacevan is scheduled to be launched on board a Falcon 9 rideshare mission in October 2023 in order to debut its mobility service. Exotrail to debut its SpaceVanTM in-space mobility service on October 2023 spacex falcon 9 mission (2022) Exotrail. Available at: https://www.exotrail.com/blog/exotrail-to-debut-its-spacevan-tm-in-space-mobility-service-on-october-2023-spacex-falcon-9-mission# (Accessed: 14 September 2023).
[23] *ION-SCV 002, ..., 011* : *Gunter's Space Page*. Available at: https://space.skyrocket.de/doc_sdat/ion-scv-2.htm (Accessed: 07 September 2023).
[24] Interview conducted by ESPI on August 10th, 2023.

The rationale for contracting such services is to reduce the time from launch to operations, allowing the satellite to generate revenues or demonstrate a technology more rapidly. OTVs are currently interesting for satellite operators due to lower launching costs, which render the combination of launch services with an OTV:

- (A) cheaper than launch services without OTVs as it will take less time for the satellite to reach its destination and generate revenues; and
- (B) cheaper than using small or micro-launchers that promise to deliver satellites to their final orbital destinations.

OTVs are generally cheaper since they are usually launched as part of rideshare missions, which are often less costly. In addition, OTVs ensure flexibility for the customer as it does not need to wait for a launcher that goes into the vicinity of its target orbital destination as the OTV will take care of the in-space transportation.

Exploring scenarios on the future of the OTV market

It remains to be seen how the OTV market will evolve in the near future.

OTVs are arguably only profitable if launch prices are rather low, frequent, and, more importantly, as long as space transportation companies allow OTV companies on their launches. Micro-launchers might become the main competitors of OTVs. Yet, it is more likely for large launch providers to become cheaper than micro-launchers becoming less costly.

Moreover, if SpaceX was to develop its own OTV or choose an exclusive U.S.-based OTV company as the sole OTV allowed on its launches, it would have a disruptive impact on the OTV market, notably for European actors. Space transportation companies such as SpaceX currently allow the OTV market to exist. This potential point of failure should be looked at in a context in which Europe does not have a launcher as Ariane 5 is discontinued and Ariane 6 is not yet operational.

However, this point should be nuanced as the current situation does not seem conducive to this kind of behaviour.[25] In addition, the OTV market will likely continue to develop and find its way onto European launchers, especially as barring entry of OTVs where the possibility exists or granting exclusivity, might be considered to have anti-competitive effects and fall under legal scrutiny.

3.2.2 Emerging demand for active debris removal

Another component of OSAM that has been highlighted in the past years is Active Debris Removal, in particular due to demonstration missions such as the one performed by Astroscale in 2021-2022 (ELSA-d) or the signature of contracts (e.g., between Clearspace and ESA).

The growing interest for this technology is particularly visible in Europe, where numerous countries are investing in the development and deployment of OSAM capabilities in the next three to five years. **This is reflected in States posing as anchor customers for first demonstration missions, which enable private companies to develop capabilities, get a first customer, and prove their business case to the space sector so that they can establish themselves on the market.**

Indeed, the Swiss start-up Clearspace received a service contract from ESA to perform an Active Debris Removal mission by 2025, for a price of €86 million. The mission is intended to remove the

[25] Interview conducted by ESPI on August, 10th, 2023.

upper part of a spent Vega launcher's Secondary Payload Adapter.[26] This is the first time that a contract was signed to remove an actual piece of debris in orbit, and the mission is expected to be the first to reach this achievement.

At the national level, the relevance of ADR for the future of space activities has also been recognised. Following successful demonstrations of its magnetic-capture technology, the UK government contracted Astroscale (a Japan-based company with an office in the UK) to launch a national mission that will remove two defunct UK satellites from LEO by 2026.[27] The mission, called COSMIC (Cleaning Outer Space Mission through Innovative Capture), will nonetheless make use of a robotic arm rather than magnetic capture to remove the spacecraft. COSMIC aims to directly contribute to implementing one of the strategic objectives of the UK space policy. UKSA also awarded a £2.2 million contract to a consortium led by Clearspace to prepare a preliminary design for the CLEAR mission, which aims at removing at least two non-functional UK spacecraft from LEO.[28]

In France, public institutions have teamed up with private companies on ADR projects. For instance, CNES awarded a contract to Dark, a start-up developing an air-launched rocket (Interceptor) with the objective to, among others, responsively capture a piece of space debris when the risk of collision is excessive. The contract aims at conducting a simulation of an emergency space debris interception.[29] Astroscale also opened a subsidiary in France and was awarded a contract from CNES to conduct a study for the active removal of a French debris.[30]

In addition, the Swedish Space Corporation (SSC) signed a memorandum of understanding with Redwire Space and Bradford Space to develop ADR technology, with the aim of defining and executing commercial ADR in the next few years.[31] A spokesperson of the Swedish National Space Agency noted that this reflects efforts by the Swedish government to stimulate other countries to follow and promote the objectives of the UN Long Term Sustainability Guidelines by actively investing in debris clean-up.

Despite this notable progress, **the actual size of the ADR market seems to remain limited and unknown, and satellite operators may arguably still prefer to install a passive system on their spacecraft to accelerate the deorbiting process rather than paying for a mission to grab it after end-of-life.** This may negatively affect the development of the ADR market in the short term.[32]

Overall, the ADR market seems to be primarily pushed by public contracts for demonstrations missions. Most of the companies active in the field seem to rely extensively on these contracts, which underlines the nascent nature of the market.

[26] *ESA purchases world-first debris removal mission from start-up (2020) ESA*. Available at: https://t.ly/c1MwH (Accessed: 19 May 2023).
[27] Robyn (2023) *Astroscale on course for first UK national mission to remove Space Debris*, *Astroscale*. Available at: https://t.ly/8DYa0 (Accessed: 12 June 2023).
[28] *ClearSpace secures a major UK contract to help clean up space* (2022) *ClearSpace*. Available at: https://clearspace.today/clearspace-secures-a-major-uk-contract-to-help-clean-up-space/ (Accessed: 12 June 2023).
[29] Parsonson, A. (2023) *CNES awards contract to dark for Space Debris Interceptor Simulation*, *European Spaceflight*. Available at: https://t.ly/049yX (Accessed: 27 June 2023).
[30] *Astroscale expands operations to France and secures contract with CNES* (2023) *Astroscale*. Available at: https://t.ly/onI_5 (Accessed: 27 June 2023).
[31] *Redwire signs MoU with Bradford space and Swedish Space Corporation to jointly develop commercial orbital debris removal service* (2022) *Redwire Space*. Available at: https://t.ly/zqV5f (Accessed: 26 June 2023).
[32] Parsonson, A. (2023) *A look at European OTVs*,. Available at: https://europeanspaceflight.substack.com/p/a-look-at-european-otvs (Accessed: 31 May 2023).

Who is incentivised to generate demand for a thriving ADR market?

One aspect which shows the dichotomy between the policy push for ADR and the likely current absence of a business case is the relative disagreement in the space community about the viability of such a market. Consulted stakeholders from the space industry had various perceptions of these services.

On the one hand, some consider that ADR is not commercially viable and that the business case does not exist. Thus, they believe it is rather irrational to develop ADR first among all OSAM applications**.** They advocated for first developing other types of services for which the business case was already proven such as life extension as there would be a better chance that the public money poured into this kind of capability development and market creation will succeed. They also considered that ADR is unlikely to become a private-to-private market and that States are likely expected to remain the sole customers of such services. Some advocated for Europe to focus on developing and selling technologies for which there is already a market and for which export is an option. They also seemed to consider that spending millions to retrieve one piece of debris only has a marginal impact on the issue of space debris. Comparatively, some even equalled such missions as removing two pieces of plastics from the ocean to fight the issue of marine plastic pollution.[33] Some were more moderate and acknowledged the criticality of the issue of space debris and the importance to address it at both the political and industrial level but considered that it would not necessarily be solved by the development of a commercial ADR market. Deorbiting thrusters at the end of life was seen as easier and more financially accessible and viable for operators.[34]

Others consider that it is highly relevant to take advantage of the policy push for space sustainability to develop ADR first and then other services. The enabling technologies of ADR are highly similar to those of other types of OSAM and there is therefore a great momentum to start with the development of capabilities considering the willingness of States to provide funding for ADR and space sustainability.

This is one of the approaches undertaken by the U.S. Space Force's Orbital Prime initiative, which is threefold:

- Unlocking OSAM markets through the development of an ADR use case in partnership with private companies, universities, governmental agencies, and international partners.
- Accelerating the development of key enabling technologies for ADR and OSAM by focusing on:
  - On-orbit object approach capabilities such as RPO technologies, inspection, characterisation, pose estimation, advanced manoeuvre, or propulsion.
  - On-orbit object acquisition capabilities such as capture mechanisms, control algorithms, etc.
  - On-orbit servicing with the development of end-of-life servicing, deorbiting, and life extension
- Demonstrating ADR with commercial and international partners and establishing international best practices and norms along the way that fit into the U.S. policy objectives.[35]

---

[33] Interview conducted by ESPI on August 4th, 2023.
[34] Interview conducted by EPSI on August 10th, 2023.
[35] *Orbital prime: Foundation for space logistics - Spacewerx*. Available at: https://spacewerx.us/wp-content/uploads/Orbital-Prime-Web-Deck-1.pdf (Accessed: 29 August 2023).

3.2.3 Refuelling: the reciprocal creation dilemma

According to Quilty Analytics, 85% of satellites are discarded only due to the depletion of fuel. They usually present no other technical issues preventing them from continuing operations, which would make a clear business case for on-orbit refuelling. Similarly, automotives or motorcycles on Earth, which are running out of fuel are not being scrapped but refuelled.[36]

While the MEV missions demonstrated a business case for on-orbit servicing on satellites that are not designed to be serviced, on-orbit refuelling is one of the on-orbit services that still appear to face the reciprocal creation dilemma, or in other words a “chicken and the egg” issue.

Figure 6: How to create the refuelling market?

On the one hand, no operator is contracting refuelling services because there is no way to refuel satellites in orbit. Refuelling requires a docking interface, which is not integrated by older satellites that could currently benefit from these services. On the other hand, satellites that have been in orbit for years are not equipped with refuelling and docking interfaces as no refuelling services existed at the time of their manufacturing.

Yet, there seems to be a nascent, although marginal, commercial interest for this market, in particular in the U.S., with the development of interfaces for refuelling and the signatures of contracts for new satellites that will be equipped with these interfaces; and with the development of concepts such as “gas stations in orbit”, which are looking to solve the “chicken and the egg” issue and foster the creation of the refuelling market by placing fuel depot in orbit (e.g., Orbit Fab).

Another aspect, which affects the development of this market may be the fluctuation of the costs of raw materials such as xenon propellant, making it more difficult to fix a price and attract potential customers.

3.2.4 Early stages of commercial development for other services

Despite initial experiments and interests from some public actors, most OSAM are not yet commercially viable and are only at a stage of early development. Most commercial projects announced by start-ups or established companies are mostly at the stage of concepts or under development. Some of them are scheduled for first demonstrations on orbit in the next five years.

According to Satellite Catapult, the Active Debris Removal market is developing itself and is expected to become commercially mature by 2030 along with end-of-life services, asset

[36] Interview conducted by ESPI on August 11th, 2023.

relocation, and inspection. Satellite Catapult considers that refuelling, repair, and upgrade are more uncertain markets and may be commercially emerging by 2030.[37]

The role of State actors that act as first customer may provide an indication of the interest of some countries to develop such capabilities as well as to make some companies emerge in this market segment so that they can provide commercial services to both State actors and other companies in the future. This is something that is noticeable lately in Europe for on-orbit demonstration missions. For instance, in 2023, the Italian Space Agency (ASI) awarded a €235 million contract to Thales Alenia Space to design, develop, and qualify an IOS mission, which will demonstrate in-orbit refuelling, component repair and replacement, orbital transfer, and atmospheric re-entry through the use of a robotic arm developed by Leonardo, SAB Aerospace, the Italian National Institute for Nuclear Physics (INFN) and the italian Institute of Technology (IIT). The project is expected to be launched in 2026.[38]

Similarly, the European Union is awarding many contracts for the development of technologies, demonstrations, and demonstration missions in the field of OSAM as part of the Horizon Europe programme in order to support initial R&D efforts. However, these projects rarely reach the stage of commercially viable products as it is not their primary objectives.

3.3 Market value and market forecasts

In this context, **several companies and institutions are attempting to conduct market assessments and market forecasts.** However, these are rarely comparable as they use different methodologies and definitions, which leads to great disparity between each study. Market forecasts and market analyses should be written and acknowledged with caution.

For instance, the fifth annual Northern Sky Research Report on OSAM recently predicted that the sector would generate $14.3 billion by 2031, with life-extension services accounting for $4.7 billion.[39] NSR's methodology includes in-orbit, space situational awareness, and active debris removal services.

Alternatively, in 2023, Euroconsult released a more conservative analysis by defining three revenues forecast scenarios of the OSAM market, with one assessment considered as optimistic, which would account for $5 billion; one baseline scenario accounting for $4 billion, and one conservative scenario accounting for $3 billion.[40] Euroconsult's 2022 market assessment considered the OSAM market to generate about $4.4 billion by 2031. Euroconsult's methodology includes launchers, Last Mile Logistics (LML), Life Extension, Active Debris Removal (ADR), On-orbit Assembly and Manufacturing (OOAM) and Space Situational Awareness (SSA) in its methodology. Yet, SSA, which is more a key enabling technologies for all OSAM rather than an on-orbit service

[37] Martin, S. (2021) *Satellite Applications Catapult annual report 2021*, *Satellite Applications Catapult*. Available at: https://sa.catapult.org.uk/news/satellite-applications-catapult-annual-report-2021/ (Accessed: 01 June 2023).

[38] *Thales Alenia Space and consortium is enlisted by Italian Space Agency for €235 for In-Orbit Servicing demonstration mission* (2023) *SatNews*. Available at: https://news.satnews.com/2023/05/17/thales-alenia-space-and-consortium-is-enlisted-by-italian-space-agency-for-e235-for-in-orbit-servicing-demonstration-mission (Accessed: 09 August 2023).

[39] Halpin, S. (2022) *NSR's in-orbit services report projects $14.3 billion in revenues as Non-Geo constellations grow demand*, *NSR*. Available at: https://www.nsr.com/nsrs-in-orbit-services-report-projects-14-3-billion-in-revenues-as-non-geo-constellations-grow-demand/ (Accessed: 03 August 2023).

[40] *Growing flexibility and sustainability requirements in space to drive space logistics revenues to $4B over 2023 to 2032*, (2023) *Euroconsult*. Available at: https://www.euroconsult-ec.com/press-release/growing-flexibility-and-sustainability-requirements-in-space-to-drive-space-logistics-revenues-to-4b-over-2023-to-2032/ (Accessed: 16 June 2023).

per se, is estimated as the largest market segment, accounting for $1.4 billion in the coming decade. The market for Last Mile Delivery is predicted to remain ten times smaller than the SSA market.[41]

On a similar note, Research and Markets estimates that the global OSAM market is currently valued at $2.4 billion and will generate $5.1 billion by 2030, with North American customers accounting for the largest share of this market.[42] Another study from Research and Markets considers that the OSAM market will be valued at $6.99 billion in 2030.[43]

While these reports differ in their methodology and optimism for fertile OSAM markets, they all agree that market maturity has not yet been attained, and that governments will have to continue to facilitate market growth by funding research and demonstrations, as well as acting as an anchor client.

3.4 Private investment in European on-orbit servicing start-ups

The assessment of investment statistics provided in this report is based on information collected by ESPI in a proprietary database. The ESPI Space Investment Database includes all deals from 2014-2023. The dataset includes publicly available data on announced operations and deals and information is collected by screening a high number of sources including investment firms', incubators and accelerators' portfolios, articles and specialised news outlets or specialised sources such as CrunchBase and Pitchbook. Furthermore, due diligence was made to appropriately filter all press and governmental releases as well as events. Cross-checking was systematically performed.

State of the European On-orbit servicing start-ups

Since 2014, European On-orbit servicing start-ups have raised €206 million over a total of 42 deals. A total of 15 companies have raised capital with 12 of these companies raising capital more than once.

These numbers provide a relatively conservative estimate of the total investment volume, as they exclude deals involving ventures that do not meet the ESPI definition of *"European space start-ups"* and only rely on publicly revealed investments.[44]

Furthermore, the database does not include companies that have not raised any funds on record. One example of this is the Berlin-based rideshare and last-mile delivery company Exolaunch. Based on public information, Exolaunch has not raised any capital on private markets. As such it is likely to have grown using funding from founders and rapidly became profitable or decided not to disclose its investors publicly.

[41] *Space Logistics markets ready to grow as on-orbit supplier services materialize* (2022) *Euroconsult*. Available at: https://www.euroconsult-ec.com/press-release/space-logistics-markets-ready-to-grow-as-on-orbit-supplier-services-materialize/ (Accessed: 16 June 2023).
[42] *On-orbit satellite servicing market by service (active debris removal (ADR) and Orbit Adjustment, robotic servicing, refuelling, assembly), end user (military & government, commercial), orbit, type, and region - global forecast to 2030* (2023) *Research and Markets*. Available at: https://www.researchandmarkets.com/reports/5807541/on-orbit-satellite-servicing-market-service (Accessed: 16 June 2023).
[43] *Global on-orbit satellite servicing market size, trends, and growth opportunity, by service type, by application, by orbit, by region, cumulative impact analysis, and forecast to 2030* (2023) *Research and Markets*. Available at: https://www.researchandmarkets.com/reports/5849709/global-on-orbit-satellite-servicing-market-size#src-pos-2 (Accessed: 29 July 2023).
[44] The ESPI Space Investment Database considers start-ups as "a company younger than 10 years, whose business tend to feature innovative concepts and models and who has not yet reached business maturity (defined according to the business stage: Public Offering, annual turnover, or number of employees). For the purpose of this study and given the usually longer timeframe required in the space sector to reach business maturity (as compared to other industrial sectors), ESPI included companies founded after the year 2000".

Notwithstanding the limitations highlighted above, **the top four deals regarding European On-Orbit operations start-ups represent about 60% of the total raised by this category to date.** Furthermore, €170 million (over 80% of the total) has been raised over the past four years.

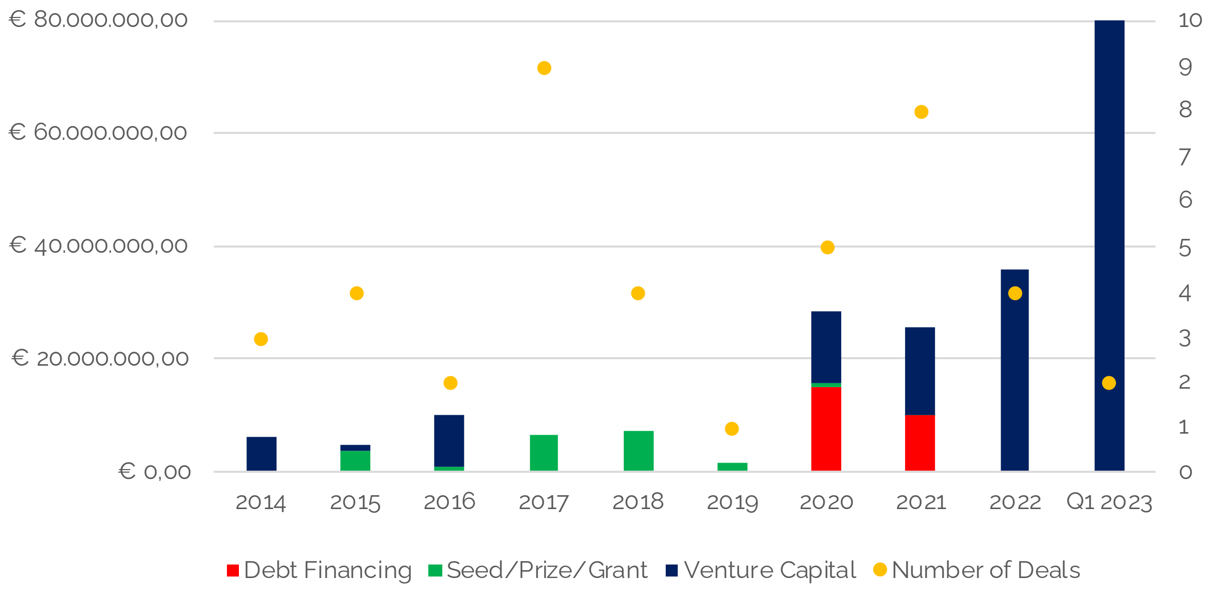

Figure 7: Total investment and deals in European On-Orbit servicing start-ups

Investment has been widespread across Europe with the largest companies in the sector being:

- **Exotrail (France):** An end-to-end space mobility operator based out of Massy in France and has raised approximately €70 million to date.
- **Morpheus Space (Germany):** A producer of modular and electric and propulsion system for the small satellite industry and which has a range of applications for on-orbit solutions. Morpheus Space is based in Germany and has raised approximately €29 million to date.
- **ClearSpace (Switzerland):** the ADR company, ClearSpace is based out of Switzerland and has raised approximately €30 million to date.
- **D-Orbit (Italy):** A company focused on last mile delivery services, space logistics and space waste management services. D-Orbit is headquartered in Italy and has raised approximately €21 million to date.

Therefore, it confirms the trend in the OOS market that the most active segment is space logistics, followed by Active Debris Removal. Other types of services do not seem to have reached the stage where funding beyond R&D grants would materialise.

Overall, it seems that start-ups that have successfully secured public contracts are the ones also attracting the most significant capital investments, suggesting that a first customer or an anchor customer likely brings a perception of sustainability and profitability for the business model and systems of these companies.

On-orbit servicing companies within the European New Space ecosystem

It is interesting and important to compare European OOS companies within the larger European New Space ecosystem.

On-orbit servicing start-ups have raised €206 million since 2014, which represents 7% of the total raised by space start-ups in Europe. The OSS ecosystem has been following a very similar path to the overall sector.

Indeed, from 2014 to 2019 the ecosystem saw a relatively large number of deals over a relatively low amount of capital invested. This is because most of the allocated capital came under the form of Seeds/Prizes/Grants. As such, and in line with these types of investments, they were often used to test products and highlight proof of concepts.

Since 2020, and in line with trends shown by the entire sector, the type of investment rapidly shifted towards Venture Capital and saw the total volume of investment change with a total invested of €170 million in just under four years (only Q1 2023 included), this represents 82% of the total raised by on-Orbit services since 2014.

Combining figures 7 and 8, it can be underlined that the dynamics of investment are very similar, highlighting a common growth pattern. Therefore, the on-orbit servicing market and its capacity to gather funding is rather representative of the rest of the space sector.

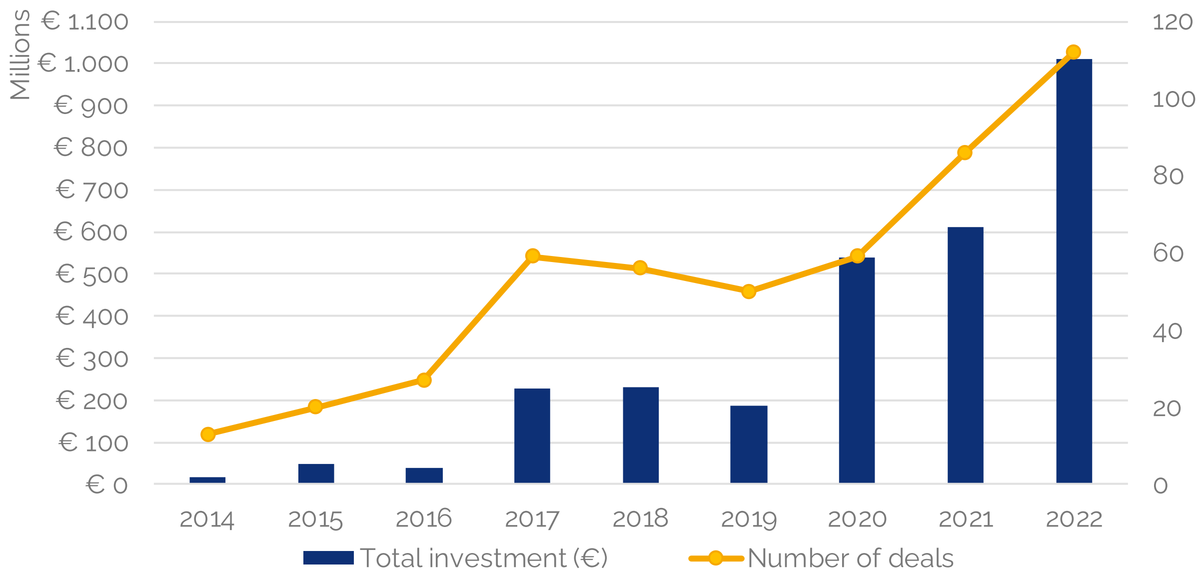

Figure 8: Total investment and number of deals in European space start-ups

3.5 Factors influencing the emergence of viable OSAM markets

In this context, several factors are influencing, either positively or negatively, the emergence of OSAM as a truly viable commercial market such as but not limited to:

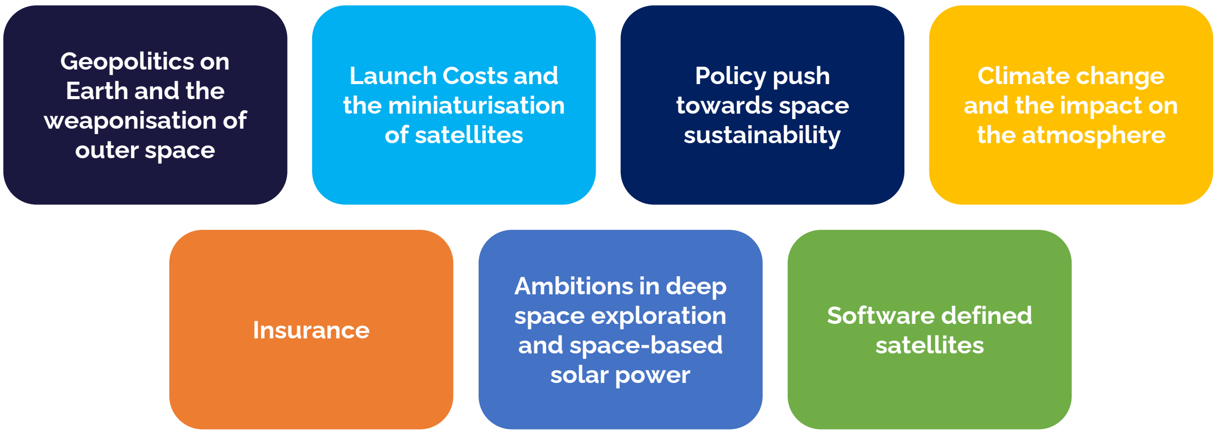

Figure 9: Factors influencing the OSAM market

Geopolitics on Earth and weaponization of outer space: a main driver in the U.S.

A driver for the development of OSAM capabilities, which has increasingly emerged over the past four years is the intensification of geopolitical tensions on Earth between major powers as well as the reflection of these tensions in outer space, with an emerging weaponization of the orbital environment.

Indeed, in the past decade, irresponsible and hostile behaviours such as ASAT tests, unwelcomed approaches, eavesdropping, electronic and cyber warfare, as well as the development of counterspace capabilities such as directed energy lasers, space-to-space orbital capabilities, etc. have increased. Some States also perceive the development of some OSAM capabilities as a potential military threat that can threaten their satellites (e.g., using a robotic arm to destroy a satellite[45], using on-orbit inspection spacecraft to gather intelligence on foreign satellites, etc.).

In order to protect themselves against such threats, some Nation-States have gradually adapted their space governance and defence policy framework, adopting an *"active defence"* posture and reserving the right to counterattack in case one of their satellites is threatened or attacked. **This defence posture mostly appears to come from the United States and creates ripple effects, hence stimulating the OSAM market and increasing the number of contracts to OSAM companies for the development of new capabilities.** However, in Europe, this posture is also present in France, which adopted an *"active defence"* posture[46] in its 2019 Space Defence Strategy. It is not yet clear whether this posture really stimulates the industry in France. One example can be highlighted: the French start-up Hemeria is contributing to the national space programme YODA, which aims at developing laser-armed patrolling satellites that could be placed around French military satellites to defend them.[47]

In the United States, the U.S. Congress has allocated an additional US$30 million to the Space Force budget for commercial logistics and in-space services. The U.S. Space Force is increasingly looking to develop refuelling and inspection capabilities.[48] Arguably, this makes the Department of Defence the only truly possible anchor customer for OSAM companies in the United States at the moment, which explains why many OSAM companies are shifting their business models towards defence markets. This situation can be explained by delays in the Orbits Act, which is expected to enable national civil agencies such as NASA and NOAA to procure on-orbit servicing from private companies.[49] This Senate proposal is still pending and there is no indication what level of funds will be available. **Perhaps, this makes the U.S. market more uncertain than the European one for some OSAM service providers, which want to work in areas such as ADR. Based on the types of services they can provide, different sets of OSAM service providers may find either the U.S. or European markets more attractive for the near future. It is uncertain at what point the two markets will overlap but it may not be for a few more years.**

---

[45] US Space Policy Review, US Department of Defense, Septembre 2023 : "The PRC has launched multiple experimental satellites to research space maintenance and debris cleanup with advanced capabilities, such as robotic arm technologies that could be used for grappling other satellites."

[46] The so-called "active defense" is seen "as part of a self-defense strategy, to protect satellites contributing to our interests, deter any aggression and be able, if necessary, to defend our interests in accordance with international law, in particular self-defense (https://www.defense.gouv.fr/dgris/approches-thematiques/champs-confrontationnels/espace-defense.)

[47] *Tour of French new space 2023: Yoda & Hemeria* (2023) *Satellite Observation*. Available at: https://satelliteobservation.net/2023/07/11/tour-of-french-new-space-2023-yoda-hemeria/ (Accessed: 24 August 2023).

[48] Holt, Lt.Col.B. (2022) *SpaceWERX awards 124 orbital prime contracts*, *AFRL*. Available at: https://www.afrl.af.mil/News/Article-Display/Article/3210527/spacewerx-awards-124-orbital-prime-contracts/ (Accessed: 01 June 2023).

[49] *Feinstein, Hickenlooper, colleagues introduce bill to clear space junk, protect space operations* (2023) *United States Senator for California*. Available at: https://www.feinstein.senate.gov/public/index.cfm/press-releases?id=8238CF91-AF17-4AD9-B0E0-56DA6E71DBC9 (Accessed: 06 June 2023).

Low launch costs and the miniaturisation of satellites as a facilitator for OSAM

Another driver for OSAM is the strong decrease in launch costs that has occurred in the past decade thanks to the entry of new competitors on the market and the emergence of new technologies, in particular reusability, which by increasing the launch rate of SpaceX, drove the prices down for the whole sector. This trend is complemented by the reduction of the average size and mass of the satellites launched.[50] These two trends have led to an increase in the number of launches per year (multiplied by two between 2017 and 2022) but also to new practices such as rideshare launches (e.g., Transporter missions of SpaceX that launch 100+ satellites per flight), which give the opportunity to an increasing number of actors to access space. In addition, small satellites (below 500 kg) have accounted for a growing share of the payloads sent to orbit, from 73.7% in 2017 to 95.3% in 2022, in large part due to the emergence of connectivity constellations such as Starlink and OneWeb in recent years. Yet, this situation may evolve as some operators are gradually sizing up their new systems (e.g., Starlink V2 to go way beyond 500kg).

OSAM activities could benefit from this context, as launching a platform weighing a few hundred kilogrammes and able to stay in orbit to serve several customers (whatever its missions: refuelling, ADR, last-mile delivery, etc.) is not as expensive as it used to be. In addition, reusability allows to significantly increase the rate of launches, thus offering more opportunities for the deployment of OSAM systems. An activity that could particularly take advantage of the aforementioned trends is last-mile delivery. Indeed, more and more small satellites are being launched on rideshare launches, and they could benefit from a service allowing them to reach their precise orbit without having to book a dedicated launch on a traditional rocket or a micro-launcher. For instance, the leader of this market, the Italian company D-Orbit, launched 11 ION spacecraft between 2017 and June 2023; out of these 11 spacecrafts, 9 were launched onboard SpaceX's Transporter missions. The same is true for another company active in the sector, Spaceflight Inc., which launched almost all its Sherpa tugs on the same SpaceX's missions.

However, the decrease of launch costs may also be perceived as a risk to these activities, especially for life-extension services conducted in GEO. Indeed, it could be argued that an operator has only a limited interest in extending the life of a satellite which is outdated, while it could launch an updated spacecraft able to improve the quality of the provided services for a reasonable price. Yet, it is worth noting that the only examples of OSAM that have taken place so far performed life-extension of GEO satellites. Therefore, some arguments must still play in favour of this latter service, in particular in GEO. Indeed, satellites located on this orbit are bigger and more difficult to de-orbit; consequently, they may become the main market for life extension, compared to LEO spacecraft, for which de-orbiting and replacement might be privileged solutions.

Sustainability: a main driver for public contracts in Europe

OSAM activities are also supported by growing global concerns towards maintaining the sustainability of the outer space environment. Indeed, there is a growing consensus that services such as ADR and in-orbit servicing will be useful, alongside sustainable design and evolved operational practices, if humans are to continue using Earth's most profitable orbits. In this context, some studies have found that, without ADR, the costs of operating in LEO could become prohibitively expensive for most space actors as early as 2045 due to the occurrence of the so-called Kessler Syndrome.[51] In response, numerous new policies are emerging that put space

[50] From approx. 800 kg in 2017 to 400 kg in 2022 according to data from the ESPI Launch Database.
[51] Rao, A. and Rondina, G. (2022) *Open access to orbit and runaway space debris growth*. Available at: https://akhilrao.github.io/assets/working_papers/Cost_in_Space.pdf (Accessed: 04 August 2023).

sustainability at the heart of space technology development.[52] These policies are partly implemented by the several contracts that European states have signed with private companies for preliminary studies or the conduct of operational ADR missions (see section above).

The multiplication of these awards sends a signal to the industry that European authorities see OSAM (and, in particular, ADR) as a critical technology for the immediate future. Moreover, the EU and individual governments are willing to serve as sources of income to emerging OSAM companies and to support them as both investor and customer. Whilst it is unclear how many OSAM companies such an ecosystem can sustain; it does position the region as an attractive market for sustainability-related services like ADR.

Climate change and its impact on the atmosphere and space operations

Climate change is decreasing progressively the frictional force that satellites are subject to in orbit, which may have an impact on the servicing market.

According to CNES Engineer Simon Tardivel, under normal conditions, the frictional force is caused by the upper atmosphere, which is proportional to the density of the atmosphere. This leads satellites in the lower altitudes of LEO to experience more frictional force and therefore see their altitude decrease more rapidly than expected. In this regard, satellites must compensate this decrease in altitude with manoeuvres, which requires more fuel. At the same time, it makes deorbiting at the end of life easier as most satellites in LEO end up being naturally dragged back into the atmosphere due to this phenomenon without significant manoeuvres.[53]

However, climate change is changing this paradigm. Indeed, climate change and particularly **concentrations of greenhouse gases are leading the middle and upper atmosphere to cool down, which leads to a shrinking of the upper atmosphere and a decline in atmosphere density, thereby reducing the frictional force that satellites are subject to and delaying their natural re-entry into the atmosphere.** Current studies suggest that frictional force may decrease by 30% by 2100.[54] A 30% decrease in thermosphere density at 400 km would also extend orbital lifetimes by 30%.[55] This phenomenon may also marginally increase with the increased number of launches to orbit.

As a result, this physical phenomenon may impact the orbital environment and the demand for OSAM. As debris will stay in orbit for a longer period and will take more time to re-enter into the atmosphere, the demand for active debris removal may increase, especially if it leads to more collisions in-between debris. At the same time, if satellites need less propellant as they do not need to conduct as many manoeuvres to stay in orbit and maintain their altitude, this amount of propellant can also be used to compensate the reduction of friction and conduct the re-entry, which

---

52 *The king unveils the Astra Carta Seal at a space sustainability reception at Buckingham Palace (2023) The Royal Family. Available at: https://www.royal.uk/news-and-activity/2023-06-28/the-king-unveils-the-astra-carta-seal-at-a-space-sustainability (Accessed: 02 July 2023).*
; *ESA Sustainability principles* (2023) *ESA*. Available at: https://www.esa.int/About_Us/Responsibility_Sustainability/ESA_Sustainability_Principles (Accessed: 04 August 2023).
; *Space defence strategy (2019) The French Ministry for the Armed Forces. Available at: https://www.gouvernement.fr/sites/default/files/locale/piece-jointe/2020/08/france_-_space_defence_strategy_2019.pdf (Accessed: 04 July 2023).*

53 Tardivel, S. (2023) *Le Saviez-vous ? Le Changement Climatique diminue progressivement la force de frottement ressenti par nos satellites en orbite basse.et ce n'est pas forcément une bonne nouvelle*. Available at: https://twitter.com/simon_tardivel/status/1681360300899987458 (Accessed: 05 September 2023).

54 Cnossen, I. (2022) *A realistic projection of climate change in the upper atmosphere into the 21st Century*, *Advancing Earth and Space Sciences*. Available at: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022GL100693 (Accessed: 05 September 2023).

55 Brown, M.K. *et al.* (2021) *Future decreases in thermospheric neutral density in Low Earth Orbit due to Carbon Dioxide Emissions*, *Advancing Earth and Space Sciences*. Available at: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021JD034589 (Accessed: 05 September 2023).

overall lead to requiring less propellant for the entire mission. **It remains to be investigated if and how this phenomenon may affect the demand for refuelling, station-keeping, altitude control, and relocation services.** It also remains to be seen whether this phenomenon will have a significant or marginal impact and how technological innovation and future trends in the space sector will alleviate or increase it.

Insurance: both a potential driver and barrier for the OSAM Market

One area that still creates a great deal of uncertainty among a would-be OSAM market is the question of insurance, particularly for any OSAM activities that involve close approaches or even contact between satellites. Today**, insurance is a mean by which actors are able to manage risk when dealing with space activities.** Policies for space objects typically cover first-party (loss or failure of the asset, replacement cost, business interruption, etc.) or third-party (damage to another) liability. For insurers, the ideal activity is one that has a high-frequency rate and low severity. In other words, insurers prefer activities that successfully take place often but, on the off chance something does go wrong, the losses incurred are minimal. Unfortunately, **OSAM is still a low-frequency activity that can have high severity of losses if something goes wrong, particularly for on-orbit servicing involving contacts and docking.**

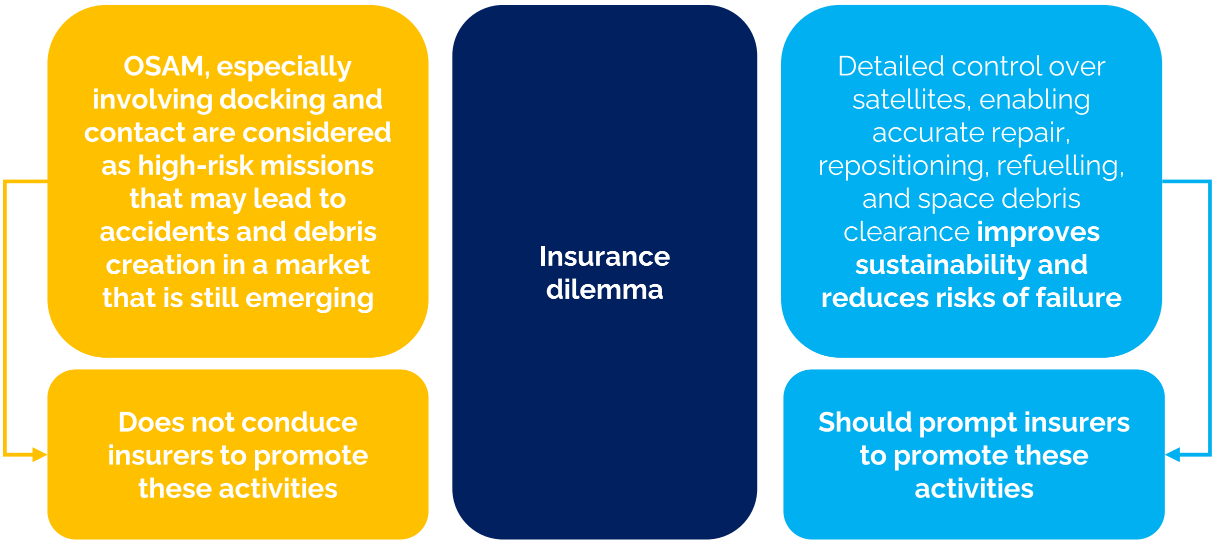

Figure 10: Insurance dilemma for OSAM missions

By allowing for detailed control over satellites, enabling accurate repair, repositioning, and space debris clearance, the risk of catastrophic failures or collisions can be minimised, which may potentially lead to reduced insurance costs, making such services more affordable for satellite operators.[56] This may have the potential of creating a virtuous circle to foster the creation of the OSAM market.

The responsibility for additional damages and third-party liability in the OSAM market remains a complex issue, requiring negotiation between providers and their clients.[57] While government agencies and major satellite companies may have the financial resources to assume all associated

[56] Malinowska, K. (2020). Risk management and the insurance of on-orbit servicing. The insurance industry as a driver of risky space innovation, p. 4.
[57] Malinowska, K. (2020) *Risk Management and Insurance of On-Orbit Servicing*, *The SAO/NASA Astrophysics Data System*. Available at: https://ui.adsabs.harvard.edu/abs/2020osn.book...13M/abstract (Accessed: 08 August 2023); Reesman, R. (2018) *Assurance through insurance and on-orbit servicing*, *Center for Space Policy and Strategy*. Available at: https://aerospace.org/sites/default/files/2018-05/OnOrbitServicing.pdf (Accessed: 08 August 2023).

risks, absorbing any potential liabilities, **this continues to pose a significant challenge for smaller OSAM companies with limited negotiating leverage**.

One of the critical elements shaping the OSAM market is the need for comprehensive and accurate data and other methods to better evaluate risks. Properly assessed, this data can lead to fair and reflective insurance policies (e.g., SSA). Also, concepts like Space Environment Capacity show significant promise in offering more precise evaluations and subsequently enhancing the insurance products on offer.[58] Lastly, initiatives like the Space Sustainability Rating can help reduce insurance premiums since missions with higher SSR scores can demonstrate reduced risks in terms of debris creation and potential collisions.[59]

Simultaneously, challenges are inherent in the OSAM market. Complex and previously unencountered risks associated with robotic handling and debris removal add to the difficulty in insurance underwriting, possibly leading to reluctance in providing coverage or demanding elevated premiums. Regulations concerning space debris mitigation and on-orbit activities further complicate matters, as aligning insurance offerings with various rules can be costly.

New and unproven technologies necessitate insurers to evaluate and quantify risks that may not be fully comprehended or mitigated. This challenge is compounded by a lack of precise and available Space Situational Awareness (SSA) data, making the risk assessment process even more complex. Different methodologies for on-orbit servicing and debris removal might lead to fragmentation in the market. Such diversity in approach can challenge insurers in standardising their products and consistently assessing risks across varying technologies and missions.

Software-Defined Satellites: competitors or drivers?

Another trend that is emerging in the space sector is software-defined satellites (SDS), which are fully reprogrammable satellites with digital payloads, enabling operators to remotely repurpose the satellite's mission while in orbit. Software-defined satellites can redirect and adjust beams, change frequency bands, coverage areas, power distribution, and mission architecture through software updates sent by operators. Fully reprogrammable satellites provide operators with the flexibility to adapt to changing demand and new market dynamics without the need to launch an entirely new satellite.

[58] Space environment capacity refers to the concept that orbital environments are a finite natural resource. It seeks to measure the proportion of this resource consumed by space missions and objects within specific orbital regions. This concept is particularly pertinent to certain orbital paths that may be approaching over-exploitation, akin to zones of significant interest to operators. The determination of space environment capacity involves three interconnected operational stages:
(1) Evaluating the current total capacity within the environment, distinguishing between utilised and unutilised capacities;
(2) Assessing the environmental impact of a specific mission; and
(3) Measuring the collective impact of all existing missions and objects in orbit on the environment.
For further information see European Space Policy Institute (2022), 'ESPI Report 82 - Space Environment Capacity - Full Report' available at: https://www.espi.or.at/wp-content/uploads/2022/06/ESPI-Report-82-Space-Environment-Capacity-Full-Report.pdf (Accessed: 12 September 2023).

[59] The Space Sustainability Rating (SSR) offers an innovative approach to promote responsible and sustainable space operations by rating missions based on their compatibility with sustainable orbital practices and potential impact on the space environment and other operators. Designed by a consortium involving global institutions, it is built on methodologies used in successful rating systems from other industries. The SSR considers various mission factors, including debris mitigation, collision avoidance, and adoption of international standards. Consequently, insurers may view missions with better SSR ratings as lower risks, which could lead to reduced insurance premiums for those operations, thereby incentivising space entities to prioritize sustainable practices; Rathnasabapathy, M. et al. (2020). 'Space Sustainability Rating: Designing a Composite Indicator to Incentivise Satellite Operators to Pursue Long-Term Sustainability of the Space Environment', in 71st International Astronautical Congress (IAC) – The CyberSpace Edition, 12-14 October. IAC-20-E9.1-A6.8.6, p. 1. Published by the IAF.

Figure 11: The impact of Software Defined Satellites on the OSAM market

In this context, the impact of such systems may indirectly impact the demand and the market for servicing missions, in particular on-orbit reconfiguration. Indeed, an operator would have one SDS that can be repurposed several times to perform different missions instead of launching several or having to contract on-orbit reconfiguration services to update its satellites' mission. However, this may only impact repurposing and to a certain extent recycling services. Indeed, SDS may still need to contract refuelling services or repair services if needed. It can even be underlined that SDS are highly expensive space systems, which would be costly to replace with new satellites. As a result, contracting repairing, refuelling, recharging, or station-keeping services to keep these systems operational for a longer period would then be potentially seen as profitable by operators.

Consulted industrial stakeholders underlined that both markets, the software defined satellites market and the servicing market, were not in competition and that SDS are unlikely to hinder the servicing market.[60]

Ambitions in deep space exploration, space-based solar power, and data centres in space

Finally, while OSAM is expected to be a market in itself, OSAM capabilities are also seen as key enabling technologies for other space missions. **OSAM can be an essential technological block for other long-term missions and markets.** This may influence the development and public funding given to capability development of such enabling technologies. This is particularly the case of space-based solar power and deep space exploration missions:

- **Space-based solar power**, which is the concept of harvesting solar energy in space through photovoltaic panels and distributing back to Earth to use as a renewable source of energy. For this to be feasible, very large solar panels would likely have to be deployed on a spacecraft to be able to transmit sufficient energy to Earth. In that regard, large solar panels would likely have to be assembled in orbit. While this is not an existing market yet, there is a rising interest in this capability in light of the goal to be carbon neutral by 2050. Lately, a significant number of space start-ups focusing on space-based solar power has emerged, in particular in the U.S. China, and in Europe.[61]
- **Deep space exploration**, whether it is on the Moon, Mars, or beyond, missions may require refuelling and in-orbit manufacturing capabilities. Indeed, the mass of a Mars/deep space mission will likely require significant fuel capability, hence suggesting the need to refuel the spacecraft during the mission in order to reduce significantly and optimise its initial mass. As one example, an MIT study suggests to mine, exploit, and manufacture propellant out of raw

[60] Interview conducted by ESPI on August 29th, 2023.
[61] *Space-Based Solar Power - Electricity from space* (2023) *Factories in Space*. Available at: https://www.factoriesinspace.com/space-solar-power (Accessed: 26 July 2023).; Frazer-Nash Consultancy (2022) Study on Cost-Benefit Analysis of Space-Based Solar Power (SBSP) Generation for Terrestrial Energy Needs, Final Report.

materials on the Moon to provide refuelling to spacecraft on their way to Mars.[62] Such ambitions may prompt further and/or faster development of refuelling, recycling, and in-orbit manufacturing capabilities, and therefore influence the market. Yet, it is worth noting the distinction between cryogenic refuelling, which aims to serve deep space and exploration missions (e.g., SpaceX and Starship) and is technically more complex and will take more time to emerge on the market due to low TRL levels; and storable propellant, which would refuel old satellites and make use of mostly attained technologies.

[62] *MIT proposes that we refuel on the Moon when traveling to Mars* (2015) *Futurism*. Available at: https://futurism.com/most-efficient-way-to-mars-is-a-moon-detour (Accessed: 26 July 2023).

4 GAP ANALYSIS: ASSESSING CURRENT POLICY, REGULATORY, AND CAPABILITIES DEVELOPMENT

This section will provide a gap analysis regarding the current policy, regulatory, and capability developments, which have taken place in the past five years. This gap analysis aims at providing an overview of the evolution of the perception and acknowledgment of OSAM at the policy level, the adaptation of legal instruments, as well as the development of capabilities. This section does not provide a historical analysis of accomplishments and capability developments and only investigates initiatives from 2018 to 2023.

4.1 Qualitative gap analysis: A Policy Analysis

The qualitative analysis first provides factsheets about European entities as well as selected spacefaring nations outside Europe. These factsheets then enable to provide a comparative assessment as well as a gap analysis regarding the policy, legal, and capability developments of OSAM in these selected countries.

4.1.1 Assessing European policy, regulatory, and capabilities developments

This section provides an overview of policy, regulatory, and capability developments in selected European countries as well as the European Space Agency and the European Union.

Factsheets of ESA and the EU as international organisations are provided first. Country factsheets of ESA and EU Member States are then presented in alphabetical order. ESA and/or EU Member States, which do not have a space policy and legal framework as well as countries for which no results or information regarding OSAM could be found are not included in the policy analysis.

European Space Agency

ESA has addressed OSAM over the past years, mostly from a technological development perspective. The Agency is working towards the development of OSAM through the Directorate of Operations and the Space Safety Programme Office as well as the Directorate of Technology, Engineering and Quality and the General Support Technology Programme (GSTP).

In 2021, when Josef Aschbacher became the new Executive Director of ESA, the Agency released **ESA Agenda 2025** to outline its main priorities for the next five years, namely: strengthening ESA-EU relations, boosting commercialisation for a green and digital Europe, develop space for safety and security, address critical programme challenges, and complete ESA transformation. With regards to OSAM, ESA Agenda 2025 is focusing primarily on space sustainability and ADR as it aims to develop *"European technological and commercial leadership in STM, debris mitigation and removal"* among other things.[63]

ESA's Technology Strategy aims to invert Europe's contribution to space debris by 2030 and plans to launch a new technology R&D initiative on in-orbit servicing and construction.[64] In line with this strategy, ESA awarded a €100 million contract to the Swiss start-up ClearSpace to contribute to the development and demonstrate the removal of an ESA-generated piece of debris, which is a Vega

[63] *ESA Agenda 2025* (2021) *ESA*. Available at: https://esamultimedia.esa.int/docs/ESA_Agenda_2025_final.pdf (Accessed: 13 April 2023).
[64] *ESA'S Technology Strategy* (2022) *ESA*. Available at: https://esamultimedia.esa.int/docs/technology/ESA_Technology_Strategy_Version_1_0.pdf (Accessed: 14 April 2023).

upper stage dating from a 2013 launch.[65] ESA's objective in awarding such a service contract aimed at contributing to the establishment of a market in Europe for OSAM by purchasing the first mission and contributing with technological capabilities through the Active Debris Removal/In-Orbit Servicing (ADRIOS) project.[66] This mission will likely be the first ADR mission conducted by a European actor.

ESA considers that *"in-orbit servicing and construction will help enable cheaper, expendable, serviceable and upgradeable space assets."*[67] The Technology Strategy underlines ESA's focus towards the development of ADR in the short term along with *"in-space manufacturing from raw materials."* Assembly, reconfiguration, reuse, and in-space manufacturing from recycled materials are planned to be developed in the mid-to-long term.[68]

By the **Ministerial Council of 2019**, ESA already agreed to award a contract to a commercial space company for the active debris removal of an ESA-owned object in LEO.[69] During the **ESA Ministerial Council in 2022**, ESA's Space Safety Programme has put more emphasis on space sustainability and put several propositions related to OSAM among its objectives such as (1) finalise and prepare to launch ESA's three first space safety missions among which ClearSpace-1 is OSAM-related; (2) develop innovative in-orbit servicing missions and technologies able to de-orbit, tug, repair and refuel; (3) develop de-orbiting kits to enable safe re-entry at the end of a mission's life; (4) develop software and systems for a 'Collision Risk Estimation and Automated Mitigation' capacity. By 2030, the Space Safety Programme aims to prepare the European industry for a zero-debris policy and a circular economy in space with the objective to support industry and foster sustainable spaceflight.[70]

ESA is also focusing on OSAM through the lens of Space Transportation, which covers end-to-end transportation. For the on-orbit part, ESA identified rendezvous, docking, automatic payload transfer, and refuelling as important aspects to tackle, in particular from the perspective of standardisation. To this end, ESA is working on the development and standardisation of interfaces for rendezvous, docking and refuelling with the industry. The objective is to develop a European standardised interface that ensures the independence of European space assets.[71] ESA is increasingly taking strategic autonomy into account by trying to develop a European interface so as not to have to use a U.S.-led standardised interface, which likely falls under the ITAR regulation. Yet, ESA is working with American partners to ensure that the future European interface is interoperable with the U.S. one. According to Agata Jozwicka-Perlant from the European Space Agency, while there is not a clearly defined process yet, it is unlikely that ESA will impose a standard on its own, but it will probably work with the industry to define standards based on their needs, usage, and experience.[72]

According to Stephan Meyer, Chairman of ESA's Programme Board on SSA, there is an increasing interest for OSAM at ESA, which realised that it is a market to address from a technological point of

---

[65] *ESA purchases world-first debris removal mission from start-up* (2020) *ESA*. Available at: https://www.esa.int/Space_Safety/ESA_purchases_world-first_debris_removal_mission_from_start-up (Accessed: 14 April 2023).
[66] *Ibid*.
[67] *ESA Agenda 2025* (2021) Op. Cit.
[68] *ESA'S Technology Strategy* (2022) Op. Cit.
[69] *ESA Commissions World's first space debris removal* (2019) *ESA*. Available at: https://www.esa.int/Space_Safety/Clean_Space/ESA_commissions_world_s_first_space_debris_removal (Accessed: 14 April 2023).
[70] *Space Safety*: *ESA*. Available at: https://esamultimedia.esa.int/docs/corporate/CM22_EO.pdf (Accessed: August 2023).
[71]Enabling a future European Space Transportation Ecosystem, ESA. Available at: https://www.esa.int/ESA_Multimedia/Videos/2023/07/Enabling_a_Future_European_Space_Transportation_Ecosystem (Accessed: 14 September 2023).
[72] Interview conducted by ESPI on August 14th, 2023.

view. Within ESA PB/SSA, there was no reluctance from ESA Member States regarding the discussion and development of such technologies. Discussions are mostly technical and technological. Political and potential military aspects of OSAM were not addressed in debates during ESA PB/SSA meetings. Yet, Member States have different priorities for different services and enabling technologies.[73]

Overall, OSAM is among various ESA priorities in terms of technology development. Several initiatives are conducted to do R&D, carry out demonstrations and missions. ESA is awarding a significant number of contracts to companies and universities in ESA Members to develop systems, conduct tests, and demonstrations. These show a **clear interest in ADR, on-orbit manufacturing, and refuelling and that most capabilities are at the stage of development or demonstrations.**

The table below provides a non-exhaustive overview of capabilities development carried out by ESA in the past five years. Projects funded by ESA are listed below.

Services	Projects and capabilities
Refuelling	**Under development**
	ESA selected Thales Alenia Space to develop the European System Providing Refuelling Infrastructure and Telecommunications (ESPRIT), which is expected to become a module of NASA's Lunar Gateway to provide in-orbit refuelling of xenon and chemical propellant.[74] ESPRIT is scheduled to be launched in 2029 as part of the Artemis 5 mission.
	Demonstrated/Concluded
	As part of the Technology Development Element (TDE) and the ESA ASSIST project, ESA worked with a consortium of European actors including GMV, MOOG, the National Technical University of Athens, DLR, Thales Alenia Space and OHB[75] to develop the International Intersatellite Fuel Transfer System Standard (IIFTSS), which was a standard docking interface to enable in-orbit refuelling in GEO. IIFTSS consisted of an end-effector to be installed on the robotic arm of a servicing satellite as well as a fixture to install on the serviced satellite to enable docking and refuelling. Environmental tests were conducted to test thermal leakage and liquid transfer.[76]
Active Debris Removal	**Under development**
	In 2021, ESA awarded D-Orbit UK a €2.19 million contract to develop ADR technologies. The contract is part of the phase 1 of the development and in-orbit demonstration of a *"Deorbit Kit"* as part of ESA'S Space Safety Programme. D-Orbit will conduct an in-orbit demonstration of its *"Deorbit Kit"*,

[73] Interview conducted by ESPI on July 28th, 2023.
[74] *Thales Alenia Space: At the heart of lunar industrial challenges* (2021) *Thales Group*. Available at: https://www.thalesgroup.com/en/worldwide/space/news/thales-alenia-space-heart-lunar-industrial-challenges (Accessed: 02 May 2023).
[75] *Docking mechanism could lead to refuelling satellites still in orbit* (2019) *ESA*. Available at: https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/Docking_mechanism_could_lead_to_refuelling_satellites_still_in_orbit (Accessed: 07 May 2023).
[76] *Testing and cross-validation of on-orbit servicing system for Geo spacecraft refuelling*. Available at: http://nereus.mech.ntua.gr/Documents/pdf_ps/astra17d.pdf (Accessed: 01 May 2023).

which is equipment that can enable satellites to conduct a propulsive decommissioning manoeuvre at the end of their life or after a failure. To develop this Kit, D-Orbit will lead a consortium, which includes Airbus Defence and Space, ArianeGroup, GMV Innovating Solutions, and Optimal Structural Solutions.[77]

Under the Active Debris Removal and In Orbit Servicing (ADRIOS) programme and the Clean Space initiative, ESA announced the ClearSpace-1 mission, which is scheduled to be launched in 2025 to remove the upper part of the Vespa (Vega Secondary Payload Adapter) from a Vega launcher. ClearSpace-1 will be carried out by ClearSpace (**Switzerland**) use the robotic arm developed by ESA to remove the targeted Vespa.[78]

Demonstrated/Concluded

In 2017, ESA awarded a study contract to the Polytechnic University of Milan (**Italy**) to assess the environmental impact of using deorbiting technologies such as sails and tethers in order to evaluate the impact of collisions between serviced and servicing space systems, model the impact of a collision, study the evolution of debris with the use of deorbiting technologies, and assess the possibility to conduct collision avoidance manoeuvres with sails and tethers.The study ended in 2018 and concluded that it tends to be better to use sails and tethers for passive deorbiting but acknowledged that scientific and technical issues remain before widespread adoption.[79]

In 2017, ESA awarded a contract to Airbus Defence and Space (**Germany**) to study end-of-life strategies for large constellations, including ADR techniques. The study ended in 2018 and came up with a design for a Shepherd servicing satellite that can capture and deorbit a non-cooperative spacecraft and then de-orbit itself as well. The study also involved Braunschweig Technical University and the École polytechnique fédérale de Lausanne (EPFL).[80]

Similarly, ESA awarded a contract to Thales Alenia Space (**France**) to also study ADR for large constellations by studying two theoretical constellations and two ADR designs. The first one was the TAS-3200 ADR design, which is based on Thales' Space Tug that would fly in sets of three to service and remove up to 35 debris using a robotic arm and then deorbit themselves at the end of the mission. The second one was the MEGA-1000 ADR design, which is a chaser equipped with a net capture system to remove debris and push them into the atmosphere.[81] The study ended in 2018.

[77] Jewett, R. (2021) *ESA Awards D-orbit UK contract for Debris Removal Demonstration*, *Via Satellite*. Available at: https://www.satellitetoday.com/in-space-services/2021/09/10/esa-awards-d-orbit-uk-contract-for-debris-removal-demonstration/ (Accessed: 19 April 2023).
[78] *Removal of the VESPA upper part (2022) Nebula Public Library*. Available at: https://nebula.esa.int/content/removal-vespa-upper-part (Accessed: 17 April 2023).
[79] *Environmental aspects of passive de-orbiting devices* (2022) *Nebula Public Library*. Available at: https://nebula.esa.int/content/environmental-aspects-passive-de-orbiting-devices (Accessed: 16 June 2023).
[80] *End of Life operations for disposal of mega constellations* (2023) *Nebula Public Library*. Available at: https://nebula.esa.int/content/end-life-operations-disposal-mega%E2%80%90constellations (Accessed: 17 April 2023).
[81] *Feasibility study of Active Debris Mitigation for Mega Constellations: Nebula public library.* Available at: https://nebula.esa.int/content/feasibility-study-active-debris-mitigation-mega-constellations *(Accessed: 17 April 2023).*

	In 2020, ESA awarded a contract to Fraunhofer CML (**Germany**) on Bioinspired Solutions for Space Debris Removal (BIOINSPACED) to find biomimetic solutions for Active Debris Removal missions. The study aimed at transferring biological models to technical applications by mimicking working principles of biology and nature that can contribute to ADR missions. Concepts were identified and were analysed in a feasibility analysis. Promising biomimetic principles and scenarios were identified for debris capture such as mosquito stinger tip, robotic mouth, distable venus flytrap; as well as for debris removal such as insects wing folding, plants seed parachute, swarms' communication. The study led to the creation of a demonstrator to show the impact of biomimetics on space systems.[82] As part of the GSTP programme, ESA awarded a contract to the University of Padova (**Italy**) to conduct a study to *"design navigation and control algorithms of a GNC system for combined control of an autonomous spacecraft equipped with a redundant manipulator with the aim of capturing a target spacecraft"*; and to *"develop a complete simulation environment used to support the design and testing of the GNC system"*.[83] The study team developed scenarios and tested and validated their solution in a simulated environment, which is assessed to have reached TRL 4.[84] In 2021, ESA awarded a contract to the University of Rome Tor Vergata (**Italy**) to define the shape memory polymer composites (SMPC) to capture small debris. They developed a grabbing device called Debris Removal by the European Autonomous Module (β-DREAM), which is fully in composite. The device was tested to capture debris of various formats and weights.[85] In 2021, ESA awarded a contract to the University Carlos III of Madrid (**Spain**) to conduct research and demonstrate the feasibility of Bare Photovoltaic Tethers (BPT) by combining solar cells and Space Electrodynamic Tethers (EDTs) to create a compact device for in-orbit propulsion, which can be used for both deorbiting and orbit reboost.[86]
Inspection	**Under development**
	ESA has been developing the Space Rider, which is an uncrewed robotic laboratory that is expected to be launched on Vega-C and stay in orbit for a period of two months. It is expected to enable experiments in microgravity and in-orbit validation and demonstration in satellite inspection.[87]

[82] *Bio-inspired Solutions for Space Debris Removal* (2022) *Nebula Public Library*. Available at: https://nebula.esa.int/content/bio-inspired-solutions-space-debris-removal (Accessed: 17 April 2023).
[83] *Preparation of enabling space technologies and building blocks: GNC and Robotic arm combined control* (2020) *Nebula Public Library*. Available at: https://nebula.esa.int/content/preparation-enabling-space-technologies-and-building-blocks-gnc-and-robotic-arm-combined (Accessed: 06 June 2023).
[84] *GNC and Robotic Arm Combined Control ESR: Executive summary report* (2022) *Nebula Public Library*. Available at: https://nebula.esa.int/sites/default/files/neb_tec_studies/2709/public/4000132611_GT17-137TIz_EX.pdf (Accessed: 12 June 2023).
[85] *European Space Debris Suppression (eSpades)* (2022) *Nebula Public Library*. Available at: https://nebula.esa.int/content/european-space-debris-suppression-espades (Accessed: 17 April 2023).
[86] *A Consumable-less Propulsion System Based on a Bare-Photovoltaic Tether* (2023) *Nebula Public Library*. Available at: https://nebula.esa.int/content/consumable-less-propulsion-system-based-bare-photovoltaic-tether (Accessed: 14 May 2023).
[87] Space rider (2023) ESA. Available at: https://www.esa.int/Enabling_Support/Space_Transportation/Space_Rider (Accessed: 10 September 2023).

Assembly	**Demonstrated/Concluded** Several studies are conducted and/or supported by ESA. For instance, the MIRROR project aims at studying the assembly of future large telescopes directly in space, making use of standard robotics interconnects and of a multi-arm installation robot. Between 2019 and 2021, ESA also conducted a study with Thales Alenia Space (**Italy**) (OMAR, for On-Orbit Manufacturing, Assembly and Recycling) aiming at assessing the system level and design of a satellite to be manufactured and assembled in-orbit, among others.[88]
Manufacturing	**Announced** ESA introduced the *"Out of Earth Manufacturing"* initiative to *"support further development and maturation of manufacturing and assembly technologies, for application on-orbit and on the surface of celestial bodies"*.[89] **Under development** ESA also supports directly European companies interested in the domain, such as SpaceForge, which received €2 million under the Boost! Programme. SpaceForge is a **UK** firm developing a new commercial space vehicle, ForgeStar, which will offer round-trip transportation services. The company targets the in-space manufacturing market, by allowing its customers to bring their payloads back to Earth with a more flexible and responsive transport solution. **Demonstrated/Concluded** ESA also conducted studies on the preliminary design of on-orbit manufacturing of large antenna reflectors[90] with the support of Airbus (**France**) or lunar ISRU demonstration[91] with the support of PTScientists (**Germany**). The On-Orbit Manufacturing, Assembly and Recycling study conducted by ESA and Thales Alenia Space (**Italy**) between 2019 and 2021 also included ideas for subsystem manufacturing in space. Several technologies were tested on the ground in demonstration projects, and enabled composite and *polymer* manufacturing. ESA contributed to the Manufacturing of Experimental Layer Technology (MELT) 3D printer (2015-2018), which was built by a consortium led by Sonaca Space (**Belgium**); the In-Orbit Manufacturing of Very Long Booms (2015-2018), which led to the

[88] *OMAR – On orbit manufactured spacecraft* (2022) *Nebula Public Library*. Available at: https://nebula.esa.int/content/omar-%E2%80%93-orbit-manufactured-spacecraft (Accessed: 05 June 2023).
[89] Makaya, A. *et al.* (2022) 'Towards out of earth manufacturing: Overview of the ESA materials and processes activities on manufacturing in space', *CEAS Space Journal*, 15(1), pp. 69–75. doi:10.1007/s12567-022-00428-1.
[90] *Preliminary design of on-orbit manufacturing of large antenna reflectors* (2022) *Nebula Public Library*. Available at: https://nebula.esa.int/content/preliminary-design-orbit-manufacturing-large-antenna-reflectors (Accessed: 30 May 2023).
[91] *Lunar ISRU Demonstration Mission Definition Study Segment 2* (2022) *Nebula Public Library*. Available at: https://nebula.esa.int/content/lunar-isru-demonstration-mission-definition-study-segment-2-0 (Accessed: 05 June 2023).

	creation of a prototype and its test in vacuum, thus demonstrating the feasibility of the technology;[92] The ESA IMPERIAL 3D printer (project started in 2019 and led by OHB in **Germany**) to develop a large-format 3D printer for the ISS and to be used with high performance thermoplastics. The project involved Sonaca Space GmbH (**Belgium**), BEEVERYCREATIVE (**Portugal**) and Athlone Institute of Technology (**Ireland**).

Table 2: ESA's capabilities developments in OSAM

European Union

OSAM is not a politically salient topic at the European Union (EU) level, yet the Union has already funded several projects for the development of the associated required technologies through its different R&I Framework Programmes (**Horizon 2020, Horizon Europe**). There is nonetheless awareness of the strategic aspect of this topic within EU institutions, which may contribute to elevate the status of this domain in the future.

OSAM is present to a limited extent in EU policies. The **Space Strategy for Europe** published by the European Commission in 2016 mentions it only once as a **topic of interest for R&D** and acknowledges that it is rather a long-term need. In line with this perspective, the policy document where the EU views on OSAM are the most developed is the **Strategic Research and Innovation Agenda (SRIA)** released in 2020.

In this document, OSAM is addressed through two different angles. Firstly, the document takes stock of the evolution of the space sector, including the emergence of on-orbit operations such as servicing or assembly, and specifies that such activities can create new business cases and foster innovation. Moreover, it recognises that other countries are making progress on this topic, specifically referring to initiatives implemented in the United States, such as CONFERS, which aims to "*research, develop, and publish non-binding, consensus-derived technical and operations standards for servicing and rendezvous, and proximity operations.*"[93]

Secondly, **a full section of the SRIA is dedicated to *"future space ecosystems"*** (i.e., on-orbit operations and new system concepts) and explains what the EU plans to achieve in this domain. The document emphasises the economic benefits expected from these activities as well as their contribution to a more sustainable space environment and to the protection of the space infrastructure (by mitigating or removing debris). **Robotic technologies and modularisation are presented as the technical elements lying at the core of future space ecosystems.** To avoid missing the opportunities offered by OSAM and not be left aside, the document calls for action: "*Ultimately, increased and advanced spacecraft modularity will unlock and generate new markets. It is of the utmost importance that the European space sector is placed at the forefront of this market generation, by introducing the new standards that will become applicable for such future space ecosystems. At the same time, a better understanding of the risk drivers for sustainable operations in*

[92] *In-orbit manufacturing of very long booms* (2018) *ESA*. Available at: https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/In-Orbit_Manufacturing_of_Very_Long_Booms (Accessed: 02 June 2023).
[93] *Strategic Research and Innovation Agenda (SRIA) of the European Open Science Cloud (EOSC)* (2022) *European Commission, Directorate-General for Research and Innovation, Publications Office of the European Union.* Available at: https://data.europa.eu/doi/10.2777/935288 (Accessed: 18 May 2023) p. 4.

orbit should be established"[94]. The **SRIA** singles out three types of OSAM activities that will be supported by EU R&I programmes:

- **New services including de-orbiting and ADR:** in particular, the Agenda mentions *"short to mid-term developments in orbit-to-orbit transportation, end-of-life operations and de-orbiting, and active debris removal"*[95] that should push the related technologies closer to market. They will be needed for the establishment of space logistics and to foster space sustainability.
- **On-orbit servicing, assembly, manufacturing**, which includes *"satellite inspection, in-orbit maintenance, repair, and refuelling, robotised deployment and in-orbit assembly and manufacturing"*[96] and which *"will allow putting structures and systems in space that are not possible with the current launch constraints"*[97]. Specific technologies (AI, GNC, robotics…) are required to support the development of this ecosystem. It is expected that these activities will benefit commercial space, space science and are an enabler for In-Situ Resource Utilisation. Therefore, they will, more broadly, contribute to the sustainability of space infrastructure and to European competitiveness.
- **New system concepts (including modularity)**, which will ultimately lead to an automated, flexible, and sustainable space infrastructure. Necessary elements to reach this objective include compartmentalised functionalities, open modularity standards and platforms supporting them.

While safety and sustainability are an important dimension of EU space activities, active debris removal is not significantly present in EU policies. Yet, it is mentioned in the EU Space Programme Regulation 2021/696, albeit indirectly. One of the objectives of the programme is indeed to "*enhance the safety, security and sustainability of all outer space activities pertaining to space objects and debris proliferation, as well as space environment, by implementing appropriate measures, including development and deployment of technologies for spacecraft disposal at the end of operational lifetime and for space debris disposal".*[98] Similarly, the regulation calls for the implementation of activities preparing a Space Surveillance and Tracking service for space debris remediation, defined as the management of existing space debris, and considers that the overall SST sub-component of the EU Space Programme should seek synergies with initiatives related to ADR or the passivation measures of space debris.

The EU also considers OSAM, or at least part of the activities and technologies making up this domain, from a security perspective. The **EU Space Strategy for Security and Defence (EU SSSD)** mentions that robotic arms could become a potential co-orbital ASAT. But, more interestingly, **in-orbit servicing is also presented as an opportunity for the security of the Union**, as it enhances the resilience of space systems and services (e.g., by extending their lifetime). The **EU SSSD** also calls for more collaboration on R&D in the domains of space, security, and defence. In this context, it requests that the technologies developed thanks to the funding of EU civilian programmes, such as Horizon Europe, **are further developed for defence purposes**. On-orbit services are explicitly singled out as one of these technologies. This element is noteworthy, as it may mark a shift in the EU mindset. Indeed, in the **Action plan on synergies between civil, defence and space industries**, released in 2021, and which aimed at fostering such synergies, there was no mention of OSAM.

---

[94] *Strategic Research and Innovation Agenda (SRIA) of the European Open Science Cloud (EOSC)* (2022) *European Commission, Directorate-General for Research and Innovation, Publications Office of the European Union.* Available at: https://data.europa.eu/doi/10.2777/935288 (Accessed: 18 May 2023) p. 9.
[95] *Ibid*.
[96] *Ibid*.
[97] *Ibid*.
[98] *Règlement (UE) 2021/696 du Parlement Européen et du Conseil* (2021) *EUR-LEX Access to European Law*. Available at: https://eur-lex.europa.eu/eli/reg/2021/696/oj (Accessed: 16 May 2023) art. 4(e), p. 25.

The EU is also an active actor in the **UN Open Ended Working Group on Reducing Space Threats**[99]**.** Like many other countries, European representatives mentioned the dual-use nature of many space systems but, surprisingly, they did not link it to RPO or any other technology. However, in the written contribution prepared by the EU to feed the debates of the working group, the dual-use character of RPOs was clearly established as well as the difficulties that it creates to identify threats.

The EU asserted that "*for instance, technologies allowing in-orbit rendezvous operations and proximity/docking operations can be used for activities such as active debris removal or on-orbit servicing. Non-transparent rendezvous operations and proximity operations may however also be perceived as a threat and be (mis-)understood as hostile actions, since they can also be used to disrupt the operation of other satellite or to destroy or de-orbit them, and a State may not know the intention associated with the manoeuvre*"[100]. Consequently, the EU considers that information, notification, or communication about proximity operations are necessary; not doing so would be irresponsible behaviour. Overall, the position defended by the European Union is that **RPOs are not a risk per se, but only when they are conducted in relation with abnormal behaviour.** To mitigate threats, the EU calls for the establishment of "*norms addressing in-orbit rendezvous (physical contact) operations that affect another State's space systems*"[101] and "*norms addressing proximity orbital operations that affect other State's space systems.*"[102]

In conclusion, OSAM is not yet fully recognised at political level (strategies) in the European Union but is an **important dimension of the space R&I activities** of the EU and is taken into account in EU reflections on space security. It is expected that the importance of this topic within EU institutions will not improve without additional political support.[103] Moreover, no policy document dedicated to OSAM is expected in the near future, but this may happen should external circumstances threaten Europe and/or demonstrate the strategic value of these activities for the continent.[104] Irrespective of the form it takes, some European stakeholders acknowledge that a move from the EU (in particular the European Commission) on the topic of OSAM may convince its Member States to invest more in this domain.[105] It remains to be seen whether the upcoming EU Space Law will even address the issue or catalyse market creation.

The table below provides an overview of projects funded by the European Union over the past five years. Projects funded by ESA but carried out by companies or entities in its Member States are listed below.

Services	Projects and capabilities
	Under development
Refuelling	In 2022, the European Commission awarded a contract to Thales Alenia Space as part of the Horizon Europe programme to develop the European Robotic Orbital Support Services In-Orbit Demonstration (EROSS IOD) mission, which is scheduled to be launched in 2026 to demonstrate refuelling

[99] *Abbreviated OEWG and in full "Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours", This working group is pursuant to General Assembly resolution 76/231*
[100] *European Union (EU) joint contribution – 1st part Scoping* (2022) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*
[101] *European Union (EU) joint contribution – 4th part Recommendations* (2022) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*
[102] *Ibid*.
[103] Interview conducted by ESPI on August 22nd, 2023.
[104] *Ibid*.
[105] *Ibid*.

	in orbit as well as other services. The project also involves GMV, the German Aerospace Center (DLR), and the French company Exotrail.[106]
	In 2023, the European Commission awarded €1.9 million to a consortium led by Space Applications Services (**Belgium**) and involving FZI Forschungszentrum Informatik (**Germany**), Reorbit (**Finland**), GMVIS Skysoft (**Portugal**), and ArianeGroup (**France/Germany**) to develop a refuellable tank that can refuel satellites and create the setup to support testing and qualification. The objective is to demonstrate that the refuelling module can be integrated at a later stage for an in-orbit demonstration mission.[107]
Active Debris Removal	**Under development**
	In 2022, the European Commission awarded €2.4 million to a consortium led by the University Carlos III of Madrid (**Spain**). This project focuses on the development of a Ready-to-Fly Deorbit Device and prepare for an in-orbit demonstration. The project is expected to be finalised in 2025.
	Concluded
	In 2016, the European Commission awarded €2.8 million to the Technology for Self-Removal of Spacecraft (TeSeR) consortium led by Airbus Defence and Space (**Germany**) to develop a debris removal module to manufacture and test an on-ground prototype. Three concepts for debris removal were investigated and prepared for prototyping with solid propulsion, a drag augmentation membrane, electrodynamic tethers. The project ended in 2019.[108]
	In 2015, the European Commission awarded €1.9 million to D-Orbit (**Italy**) to continue the development of its Smart propulsive device for controlled satellite decommissioning and re-entry (D3) and to demonstrate in-orbit the operation of the D3 system in a small test satellite. The onboard propulsive system demonstrated the decommission of the test satellite. The project ended in 2018.[109]
	In 2019, the European Commission awarded €168,277 to the Polytechnic University of Milan (**Italy**) for the *"Rendezvous Modelling Visiting and Enhancing (ReMoVE)"* Action. The project aimed at developing a small satellite platform that can rendezvous and de-orbit a non-cooperative object. Mathematical studies focused on docking with a non-cooperative target and the project led to the development of the SKiLLeD-RdV (Simulation Kit for Logic and Layout Design of RdV) simulation environment, which can model and verify GNC algorithms for RPOs.[110]

[106] *Thales Alenia Space to lead EROSS IOD, on-orbit servicing project* (2022) *Thales Group*. Available at: https://www.thalesgroup.com/en/worldwide/space/press_release/thales-alenia-space-lead-eross-iod-orbit-servicing-project (Accessed: 02 May 2023).
[107] *Satellite construction kit for highly unified modular assembly in New Space applications* (2022) *Cordis*. Available at: https://cordis.europa.eu/project/id/101082449 (Accessed: 03 May 2023).
[108] *Technology for self-removal of spacecraft* (2016) *Cordis*. Available at: https://cordis.europa.eu/project/id/687295 (Accessed: 24 April 2023).
[109] *Smart propulsive device for controlled satellite decommissioning and re-entry* (2015) *Cordis*. Available at: https://cordis.europa.eu/project/id/711193/reporting (Accessed: 24 April 2023).
[110] *Rendezvous modelling visiting and enhancing* (2019) *Cordis*. Available at: https://cordis.europa.eu/project/id/793361 (Accessed: 24 April 2023).

	In 2019, the European Commission awarded €2.99 million to a consortium led by the University Carlos III of Madrid (**Spain**) to develop an Electrodynamic Tether Technology for Passive Consumable-less Deorbit Kit and push it to TRL4. The Kit is a propellant-free device, which produces a drag force and has the capability to de-orbit spacecraft.[111] In 2022, the European Commission awarded €75,000 to IENAI SPACE (**Spain**) to develop, industrialise, and introduce to market the ATHENA (Adaptable Thruster based on Electrospray for Nano-/micro-/pico-satellites), which is an electric thruster for on-board propulsion that can conduct collision avoidance and de-orbit. IENAI SPACE already launched its prototype in October 2022.[112]
Station-keeping	**Concluded** In 2021, the European Commission provided funding to a consortium led by GTS (**Germany**) to develop a High Efficiency Multistage Plasma Thruster – Next Generation (HEMPT-NG2) system with the goal of creating capabilities for station-keeping and orbit raising as well as manoeuvring capabilities for space systems.[113]
Assembly	**Concluded** The PERASPERA consortium has been created and funded by the two Framework Programmes. PERASPERA gathers several national space agencies working on space robotics, of which one of the applications is in-orbit assembly. In 2021, Airbus Defence and Space (**Germany**) was selected by the European Commission to conduct the Horizon 2020's PERIOD (PERASPERA In-Orbit Demonstration) project. This project received €3 million for two years (2021-2022) and is expected to pioneer the in-orbit assembly of antenna reflectors, spacecraft components and enable in-orbit reconfiguration (replacement of payloads).[114] The antenna reflector will be directly manufactured in orbit.[115] The EROSS IOD project (see above), building on its precursor projects EROSS and EROSS+, will investigate several tasks such as rendezvous, refuelling and replacement of components with the objective to pave the way for assembly, repair and waste management activities. The project started in January 2023 and received a €26 million grant from the EU for a duration of 26 months.[116]

[111] *Electrodynamic tether technology for passive consumable-less deorbit kit* (2019) *Cordis*. Available at: https://cordis.europa.eu/project/id/828902 (Accessed: 24 April 2023).
[112] *Ibid.*
[113] *High efficiency multistage plasma thruster* (2021) *Cordis*. Available at: https://cordis.europa.eu/project/id/101004140 (Accessed: 26 May 2023).
[114] *ESPI Yearbook 2021 – Space policies, issues and trends* (2022) *ESPI*. Available at: https://www.espi.or.at/wp-content/uploads/2022/07/ESPI-Yearbook-2021-1.pdf (Accessed: 06 May 2023).
[115] *PERASPERA In-Orbit Demonstration | PERIOD Project* (2021) *Cordis*. Available at: https://cordis.europa.eu/project/id/101004151 (Accessed: 04 June 2023).
[116] *European Robotic Orbital Support Services In-Orbit Demonstration* (2023) *Cordis*. Available at: https://cordis.europa.eu/project/id/101082464 (Accessed: 02 June 2023).

	URO-BOAS, a 2-year initiative funded for €2 million by Horizon Europe and led by Sener (**Spain**), which aims at developing an orbital replacement unit at TRL 6 to make them compatible with different standard interfaces and payloads in order to be able to easily replace them (plug-and-play approach).[117] The PULSAR project (€4 million funded under Horizon 2020 between 2019 and 2021) led by Magellium (**France**) worked on the development and demonstration of technologies for the in-space assembly of a mirror for a 12m-diameter space telescope. PULSAR's overall concept is aimed at the creation of a fully autonomous, in-orbit robotic assembly system. Beyond mirrors, the results of the project aim at being useful for other large structures.[118] The MOSAR project (€4 million funded under Horizon 2020 between 2019 and 2021 and coordinated by Space Applications Services (**Belgium**) aimed at standardising satellite components to enable quicker assembly and commissioning to space, but also to facilitate repair and upgrade of the satellites when they are in orbit.[119] The end goal of the project was to develop a ground demonstrator.
	Concluded
Manufacturing	The PERIOD (PERASPERA In-Orbit Demonstration) project supported by Horizon 2020, helped demonstrate in-orbit manufacturing. An *"orbital factory"* will be launched to the Bartolomeo platform of the ISS by 2025 and manufacture a functioning satellite. More precisely, an antenna reflector will be fabricated, satellite components will be assembled and the satellite itself will be reconfigured in the factory. This project received €3 million for two years (2021-2022) and was led by Airbus Defence & Space (**Germany**).[120] The Development of a Machine for Multi-Material Manufacturing (4M) supported by Horizon 2020 (€950,000 between 2015 and 2017) and coordinated by RHP Technology (**Austria**), which developed a technology allowing to use an additive manufacturing process based on metallic powder and able to make use of several materials at the same time. RegoLight (funded for €1 million and led by DLR (**Germany**)) aims at supporting the development of technologies using lunar soil for the 3D printing of infrastructure (levelled terrain, dust shelters, launch pads, etc.) and structural components for lunar habitats for use in future lunar missions.

Table 3: The EU's capabilities developments in OSAM

[117] *ORU Based on Building Blocks for Advanced Assembly of Space Systems* (2023) *Cordis*. Available at: https://cordis.europa.eu/project/id/101082078 (Accessed: 30 May 2023).
[118] *Prototype for an Ultra Large Structure Assembly Robot* (2019) *Cordis*. Available at: https://cordis.europa.eu/project/id/821858 (Accessed: 04 June 2023).
[119] *Modular Spacecraft Assembly and reconfiguration \| MOSAR project* (2019) *Cordis*. Available at: https://cordis.europa.eu/project/id/821996 (Accessed: 01 June 2023).
[120] *PERASPERA In-Orbit Demonstration \| PERIOD Project* (2021) *Cordis*. Available at: https://cordis.europa.eu/project/id/101004151 (Accessed: 04 June 2023).

Austria

In analysing **Austria's space strategy Austria 2030+**, it is important to underline that there is a strong focus on space sustainability as it is the first main target of the policy: *"Sustainable development on Earth and in Space"*, which includes working towards the *"the UN Guidelines for Long-term Sustainability of Outer Space Activities, including space traffic management and the prevention of space debris"*. However, the strategy does not refer to OSAM (or related concepts) explicitly and does not aim to develop specific capabilities in the field of OSAM.

Among its specific measures in space sustainability, Austria's space strategy specifically outlines that it will *"advocate for the sustainable use of space in the context of space diplomacy at the United Nations level (including the World Space Forum)."* Indeed, Austria is rather active within COPUOS. It often makes statements on capacity building and promotion of space sustainability initiatives and issues such as the LTS Guidelines, space resources, etc. However, Austria does not appear to have mentioned OSAM in these statements.

At the legal level, Austrian national space law does not refer to OSAM.

Overall, Austria's objectives in space are mostly focused on developing capacity and capabilities on space applications and downstream applications for Earth. Capabilities development in OSAM in Austria is very limited and focuses mostly on interfaces and last mile delivery (e.g., GATE Space). Some are developing thrusters for deorbiting at the end of life (e.g., Enpulsion). Yet, Austria is contributing at its own level to OSAM capability building through its participation in ESA programmes. Consulted stakeholders mentioned that Austria was seeing OSAM positively as a contribution to space sustainability and as a potential new market.[121]

Czech Republic

The Czech Republic's **National Space Plan 2020** shows that the country is making significant efforts in building capacities and capabilities for its space industry and academic sphere. The plan acknowledges the potential of OSAM and demonstrates an interest in developing its space activities.[122]

The **National Space Plan 2020** aims to stimulate private investment in space activities, accelerate technology and knowledge transfer, and encourage cooperation between academia and industry, in particular through activities in ESA programmes.[123] In the section on *'Priority Areas for Intervention'*, the Plan explicitly mentions OSAM as an area of interest, along with space debris removal, utilisation of space resources, space weather, and planetary defence. It further emphasises the benefits these projects would bring to the Czech Republic and its citizens, including increased global reputation and visibility, enhancement of industrial capabilities, demonstration of scientific excellence, and broad application of industry and academia's capacities.[124] The ESA Space Safety Programme (SSP) replacing the Space Situational Awareness (SSA) programme is also highlighted in the Plan. This focus on space safety is further emphasised by the increased funding for the SSP, reflecting the importance placed on these activities.[125]

While OSAM is recognised as an economic perspective activity, there is little detail provided about how it will be implemented, or any dedicated resources or strategies to foster its development

[121] Interview conducted by ESPI on July 28th, 2023.
[122] *National Space Plan 2020- 2025* (2019) *Czech Space Portal*, p.21.
[123] Ibid., p. 9.
[124] *National Space Plan 2020- 2025* (2019), *Czech Space Portal*, section 3.2.1.2, p. 30.
[125] *Ibid.*, pp. 74-75.

within the Czech space industry. This suggests that while the Czech Republic recognises the value and potential of OSAM, the approach to its integration into their space activities is still in its early stages. At the moment, Czech Republic mostly sees OSAM from an economic and technological perspective.

Finland

In analysing **Finland's Space Strategy 2025**, it appears that the document outlines the country's commitment to enhancing space technology, supporting research organisations, and participating in international cooperation within the space sector.[126] Despite these objectives, the strategy does not mention OSAM as a targeted area of development.

The strategy prioritises the growth of both upstream and downstream space technology sectors, calling for an increase in turnover for companies producing and utilising space technology.[127] The establishment of new space sector companies is also emphasised, showing a strong focus on domestic growth and capacity building.[128] However, the strategy does not explicitly mention OSAM. Yet, the strategy emphasises the sustainable use of space, which could indirectly encompass OSAM, without providing any details or measures on the matter.

At the programmatic level, no project is dedicated to developing capabilities in the field of OSAM.

At the legal level, the **Act on Space Activities** does not address OSAM or even deorbiting at the end of life.[129]

In conclusion, while the **Finland 2025 strategy** represents a comprehensive approach to expanding their space industry and fostering innovation, it falls short of clearly defining plans or resources dedicated to OSAM. This indicates that while Finland acknowledges the importance of space sustainability, it may benefit from more explicit mention and exploration of OSAM to fully take advantage of the potential it offers for space sustainability, economic growth, and international leadership in the space sector.

France

France recently updated its policy framework with the development of a space defence strategy (2019) and reorganised its space governance (2020) by adding the Ministry of the Economy to the ministerial supervision of the national space agency (CNES), already under the responsibility of the Ministry of the Armed Forces and the Ministry of Higher Education and Research. Furthermore, the national civil space policy responsibility has been transferred from the Ministry of Higher Education and Research to the Ministry of the Economy which in part shifted the focus towards support to the New Space ecosystem, including in the field of OSAM. At the policy level, France does not have a dedicated OSAM policy. However, this topic is addressed in French space policy documents such as the French **Space Defence Strategy of 2019** as well as in parliamentary documents and in French strategic debates.

The **Space Defence Strategy** references on-orbit servicing such as Active Debris Removal, in-orbit refuelling, and proximity operations. While it is not the main focus of the strategy, **France seems to**

---

[126] *Finland 2025* (2018) *Ministry of Economic Affairs and Employment, Ministry of Transport and Communications,* p. 11.
[127] *Ibid*.
[128] *Ibid*.
[129] *Act on Space Activities* (2018) *Ministry of Economic Affairs and Employment*. Available at: https://tem.fi/documents/1410877/3227301/Act+on+Space+Activities/a3f9c6c9-18fd-4504-8ea9-bff1986fff28/Act+on+Space+Activities.pdf?t=1517303831000 (Accessed: 10th July 2023)

perceive OSAM as a potential military threat by strongly highlighting the dual use nature of such capabilities and the risk for the weaponisation of outer space: *"active debris removal systems are being developed, along with systems capable of making orbital rendezvous in order to repair satellites, refuel them, keep them on station, move or deorbit them. Under cover of civilian objectives, States or private actors can thus openly finance potential anti satellites technologies."*[130] It further outlines that *"the orbital services currently being developed by commercial enterprises and trials of proximity operations such as refuelling and cooperative inspection in the event of failure could be deflected from their purpose and the associated systems could be used as effectors capable of docking with, mooring on, capturing, degrading or displacing a satellite."*[131] This is considered by the Strategy as a threat, which may hinder France's access to space and freedom of action in space. Yet, the Strategy also sees OSAM as part of space military operations to protect French space assets and deter potential attacks. To counter these threats, which go way beyond the potential malicious use of OSAM, France decided to change its posture to "active defence", which is a counter-offensive posture allowing France to retaliate and take countermeasures to defend its assets in space.

The strategic debate in France demonstrates an interest for OSAM as illustrated by parliamentary sessions and reports. High-level civil servants and executives are regularly invited to parliamentary hearings, in which the topic of OSAM is addressed, although not being the central subject. These often lead to OSAM being referenced in several parliamentary reports which aim to inform policy and legal updates, policy implementation, and evaluation:

- In 2019, the French National Assembly drafted a parliamentary report on the Space Defence Sector, which addressed OOS activities from an economic perspective, looking into the potential financial and economic benefits that those new operations could generate. The report emphasises the economic rationale of on-orbit refuelling in comparison to launching new assets and explores the potential benefits of the development of fuel depots between the Earth and Mars. The report further outlines that the first manufacturers to take dominant positions in these emerging fields will have greater opportunities of establishing new standards. The use of OOS space vehicles for military applications is also mentioned, with a specific emphasis on the dual use of these spacecrafts.[132]
- In 2022, the National Assembly released a parliamentary report on space which demonstrates a certain interest for OSAM and the role that ISRU could have for specific activities such as in-orbit refuelling. Generally, the report addresses OSAM capabilities as new opportunities for economic growth and sustainability, underlining that "*these economic and technological prospects are highly attractive for both industrials and scientists, and the technological complexity of these missions requires major spacefaring nations to prepare now,"* but also as potential future military threats: "*diverted from their initial purpose, they could be used as effectors capable of approaching, docking, capturing, degrading, or displacing a satellite."*[133]
- In 2023, the Senate released a parliamentary report on the topic of the exploitation of space resources, making direct references to OSAM activities from different angles (economic, sustainability, and military). It highlights the potential relation between ISRU and such services in orbit (i.e., space logistics, space-based solar power, refuelling, repairing, in-space manufacturing, recycling) and puts forward the benefits of those activities: *"the environmental impact would be significant. Used in combination with other services (maintenance, repair, recycling, etc.), refuelling would extend the lifespan of satellites, whereas currently they are*

---

130 *Space Defence Strategy* (2019) *gouvernement.fr*. Available at: https://www.gouvernement.fr/sites/default/files/locale/piece-jointe/2020/08/france_-_space_defence_strategy_2019.pdf (Accessed: 05 July 2023).
131 *Ibid*.
132 *Rapport d'information n°1574* (2019) *Assemblée nationale*. Available at: https://www.assemblee-nationale.fr/dyn/15/rapports/cion_def/l15b1574_rapport-information (Accessed: 05 July 2023).
133 *Rapport d'information n 4991* (2022) *Assemblée Nationale*. Available at: https://www.assemblee-nationale.fr/dyn/15/rapports/cion_afetr/l15b4991_rapport-information.pdf (Accessed: 10 July 2023)

considered disposable," "refuelling could also be an economically viable model in the much shorter term, with fuel produced on Earth and stored in orbital depots."[134]

While these reports do not constitute the official position of the executive government, it provides an overview of the status of the public debate as well as the perception of OSAM in France.

Additionally, the **French Space Operations Act** does not refer to OSAM but provides specific rules in line with IADC guidelines regarding debris and governs activities including de-orbiting and passivation manoeuvres, re-entry of satellites into the atmosphere and situations in which the operator loses control of its asset. While France is not specifically active with regard to standardisation efforts on a global scale, it is looking to advocate for a translation of the obligations of the French space law with regard to space sustainability into European law and beyond.[135] Due to the recent evolution of the space sector, France also conducted a series of consultations in early 2023 in order to update the space law, **with the explicit goal to adapt it to the development of on-orbit servicing and the exploitation of space resources**.[136] It remains to be seen what kind of provisions the update will integrate. So far, neither the Government nor the Parliament has unveiled a draft.

Furthermore, on-orbit servicing is also mentioned by France in diplomatic fora, such as COPUOS and the UN OEWG on Reducing Space Threats. During two sessions of UN OEWG on Space Threats, in 2022 and 2023, the French delegation underlined the potential increase of tensions between countries in case of "hidden" proximity operations under the cover of an Active Debris Removal mission for example. In addition, in the most recent sessions at COPUOS in 2022, and 2023, the French delegation took the opportunity to present its willingness to discuss about standards governing space proximity manoeuvres, eventually having implications for OSAM.[137] Indeed, France mentioned in 2023 that they wished to *"discuss a norm obliging States to obtain the prior consent of another State before any orbital rendezvous operation"* and *"to continue discussions around one or more standards governing proximity manoeuvres"*.[138]

At a programmatic level, the investment programme France 2030 aims to financially support emerging companies (mostly start-ups and innovative SMEs) in the field of on-orbit services, and to enable them to increase TRLs.[139] CNES is supporting on-orbit servicing activities and programmes, further demonstrating a certain interest for such applications. Among other projects, CNES, together with the DGA (i.e., French military procurement agency) and the AID (i.e., French Defence Innovation Agency), is developing a demonstrator called YODA, and planned to be launched in 2024 or 2025 to demonstrate the capacity to conduct close proximity operations in GEO. It will mostly serve to validate close proximity operations technologies and train the Space Command to conduct in-orbit operations. CNES is also involved in supporting OOS activities and programmes through public contracts with private companies. For example, in 2023, CNES awarded a contract to Astroscale France to conduct an ADR mission of a French space debris as of 2024. Similarly, in 2023, CNES

---

[134] *Rapport d'information n 668* (2022) *Sénat*. Available at: https://www.senat.fr/rap/r22-668/r22-6681.pdf (Accessed: 10 July 2023)

[135] Interview conducted by ESPI on September 13th, 2023

[136] CP, (2023) Consultation auprès des opérateurs spatiaux sur les enjeux du New Space. Communiqué de Presse, [online] 23 January, No. 528. Available at: https://presse.economie.gouv.fr/23012023-cp-consultation-aupres-des-operateurs-spatiaux-sur-les-enjeux-du-new-space/ (Accessed: 14 September 2023).

[137] *Statement of Mme Camille PETIT, Ambassador* (2023) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*

[138] *Statement of France (2023) Scientific and Technical Sub Committee - United Nations Committee on the Peaceful Uses of Outer Space.*

[139] *Présentation des résultats du volet spatial de France 2030* (2023) *Gouvernement.fr*. Available at: https://www.gouvernement.fr/sites/default/files/contenu/piece-jointe/2023/07/dp_assises_du_newspace.pdf (Accessed: 07 July 2023).

awarded Dark for its Interceptor system, designed "*to be rapidly deployed to capture large space debris objects like rocket bodies.*"[140] The maiden launch is scheduled to take place in 2026.

Furthermore, as part of the Tech for Space Care initiative, CNES develops the technological elements to ensure that satellites can be serviced by developing interfaces that can be used freely by all French space actors.[141] The objective of this initiative is to support the industry in implementing the French Operations Act while remaining competitive on global markets. To this end, the Tech for Space Care initiative also provides funding to space companies and start-ups through call for tenders or call for ideas to develop capabilities. Most of the funding is directed to established prime contractors (approx. 70%) and some start-ups (approx. 30%). Unlike the France 2030 investment plan which focuses on the development and purchase of services, Tech for Space Care focuses on the development of systems.[142]

Overall, while OSAM is not the main priority for France, it is **clearly integrated into its global vision and posture on space sustainability, space safety, and space security as well as regarding the development of commercial space**. France mostly opts for an approach in which it is supporting the development of the New Space ecosystem by awarding contracts to start-ups, mostly as part of its **France 2030 plan**.

The table below provides a non-exhaustive overview of capabilities development carried out by France in the past five years:

Services	Projects and capabilities
	Announced
Active Debris Removal	In 2019, the start-up **Space Drone** was founded to develop an orbital vehicle, which is expected to provide active debris removal and maintenance services.[143] In 2023, CNES awarded a contract to **Astroscale France** for a study on the active debris removal of a French space debris. The specific debris will be decided upon in 2024.[144]
	Under development
	As part of the France 2030 investment plan, the French government awarded €2 million to the company **CTI** for its project called INSIDeR, which aim to

[140] Parsonson, A. (2023) *CNES awards contract to dark for Space Debris Interceptor Simulation*, *European Spaceflight*. Available at: https://europeanspaceflight.com/cnes-awards-contract-to-dark-for-space-debris-interceptor-simulation/ (Accessed: 27 June 2023).
[141] *Débris Spatiaux : Vers des satellites réparables ?* (2023) *Techniques de l'Ingénieur*. Available at: https://www.techniques-ingenieur.fr/actualite/articles/debris-spatiaux-vers-des-satellites-reparables-122300/ (Accessed: 15 May 2023). ; *Technologies for Space Care* (2018) *Space Safety Office CNES*. Available at: https://indico.esa.int/event/234/contributions/4044/attachments/3061/3764/2018CSID_POmaly_TechnologiesForSpaceCare.pdf (Accessed: 15 May 2023).
[142] Interview conducted by ESPI on September 13th, 2023.
[143] *Products Space Drone*. Available at: https://spacedrone.eu/dev/index.php/products/ (Accessed: 14 April 2023).
[144] *Astroscale expands operations to France and secures contract with CNES* (2023) *Astroscale*. Available at: https://astroscale.com/astroscale-expands-operations-to-france-and-secures-contract-with-cnes/ (Accessed: 21 June 2023).

	demonstrate on the ground a debris capture system dedicated to nano satellites.[145] In 2023, CNES awarded a contract to the start-up **Dark** to conduct a private emergency interception simulation and assess Dark's Interceptor system, which is expected to capture large pieces of debris. The simulation will test various scenarios and mission types. In 2023, the start-up Dark successfully tested its interceptor's low-energy propulsion devices as part of a test campaign at ONERA. Different propellants and ignition modes were tested.[146]
Space Logistics	**Announced**
	The start-up **Hybrogines** announced the development of an orbital transfer vehicle that is expected to conduct space logistics missions, delivering satellites to their final orbits.
	Under development
	The start-up **Exotrail** is developing in-space logistics capabilities in LEO, notably spacedrop, which is a deployment service to final orbital destination for nano, micro, and small satellites. In 2021, Exotrail was awarded a contract by the French Government to conduct an orbital logistics demonstration mission to change a satellite's altitude by 2024 and, in another mission, an in-orbital delivery by 2025 to move a satellite to its final orbital destination. The contract is part of the France 2030 public investment plan launched in 2021.[147] **Thales Alenia Space** received funding from the France 2030 investment plan for its ASTARTE project, which aims to carry out a demonstration of a transfer service to the final operational orbital destination of a satellite without using any energy on-board the satellite thanks to electric propulsion. A first demonstration without a payload will first be conducted and a second one with a payload provided by CNES from 2025. This project aims to provide station-keeping, refuelling, and deorbiting in the long term.[148]
Inspection	**Under development**
	France, through the DGA, the AID and CNES, is developing the **YODA Programme**, which is expected to be a patrolling spacecraft that will be able to manoeuvre and conduct RPOs in GEO. It will be composed of two nanosatellites that will validate RPO capabilities and train the Space Command operators in conducting such activities. It is then expected that a

[145] *France 2030 : Premiers lauréats du volet spatial* (2022) *entreprises.gouv.fr*. Available at: https://www.entreprises.gouv.fr/fr/actualites/france-2030/france-2030-premiers-laureats-du-volet-spatial (Accessed: 02 June 2023).
[146] *Dark* (2023) *LinkedIn*. Available at: https://www.linkedin.com/company/darkaerospace/ (Accessed: June 2023).
[147] Werner, D. (2023) *ExoTrail wins contract to demonstrate orbital transfer for French agencies*, *SpaceNews*. Available at: https://spacenews.com/exotrail-wins-contract-to-demonstrate-orbital-transfer-for-french-agencies/ (Accessed: 28 April 2023).
[148] *Présentation des résultats du volet spatial de France 2030* (2023) *Gouvernement.fr*. Available at: https://www.gouvernement.fr/sites/default/files/contenu/piece-jointe/2023/07/dp_assises_du_newspace.pdf (Accessed: 07 July 2023).

	heavier YODA patrolling system will be launched by 2030 if the first part of the YODA programme is successful.[149] The start-up **SpaceAble** is developing both in-space SSA and inspection capabilities. SpaceAble is developing an inspector space system called *"the Orbiter"* as well as a software platform of LEO data, which leverages AI and blockchain technology. SpaceAble is looking for a customer satellite to conduct a demonstration mission in 2024 and a first mission in 2025.[150] SpaceAble received funded under the France 2030 investment plan for its CIPACO (Capacité d'Inspection Pour Assurabilité des Constellations en Orbitre terrestre basse) to develop its inspector spacecraft, detect defaults, debirs, and impacts due to space weather of up to 12 mm and support deorbiting.[151] The start-up **Infinite Orbits**, which is based both in France and Singapore, is developing a close in-orbit inspection solution through the development of an Autonomous Vision-Based Navigation Software to ensure rendezvous and docking. The servicer named OrbitGuard is equipped with sensors with a vision based GNC software as well as self-learning neural networks. OrbitGuard-1 was launched to GEO in May 2023[152] and is expected to demonstrate attitude determination, debris detection, orbit estimation and tracking, manoeuvre planning, near range rendezvous, inspection, and formation flying.[153] Infinite Orbits, with Telespazio, IMCCE (Observatoire de Paris), IRT Saint Exupery, were selected by the French government's France 3030 investment plan for the first phase of a demonstration of a pre-operational service of in-space SSA in GEO that aims to provide on-demand inspection capabilities.[154] **Telespazio France** received funding from the France 2030 investment plan to develop in-orbit SSA in GEO using Earth observation satellite to provide on-demand inspection services.[155]
Assembly	**Under development** The start-up **The Exploration Company** is developing space logistics capabilities along with refuelling capabilities and received funded under the France 2030 investment plan to demonstrate on-orbit assembly and manufacturing in partnership with Airbus and Magellium as part of the DEMARLUS project.[156]

[149] *Assemblée nationale* (2020) *Avis n°3465 - Tome VI*, *Assemblée nationale*. Available at: https://www.assemblee-nationale.fr/dyn/15/rapports/cion_def/l15b3465-tvi_rapport-avis (Accessed: 02 June 2023).
[150] Rainbow, J. (2023) *Getting SSA off the ground*, *SpaceNews*. Available at: https://spacenews.com/getting-ssa-off-the-ground/ (Accessed: 02 June 2023).
[151] *Présentation des résultats du volet spatial de France 2030* (2023) Op. Cit.
[152] *G-space 1 (GS 1, Nusantara H-1A) (2023) Gunter's Space Page.* Available at: https://space.skyrocket.de/doc_sdat/g-space-1.htm (Accessed: 28 May 2023).
[153] *Our Mission* (2023) *infiniteorbits*. Available at: https://infiniteorbits.io/missions/ (Accessed: 16 May 2023).
[154] *Sécurité des Opérations Spatiales : 5 lauréats de l'appel d'offres 'catalogue de Données pour la surveillance de l'espace' De France 2030* (2022) *Gouvernement.fr*. Available at: https://www.gouvernement.fr/securite-des-operations-spatiales-5-laureats-de-l-appel-d-offres-catalogue-de-donnees-pour-la (Accessed: 15 May 2023).
[155] *Présentation des résultats du volet spatial de France 2030* (2023) Op. Cit.
[156] *Ibid*.

	Under Development
Manufacturing	The start-up **Space Cargo Limited** and its subsidiary **Space Biology Unlimited** is a French biotech company, subsidiary of space Cargo Unlimited, which aim to conduct life science research in Space with various techniques including in-orbit manufacturing. It has been conducting the WISE mission on the ISS since 2019, which aim at studying specific materials and tissues in space for the agri-food sector.[157]

Table 4: France's capabilities developments in OSAM

Germany

Germany has a longstanding expertise in robotics technologies and other key enabling technologies that have a use for on-orbit servicing, assembly and manufacturing.

The **2010 German Space Strategy** displays awareness of the community on progress in in-orbit servicing, as it recognises that *"work is ongoing into ways of extending satellite lifetimes and recovering objects from space"*.[158] However, although on-orbit servicing is mentioned, it is not considered and investigated as a domain in itself, but rather as a promising application for German robotics and mechatronics activities in the future (as well as artificial intelligence and autonomous systems). Robotics is an area of excellence of the German ecosystem and the Strategy clearly promoted the development of such activities. In this context, **on-orbit servicing is viewed as an economic opportunity but also as a way to ensure sustainability in orbit.** Indeed, the Strategy explains that *"On-orbit satellite servicing will open up a new dimension for the commercial space sector, too: in future, robots will be responsible for the refuelling, servicing, repair, and controlled disposal of satellites in orbit, enabling operators to manage entire satellite fleets. In this way, it will be possible also to address the growing problem of space debris and improve the sustainability of space activities."*[159]

In line with the evolution of the space sector, the importance of the sustainability dimension has risen over time. For instance, while the **Future Strategy for Research and Innovation** released in 2023 does not make reference to on-orbit servicing, assembly and manufacturing in general, one area of this domain is explicitly mentioned as an objective for public action measures: active debris removal. The document states that the German government *"will increasingly support technologies that avoid the creation of space debris or enable the robotic removal of space debris."*[160]

In September 2023, Germany released a new **Space Strategy**, which identifies sustainable use of space as an area of action for the Federal Government and states that *"the active disposal of space debris also requires highly reliable robotic systems that enable the safe removal of objects from the relevant orbit regions (Active Debris Removal). To avoid misunderstandings, such robotic capabilities must be used in a predictable and transparent manner."*[161]

[157] Home (2023) Space Cargo Unlimited. Available at: https://space-cu.com/#what-we-do (Accessed: 27 September 2023).
[158] *Ibid.*, p. 14.
[159] *Ibid.*, p. 13.
[160] *Die Bundesregierung, Zukunftsstrategie Forschung und Innovation* (2023), our translation. The original quote is: "Wir werden verstärkt Technologien unterstützen, welche die Entstehung von Weltraumschrott vermeiden bzw. die robotische Beseitigung von Weltraumschrott ermöglichen" (p. 71). Available at: https://www.bmbf.de/SharedDocs/Publikationen/de/bmbf/1/730650_Zukunftsstrategie_Forschung_und_Innovation.pdf?__blob=publicationFile&v=4 (Accessed: July 2023).
[161] Raumfahrtstrategie der Bundesregierung (2023) Bundesministerium für Wirtschaft und Klimaschutz (BMWK). Available at: https://www.bmwk.de/Redaktion/DE/Publikationen/Technologie/20230927-raumfahrtstrategie-breg.pdf?__blob=publicationFile&v=6 (Accessed: 27 September 2023).

Furthermore, **German representatives also addressed OSAM-related technologies through the risks that they create for security and stability in outer space.** In their contributions to the UN Open-ended Working Group on Reducing Space Threats (UN OEWG), they stated that *"Capabilities and technologies that are essential for preserving the free and sustainable use of outer space - such as active debris removal or on-orbit servicing - might also be misused with the aim to destroy or impair space assets of others."*[162] **Germany also expressed concern regarding the dual-use nature of two specific activities/technologies in particular**: rendezvous and close proximity operations as well as satellites with robotic arms. German representatives were more specific during the second session of the Working Group, making reference to "*rendezvous and proximity operations, mission extension vehicles or robotic arms, harpoons and nets for active debris removal*" and calling for the establishment of behavioural standards allowing to leverage the benefits of these technologies while preventing their use for nefarious purposes. For example, Germany considers that the conduct of rendezvous (docking) operations requires consent and that such activities should not be conducted if they impair the safe operation of space systems of another state.

However, the perception of OSAM as a specific military threat is not central in Germany's posture. Germany has continuously stressed the relevance of these activities and technologies to ensure the sustainability of outer space, for instance clarifying that *"Rendez-vous and close proximity operations (RPO) are essential for maintenance, repair, fuelling of spacecraft or docking of space capsules."*[163]

At the national level, on-orbit servicing, assembly, or manufacturing activities do not seem to be a priority. For instance, the topic is not regularly mentioned in parliamentary questions or reports that address German space activities. Similarly, although space is mentioned in the **coalition's contract**[164] set up by the political parties currently at the power (SPD, FDP, Bündnis 90/Die Grünen), nothing related to OSAM can be found in the document.

At the regulatory level, German space-related laws (the **1998 Law governing the transfer of administrative functions in the sector of outer space activities** and the **2007 Satellite Data Security Act**) are quite old and/or address very specific questions, therefore, make no mention of OSAM. Germany is currently looking to update its national space law in the near future. The new German space strategy underlines that *"a national space law, in which Germany will, among other things, implement its international legal obligations under the Outer Space Treaty, also makes the creation of space debris less likely and contributes to the sustainable and safe use of space."*. However it remains to be seen whether it will integrate OSAM.

Overall, Germany considers OSAM as a source of opportunities for its robotics technologies, as a decisive factor to ensure the sustainability of outer space and, at the same time, as a potential risk for security in this domain.

The table below provides a non-exhaustive overview of current capabilities developments in Germany:

---

[162] *DEU Initial Statement (2022) Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*

[163] *Submission of Germany - Responsible behaviours as a practical contribution to the prevention of an arms race in outer space and to strengthening the international frameworks on space security* (2022) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours*

[164] (2021) *Mehr Fortschritt Wagen - Sozialdemokratische Partei Deutschlands (SPD)*. Available at: https://www.spd.de/fileadmin/Dokumente/Koalitionsvertrag/Koalitionsvertrag_2021-2025.pdf (Accessed: July 2023).

<table>
<tr><th>Services</th><th>Projects and capabilities</th></tr>
<tr><td rowspan="5">Active Debris Removal</td><td>Under development</td></tr>
<tr><td>In 2021, the start-up Exolaunch unveiled its Eco Space Tug Program. The company announced it was developing a line of space tugs called Reliant that will be able to conduct ADR, de-orbiting, and relocation missions. Reliant is expected to be powered by green propulsion system and contains 3D-printed components and carbon fibre composites. Exolaunch will develop two versions of Reliant.
• The first version is "the Standard", which will be able to conduct orbit correction and relocation missions. It is expected to lift the orbit of a satellite from 250-300 km to 550 km in one hour.
• The second version is the "Pro", which will be equipped with a hybrid propulsion system and will enable serviced spacecraft to change their altitude and inclination, conduct orbital phasing, and de-orbit. Additionally, Reliant is expected to conduct ADR missions by collecting authorised debris.[165]</td></tr>
<tr><td>The start-up Kinetik Space is developing a robotic arm, which is equipped with a magnetic end effector and is expected to be installed on the launcher of Rocket Factory Augsburg (RFA) in order to conduct ADR.[166] In 2022, DLR selected Kinetik Space as one of the actors, which will fly on RFA ONE's first flight for an on-orbit demonstration mission, in which a CubeSat will be released and then captured by Kinetik Space robotic arm.[167]</td></tr>
<tr><td>Demonstrated/Concluded</td></tr>
<tr><td>The start-up High Performance Space Structure Systems (HPS) developed the ADEO-N subsystem, which is a drag augmentation device that takes advantage of the residual Earth atmosphere in LEO to push back CubeSats into the atmosphere and de-orbit them. It is a method of deorbiting that is "passive" as it does not require GNC.[168] HPS already launched three missions to space in 2018, 2021, and 2023. HPS is also developing ADEO-M to deorbit medium satellites as well as ADEO-L to de-orbit large satellites. HPS is currently developing a Proto-Flight Model (PFM) of ADEO-L, which is scheduled to be launched on ESA/EC IOV-spacecraft in 2025.[169]</td></tr>
<tr><td rowspan="2">Repair</td><td>Operational</td></tr>
<tr><td>DLR developed the Compliant Assistance and Exploration Space Robot (CAESAR), which aims to perform on-orbit refuelling, repair, debris removal and on-orbit assembly.[170] The Robot includes robotic joints that are</td></tr>
</table>

[165] *Products* (2022) *Exolaunch*. Available at: https://exolaunch.com/products.html (Accessed: 12 April 2023)
[166] *The heart of motion in space* (2023) *KINETIK Space*. Available at: https://kinetik.space/ (Accessed: 07 June 2023).
[167] Arizaga, M. (2023) *Fully booked! DLR selects seven customers for RFA's inaugural flight, Rocket Factory Augsburg.* Available at: https://www.rfa.space/fully-booked-dlr-selects-seven-customers-for-rfas-inaugural-flight/ (Accessed: 02 June 2023).
[168] *Time to act - CleanGreenSpace Missions: High Performance Space Structure Systems GmbH.* Available at: https://www.hps-gmbh.com/wp-content/uploads/2023/02/2023_HPS_ADEO_Flyer.pdf (Accessed: 23 May 2023).
[169] *Ibid*.
[170] *On-orbit servicing* (2022) *DLR Event.* Available at: https://event.dlr.de/en/ila2022/on-orbit-servicing/ (Accessed: 26 May 2023).

	replicating the flexibility of a human arm, whose length and format can be adapted to the mission.[171] **Airbus** developed CIMON-2 for DLR. It is an astronaut assistant developed with AI capabilities, autonomous flight capabilities, and voice-controlled navigation to assist astronauts in their repair missions on board the ISS.
Relocation	**Under development** **Exolaunch**'s Reliant Pro and Reliant Standard space tugs (mentioned in Section 3.1.2) will be capable of relocating satellites in orbit. Reliant Pro has the capabilities to change a satellite's altitude and inclination as well as to perform orbital phasing for constellations. Reliant can deorbit itself at the end of its mission.[172] The start-up **Astrait** is developing its NEMO platform, which is expected to have the ability to transport small satellites into higher orbits, up to the lunar orbit using ion thrusters. The NEMO platform is described as a *"kickstage to provide last mile transfer."*[173]
Assembly	**Demonstrated/Concluded** The company **iBOSS** is offering its Space System Interface. "*The iSSI allows for any manual or robotic coupling, reconfiguration, or extension of systems, both on ground and in space [...] When the iSSI is used in space, the objects could be a client and a servicer, two modular building blocks as parts of a larger satellite, a robotic end effector and a block, and more, so long as both objects have iSSI integrated into their structures*".[174] The company is a spin-off of a DLR project started in 2010, which aimed at developing "*a reconfigurable spacecraft that uses standardised interfaces and modular design and manufacturing for on-orbit service and assembly*".[175]
Manufacturing	**Under development** The start-up **MoonFibre** is developing ISRU and on-orbit manufacturing capabilities to produce fibre-based materials with lunar regolith on the Moon. The company received funding from DLR to analyse how fibre-based resources making future lunar settlement sustainable and cheaper. It is also developing a proof of concept for a fully autonomous terrestrial fibre spinning facility, which will then be tested on the lunar surface.[176]

[171] *Space heritage: DLR at a glance*: *DLR.de*. Available at: https://www.dlr.de/rm/en/Portaldata/52/Resources/Flyer/Systeme/CAESAR_Flyer_engl_2018.pdf (Accessed: 03 June 2023).
[172] *Exolaunch introduces eco space tug program* (2021) *Exolaunch*. Available at: https://exolaunch.com/news_54 (Accessed: 05 June 2023).
[173] ASTRAIT. Get your specific photographic radiation geographic communication spectral cartographic navigation meteorologic. Available at: https://astrait.space/ (Accessed: 14 September 2023).
[174] *Global trends in on Orbit Servicing, Assembly and Manufacturing (OSAM)* (2020) *Institute for Defense Analyses*. Available at: https://ida.org/-/media/feature/publications/g/gl/global-trends-in-on-orbit-servicing-assembly-and-manufacturing-osam/d-13161.ashx (Accessed: 15 April 2023).
[175] Xue, Z. *et al.* (2021), *op. cit.*
[176] Moonfibre aims to produce fibres from the Moon's soil · Fibres from Lunar Regolith. Available at: https://moonfibre.de/ (Accessed: 14 September 2023).

Table 5: Germany's capabilities developments in OSAM

Italy

In the 2016 **Strategic Plan for Space Economy** OOS systems were only mentioned as innovative technologies. However, limited developments had took place at the time. But it is important to underline that OSAM has taken some importance at the policy level since then.

Indeed, in the wake of recent space governance reforms, Italy has indicated OOS as a strategic national sector in its **Government Guidelines on Space and Aerospace.**[177] Signed by the Prime Minister in mid-2019, this high-level policy document acknowledges the economic value of in-orbit activities, including de-orbiting of spacecraft, while recognizing the need to conduct further research in the field of low-thrust propulsion, identification, tracking and docking tools, as well as AI applications.[178]

Moreover, in 2019 the Italian Government Presidency of the Council of Ministers unveiled the **National Security Strategy for Space**, which mentions OOS as one of several developing sectors (such as sub-orbital flight, Lunar robotic exploration) and underlines its relevance as part of the response to urgent challenges to space security. In particular, orbit congestion is seen as one of the main factors contributing to the risks of orbital collisions, which add to intentional threats. In this specific context, the Strategy also highlights the strategic importance of further developing Space Situational Awareness (SSA) capabilities[179], participating in international Space Traffic Management (STM) initiatives, and fostering the evolution of OOS technologies.[180]

Informed by the content of the 2019 Government Guidelines, ASI has released its most recent strategic document (**DVSS 2020-2029**),[181] which identifies OOS technology as a programmatic sector and recognised the need to address this topic from both a technology development and regulatory perspective. OOS systems are perceived as capable of significantly impacting the spacecraft manufacturing and operation activities since the design phase, with the final aim of maintaining safety and sustainability of the orbital environment. In this context, ASI recognises the existing national capabilities in the field, while setting the goals for the development of multi-mission reusable OOS platforms. The **DVSS** calls for a significant public investment plan in OOS technologies, thus facilitating Italy in carving out a considerable international niche in offering competitive services.[182] **ASI's Plan of Activities** for the next few years complements the picture mentioning the interest in the OOS field of big international operators, potentially affecting competitiveness of European actors. The Plan also specifies that national programmes will be conducted in parallel and without overlaps with the one conducted at the European level. Among technologies listed in the plan, advance sensors for inspection and detection, systems to capture and move objects in orbit, machine and reinforced learning and AI algorithms, interoperability and proximity operations technologies and green propulsion systems are mentioned as transversal capabilities to be developed to enable specific OOS services.

---

[177] Presidenza.governo.it. 2019. [online] Available at: Indirizzi del Governo in materia spaziale e aerospaziale - https://presidenza.governo.it/AmministrazioneTrasparente/Organizzazione/ArticolazioneUffici/UfficiDirettaPresidente/UfficiDiretta_CONTE/COMINT/DEL_20190325_aerospazio.pdf (Accessed: 14 September 2023).
[178] *Ibid*. Pp. 4-5.

[179] The Italian SSA Joint Forces Center is under the command of the new *Comando delle Operazioni Spaziali, created in 2020*
[180] Presidency of the Council of Ministers - Governo, National security strategy for space Available p.3 .at: https://presidenza.governo.it/AmministrazioneTrasparente/Organizzazione/ArticolazioneUffici/UfficiDirettaPresidente/UfficiDiretta_CONTE/COMINT/NationalSecurityStrategySpace.pdf (Accessed: 14 September 2023).
[181] Documento di Visione strategica per lo Spazio - Italian Space Agency. Available at: https://www.asi.it/wp-content/uploads/2020/04/DVSS-2020-2022-Finale_compressed_compressed.pdf (Accessed: 14 September 2023).
[182] *Ibid*, pp. 20-21.

These technological development and capabilities objectives are translated into contracts awarded to established large industries. In this regard, in May 2023, the Italian Space Agency (ASI) granted €235 million to Thales Alenia Space for the development and demonstration of an on-orbit servicing project set to launch in 2026.[183] Consulted stakeholders mentioned that Italy was implementing a strategy in which it considers that only large space industries can develop a full suite of integrated technologies and is therefore prioritizing contracts with established actors such as TAS rather than space start-ups.[184]

The table below provides a non-exhaustive overview of current capabilities developments in Italy:

Services	Projects and capabilities
Active Debris Removal	**Under development**
	The start-up **SAB Launch Services** is developing the IOSHEXA, which is a space tug that is expected to have ADR capabilities. The first in-orbit demonstration is scheduled for 2025 and will showcase rendezvous.[185]
Inspection	**Under development**
	The start-up **Kurs Orbital**, which is based both in Ukraine and Italy, is developing inspection capabilities along with de-orbiting and life extension. Kurs Orbital already announced that it successfully conducted tests of the Kurs One machine vision system to detect images of a non-cooperative satellite and detect the edges of the targeted satellite as well as area of interest on the satellite for further analysis. The test also aimed at detecting the noncooperative satellite mock-up position and orientation relative to the camera in order to identify docking surface corner points.[186]
Space Logistics	**Announced**
	In 2023, the Italian Space Agency (ASI) awarded a €235 million contract to **Thales Alenia Space** to design, develop, and qualify an IOS mission, which will demonstrate in-orbit refuelling, component repair and replacement, orbital transfer, and atmospheric re-entry through the use of a robotic arm developed by Leonardo, SAB Aerospace, the Italian National Institute for Nuclear Physics (INFN) and the Italian Institute of Technology (IIT). The project is expected to be launched to LEO in 2026.[187]
	Operational

[183] Rainbow, J. (2023) Italy awards $256 million contract for 2026 in-orbit servicing mission, SpaceNews. Available at: https://spacenews.com/italy-awards-256-million-contract-for-2026-in-orbit-servicing-mission/ (Accessed: 14 September 2023).
[184] Interview conducted by ESPI on August, 29th, 2023
[185] IOSHEXA: a hybrid payload adapter/spacecraft for in-orbit servicing: Indico. Available at: https://indico.esa.int/event/321/contributions/6416/attachments/4373/6595/IOSHEXA_Cleanspace_Final.pdf (Accessed: 25 May 2023).
[186] Kurs One Machine Vision System Bench testing was successfully conducted (2022) Kurs. Available at: https://kursorbital.com/tpost/spiila6p11-kurs-one-machine-vision-system-bench-tes (Accessed: 25 May 2023).
[187] Thales Alenia Space and consortium is enlisted by Italian Space Agency for €235 for In-Orbit Servicing demonstration mission (2023) SatNews. Available at: https://news.satnews.com/2023/05/17/thales-alenia-space-and-consortium-is-enlisted-by-italian-space-agency-for-e235-for-in-orbit-servicing-demonstration-mission/ (Accessed: 25 May 2023).

	The start-up **D-Orbit** developed the ION Satellite Carrier, which is a spacecraft that can deploy other satellites by taking them from the launcher's separation stage to their final orbital destination. D-Orbit already conducted several missions in space. The mission ION-SCV 002 Pulse deployed 20 CubeSats to their precise orbital slots. Since then, D-Orbit has been conducting many missions to transport small satellites to their final orbital destination. Once their mission is over, IONs Satellite Carrier are deorbiting themselves.[188] These capabilities are for space logistics and last mile deliveries, but they may also be used to develop relocation and repositioning capabilities.
Recharging	**Announced**
	The company **Orbital Recharge in Space (ORiS)** is involved in the field of in-orbit recharging and wants to wirelessly recharge satellites in LEO. The company is only nascent and is working on a proof of concept with the Polytechnic University of Turin in order to test its technology and increase its TRL.[189]

Table 6: Italy's capabilities developments in OSAM

Luxembourg

Luxembourg is an emerging spacefaring nation, which is looking to increasingly develop its commercial space sector and focuses on niche and underexplored segments such as space resources, among other things.

While Luxembourg does not have a dedicated OSAM policy, the theme is largely addressed in several policy documents, highlighting Luxembourg's perception of OSAM as an opportunity for space sustainability and economic growth.

Luxembourg's Space Strategy for the period 2023-2027 focuses on sustainability issues and therefore highlights four priorities: economic sustainability, sustainability on Earth, sustainability in space, and the sustainable use of space resources. The strategy aims to promote a sustainable and responsible use of space by, among other things, developing capabilities in space traffic management and on-orbit services. OSAM is seen both as a solution to alleviate the creation of the debris due to the intensive use of LEO and a response to counter irresponsible space behaviours that generate debris. In addition, on-orbit servicing is perceived as contributing to *"the development of a circular economy in space, ranging from deployment to the final operational slot, in-orbit manufacturing and assembly, to mission life extension and debris removal."* The strategy also positions Luxembourg on the exploration and utilization of space resources, which may foster the development of in-orbit refuelling and manufacturing. In the strategy, Luxembourg underlines its support for *"the development of rendezvous technologies and a robotic arm"* and commits to support

[188] Ion-SCV 002, 011: Gunter's Space Page. Available at: https://space.skyrocket.de/doc_sdat/ion-scv-2.htm (Accessed: 14 May 2023).
[189] Oris - orbital recharge in space: Linkedin. Available at: https://www.linkedin.com/company/oris-orbital-recharge-in-space (Accessed: 21 May 2023).

the development of additional technologies.[190] Beyond technological development, Luxembourg plans to position itself on the life extension market for telecommunications satellites in GEO.[191]

This focus on life extension stems from the approach adopted by the Luxembourg Space Agency (LSA), which positions itself as a space economy development agency to support space companies. In the field of OSAM, LSA, as a young space agency, is not yet defining priority market segments to develop, but rather acknowledges the opportunities and areas that the industry and start-ups see to then extend support in these specific domains accordingly. Luxembourg hopes to attract private investors in OSAM projects in the longer term.[192]

Furthermore, the **National Action Plan 2020-2024** underlined Luxembourg's approach to OSAM missions, which is to contribute through its membership to ESA and its Space Safety Programme.[193] Luxembourg's National Space Programme mostly support the development of OSAM capabilities by contributing to ESA's active debris removal mission. This approach is then complemented by more specific R&D projects at the national level with small companies and universities that benefit from the space agency's sponsorship.[194] In this regard, the LuxIMPULSE programme, which was established in 2009 to develop new technologies, undertake market research, and study new concepts contributes to build technology blocks for OSAM. For instance, in May 2022, Lift Me Off was awarded a LuxIMPULSE contract for the development of OSAM key enabling technologies in partnership the University of Luxembourg's Interdisciplinary Centre for Security, Reliability and Trust (SnT).[195]

In 2020, Luxembourg partnered with ESA to create the European Space Resources Innovation Centre (ESRIC) to foster R&D activities in the field of in-situ resource utilization (ISRU). ESRIC is also looking to contribute to commercial developments in the long-term, in particular through partnerships with established industry and through its start-up support program.[196] Luxembourg aims to position itself on this specific topic to attract companies in this field. ESRIC focuses on thematic areas of research, including manufacturing components, repairing parts, and building infrastructures thanks to space resources, which are reflected in the Action Plan.[197] While the focus is ISRU, ESRIC activities may contribute to also fostering in-orbit manufacturing as the Action Plan refers to several national companies developing technologies designed for manufacturing composite materials and solar panels both on earth and in space (e.g., Maana Electric).

Beyond the sustainability and commercial perceptions of OSAM, the national **Defence Space Strategy** also refers to OSAM. Luxembourg's Directorate of Defence commits to monitor the development of such technologies, in particular Active Debris Removal and repair as well as to participate and invest in space debris remediation initiatives. Yet, the strategy does not specifically underline OSAM as a potential military threat. At the moment, the Directorate of Defence does not have a specific programme for OSAM and does not seem to develop military capabilities in this domain.

[190] *Stratégie Spatiale 2023-2027* (2022) *LSA*. Available at: https://space-agency.public.lu/dam-assets/publications/2023/strategie2023-2027.pdf (Accessed: 13 July 2023).
[191] *Ibid.*
[192] Interview conducted by ESPI on September 7th, 2023.
[193] *National Action Plan 2020-2024 - Space Science and Technology* (2020) *LSA*. Available at: https://space-agency.public.lu/dam-assets/publications/2020/Luxembourg-space-action-plan-ENG-final-kw.pdf (Accessed: 13 July 2023).
[194] Interview conducted by ESPI on September 7th, 2023.
[195] *Luxembourg Space Start-Up LMO, Uni.lu Awarded ESA LuxImpulse Contract* (2022) *Chronicle.lu*. Available at: https://chronicle.lu/category/space/40850-luxembourg-space-start-up-lmo-uni-lu-awarded-esa-luximpulse-contract (Accessed: 26 May 2023).
[196] Interview conducted by ESPI on September 7th, 2023.
[197] *Research* (2023) *ESRIC*. Available at: https://www.esric.lu/research (Accessed: 13 July 2023).

At the regulatory level, the national space law of 2020 does not address in-orbit servicing.[198] In 2017, Luxembourg adopted a national law allowing the commercial exploitation of space resources. While the law does not mention in-orbit manufacturing, it may indirectly foster the development of this technology in Luxembourg in the long-term.[199] While Luxembourg recognizes the importance and the need for standardization efforts for OSAM in a commercial environment, it did not yet carry out any initiative in that regard.[200]

At the diplomatic level, Luxembourgish delegations at COPUOS underlined their activities and support for OSAM, in particular "*satellite deorbiting, capturing, and repatriating inanimate objects, passivation, extending the lifespan, end-of-life operations, and developing specific software and models to support these activities.*"[201] Luxembourg's delegations also highlighted their perception of on-orbit servicing as a tool that can contribute to space traffic management.[202]

Overall, Luxembourg is demonstrating an emerging interest in OSAM and is involved in this domain mostly through its contribution to ESA. While it is not the main priority of the country, it perceives OSAM as an opportunity to develop its commercial space sector and an opportunity to contribute to sustainability in space. Luxembourg's peculiar focus on ISRU is expected to drive interest and capability development in on-orbit manufacturing in the long term.

The table below provides a non-exhaustive overview of capability developments in Luxembourg:

Services	Projects and capabilities
	Announced
Repair	In 2020, the **University of Luxembourg**'s Interdisciplinary Centre for Security, Reliability and Trust (SnT), which has a Computer Vision, Imaging & Machine Intelligence research group, signed a partnership agreement with the space company **Lift Me Off** to carry out research on the future needs of autonomous in-orbit satellite repairs. The partnership's purpose is to "*develop technologies to give service vehicles intelligent visual processing.*" The objective is to develop computer vision, which will allow the spacecraft to recognise the parts of the satellite it is working on and to process the data it receives, to then make autonomous decisions and successfully repair or refuel the spacecraft.[203]
	Under development
Manufacturing	The start-up **Maana Electric's** aim "*is the development of dual use applications integrating In-Situ Resource Utilisation (ISRU) concepts and sustainability/power systems technologies, with the aim to become the utility company of the solar system*". The start-up is developing MaanaBoxes, which

[198] *Loi du 15 décembre 2020 portant sur les activités spatiales* (2020) *Legilux*. Available at: https://legilux.public.lu/eli/etat/leg/loi/2020/12/15/a1086/jo (Accessed: 07 July 2023).
[199] *Loi du 20 juillet 2017 sur l'exploration et l'utilisation des ressources de l'espace.* (2017b) *Legilux*. Available at: https://legilux.public.lu/eli/etat/leg/loi/2017/07/20/a674/jo (Accessed: 07 July 2023).
[200] Interview conducted by ESPI on September 7th, 2023.
[201] *Statement of Luxembourg – item 7 Space debris* (2023) *Scientific and Technical Sub Committee - United Nations Committee on the Peaceful Uses of Outer Space*
[202] *Statement of Luxembourg – point 8 Space and sustainability* (2023) *Plenary Sessions - United Nations Committee on the Peaceful Uses of Outer Space*
[203] *Inventing autonomy for in-orbit satellite repairs* (2020) *Interdisciplinary Space Master - University of Luxembourg*. Available at: https://ism.uni.lu/news/inventing-autonomy-for-in-orbit-satellite-repairs/ (Accessed: 02 May 2023).

	aim to produce solar panels using space resources, notably on the Moon and Mars with the objective to contribute to both terrestrial and space applications. The TerraBox system is targeted to provide power to remote areas on Earth and the LunaBox system is aimed to provide power on the Moon and develop the lunar economy.[204]

Table 7: Luxembourg's capabilities developments in OSAM

The Netherlands

The Netherlands has various policy documents geared towards its space activities, but do not have a dedicated policy for OSAM. OSAM doesn't seem to be the main priority of the country in the space sector. In fact, OSAM activities are not mentioned in its **Space Activities 2020 – NSO** policy document.

In the **Memorandum of Space Policy 2019,** the contribution of the Netherlands towards monitoring space weather, space debris, and natural objects to prevent and guarantee safety in and from space is mentioned. However, the means to prevent such threats are not explicitly presented. The policy document only mentions it from a general perspective, and at the level of its contribution to the ESA safety programme declaring that *"this includes developing technology to prevent and remove space debris and reduce associated risks."*[205]

Before the publication of its **Space Activities 2020** – NSO policy document, a report entitled **NSO Pre-advice for its space policy from 2020** was released to shape the final version of its space policy. It is stated that based on the Dutch's technology roadmaps, space architecture is a topic of interest, particularly when it *"concerns research into the development of satellite constellations and possibly in-orbit service services."*[206] It appears that this reference was included to create the possibility for the government to fund OOS-related R&D in Dutch companies, institutes, and universities as it was perceived as a potential market for the Netherlands to enter at the time of writing the report. However, it does not seem that institutional funding is currently provided to Dutch entities through these roadmaps.[207]

At the diplomatic level, both at COPUOS and UN OEWG on Space Threats, Dutch delegations focused rather on supporting the implementation of the Long-Term Sustainability Guidelines, and the Space Debris Mitigation Guidelines than explicitly mentioning OSAM. For example, they emphasised that *"states should not only implement post mission disposal measures, but also implement the active removal of space debris,"*[208] as it is vital to *"stabilise the space debris environment at a safe level".*[209] While it is mentioned a few times, the development of OSAM does not seem to be a main priority for the Netherlands in diplomatic discussions.

During the UN OEWG on Space Threats of 2022, the Netherlands also supported other delegations in expressing their concerns regarding *"security implications of rendezvous and proximity operations*

[204] Maana Electric (2023) Luxembourg Space Agency. Available at: https://space-agency.public.lu/en/expertise/space-directory/MaanaElectric.html (Accessed: 14 September 2023).
[205] *Space Policy Memorandum* (2019) *Spaceoffice.nl*. Available at: https://www.spaceoffice.nl/en/about-nso/space-policy/ (Accessed: 06 July 2023).
[206] *NSO Pre Advice for its Space Policy (2020)* *Spaceoffice.nl*. Available at: https://www.spaceoffice.nl/en/about-nso/space-policy/ (Accessed: 06 July 2023).
[207] Interview conducted by ESPI on August 31st, 2023.
[208] *Statement of the Netherlands – item 11 General Exchange of information and view on legal mechanisms relating to space debris mitigation measures, taking into account the work of the Scientific and Subcommittee* (2023) *Legal Subcommittee - United Nations Committee on the Peaceful Uses of Outer Space.*
[209] *Statement of the Netherlands – item 5 Way and means of Maintaining outer space for peaceful purposes* (2023) *Plenary Sessions - United Nations Committee on the Peaceful Uses of Outer Space.*

[…] without the permission of the owner of the satellite that is the target…".[210] However, the perception of OSAM technologies as a potential threat to security and sustainability in space is not at the core of the Dutch posture.

It is worth noting that the Netherlands do have some capabilities in the field of robotic arms as Dutch companies developed the European Robotic Arm (ERA), which are on the ISS and may be used as a foundation to further develop the technology in the country.

Overall, the Netherlands mostly perceives OSAM from a sustainability opportunity and market opportunity perspective. Although the Ministry of Foreign Affairs is strongly involved in international fora (e.g., COPUOS, UN OEWG), political actors mostly see these technologies from a civilian point of view rather than from a military one.[211]

The table below provides a non-exhaustive overview of capability developments in the Netherlands:

Services	Projects and capabilities
	Operational
Assembly	**Airbus Netherlands** (Dutch Space) developed for the European Space Agency the European Robotic Arm (ERA), which is a robotic arm that was attached to the Russian segment of the ISS in 2021. Airbus Netherlands also provided the flight model, spare model, a qualification model and several test models. Control software and advanced simulator system to support operational planning, procedures definition, mission evaluation and cosmonaut training. The robotic arm can assist astronauts during EVAs and grab payloads, assemble, inspect, and replace elements of the Russian segment.[212]

Table 8: The Netherland's capabilities developments in OSAM

Norway

Analysing **Norway's space strategy**, it is apparent that Norway recognises the significance of space technologies, particularly in the areas of maritime surveillance, transportation, communications, and sustainable development. However, Norwegian space policies do not refer to OSAM.[213]

Norway's space policy has not identified or prioritised OSAM as a strategic focus area. Despite the extensive use of satellite services across different sectors and the recognition of the importance of secure and efficient maritime traffic monitoring, environmental surveillance, and communication networks, there is no mention of initiatives related to the maintenance, repair, or upgrade of these assets once they are in orbit.

[210] *Statement of the Kingdom of the Netherlands Second Session* (2022) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*
[211] Interview conducted by ESPI on August 31st, 2023.
[212] ERA (2023) Airbus Defence & Space Dutch Technology. Available at: https://www.airbusdefenceandspacenetherlands.nl/project/era/ (Accessed: 14 September 2023).
[213] Norsk Romsenter (no date) The government's strategy for Norwegian Space Activities, Norsk Romsenter. Available at: https://www.romsenter.no/Aktuelt/Publikasjoner/The-Government-s-strategy-for-Norwegian-space-activities (Accessed: 14 September 2023).

At the legal level, Norway does not yet have a national space legislation. Norway is currently in the process of drafting such a law. It remains to be seen whether OSAM or deorbiting at end of life will be addressed in the draft.

Norway's emerging interest in OSAM can be considered within the broader framework of Norway's focus on sustainability.[214] The Norwegian Space Agency does not develop projects or capabilities in this domain. Few projects in this field exist in Norway and are usually funded by the EU. For instance, the Norwegian research institute SINTEF is involved in the consortium EROSS (European Robotic Orbital Support Services), which is developing key enabling technologies for OSAM and is funded by the European Union[215]

Portugal

Portugal's space strategy focuses on key areas such as R&D, skills and training, regulatory framework development, international partnerships, and investment attraction. While the core of the strategy does not explicitly mention OSAM, the strategy integrates an introductory note from the President of the Foundation for Science and Technology, emphasising that *"with this strategy, Portugal declares its intention to affirm itself as a space nation, supporting Europe in its ambition to guarantee, in its territory, competitive access to space as well as the provision of services in orbit."* [216]

Back in 2019, the Portuguese Space Agency released the **Strategy for the Portuguese participation in the 2019 ESA´s Ministerial Meeting Space19+ and the articulation of national/EU/ESA/business funding sources**, with a clear diversification strategy for investment in space. The **Portuguese Strategy for Space19+** suggests that Portugal rather sees OSAM as an opportunity for both space sustainability and economic growth. On-orbit servicing is seen as a key component in sustainable space traffic management, promoting both debris mitigation and satellite protection. As part of its contribution to ESA, Portugal was looking to *"co-lead in active debris removal/in-orbit servicing."*[217] Although Portugal is a relatively small contributor to ESA, its position aimed at *"enabling a world 1st, European leadership and competitive advantage in one of the largest future markets in space."*[218] Portugal considers that activities to tackle the issue of space debris, including in-orbit servicing, *"will empower institutional, industrial, and governmental users"* across the supply chain and will provide the industry with long-term competitive advantage. [219]

In terms of capability development, Portugal considers that *"precursors for active debris removal can build new European industrial capabilities needed to perform in-orbit servicing,"*[220] underlying that the country's favourable position to first develop the ADR market and then develop other services as key technologies are the same. The document further outlines that Portugal considers ISRU and on-orbit manufacturing as the next technological breakthroughs in space and sees power and artificial intelligence as key enabling technologies.[221]

---

[214] Interview conducted by ESPI on August 30th, 2023.
[215] Sintef, I3DS, SINTEF. Available at: https://www.sintef.no/en/projects/2016/i3ds/ (Accessed: 14 September 2023).
[216] A RESEARCH, INNOVATION AND GROWTH STRATEGY FOR PORTUGAL SPACE 2030 APPROVED BY THE GOVERNMENT, 15 FEBRUARY, 2018 (RESOLUTION N.º 30/2018), p. 15 available at: https://ptspace.pt/wp-content/uploads/2020/08/PortugalSpace2030_EN_web.pdf
[217] *Ibid*.
[218] *Ibid*.
[219] *+Space in Portugal and Europe with ESA* (2019) *Portugal Space (the Portuguese Space Agency).* Available at: https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=%3D%3DBAAAAB%2BLCAAAAAAABACzNDAyBADs2aI0BAAAAA%3D%3D (Accessed 29 June 2023
[220] *Ibid*.
[221] *Ibid*., p.25.

Portugal acknowledges its limited capacity to contribute to large exploration missions but still outlines clear objectives in the field of on-orbit manufacturing such as *"strengthening of the scientific "mining" of exploration activities" or "invest in in-situ resource utilisation and in-space manufacturing opportunities."*[222]

The implementation of the ADRIOS (Active Debris Removal/In-Orbit Servicing) project, the first active debris removal and on-orbit service worldwide.[223] Led by Deimos and Critical Software, this project will contribute to the development of the Guidance, Navigation and Control subsystem of ADRIOS. The ADRIOS project exemplifies Portugal's commitment to concrete steps towards the implementation of IOS capabilities.[224]

Overall, Portugal is demonstrating an interest in OSAM and is looking to actively contribute at its level to OSAM capability development through its participation in ESA programmes in order to generate economic growth and stimulate its space industry.

Spain

As a space-faring nation, Spain has a longstanding history of contribution and participation in space activities, particularly within the framework of the European Space Agency. Despite this, the establishment of a formal space agency and a comprehensive space policy framework within the country is a relatively recent development.

However, within this strategic space framework, it is important to note that Spain does not currently have a dedicated OSAM policy. There is no explicit mention of OSAM in its existing space policies. OSAM is not a main priority for Spain's space policy but remains an area of interest. The country is rather focusing on OSAM's key enabling technologies such as small components, GNC, and docking interfaces, in particular for refuelling and ADR. Spain is willing to work on OSAM missions but mostly plans to collaborate with partners for the development of capabilities and conduct of missions as it does not plan to carry them out fully on its own.[225]

Spain's Recovery, Transformation and Resilience Plan (also referred in Spanish as **PERTE Aeroespacial**), emphasises the creation of an innovative and industrial space technology programme and highlights Spain's ambition to assert its space sector prominently within the European commercial space landscape.[226] This includes strengthening the competitiveness of its industry and exploring new small satellite applications, but does not provide any measures regarding OSAM.

While Spain's plans to enable public-private funds to strengthen industry companies, which could provide the necessary capital for innovative businesses focused on OSAM, the state did not yet establish a fund or a budget line focused on OSAM.[227]

At the legal level, Spain is working towards the development of its national space law, in which OSAM is expected to be mentioned, enabling the creation of a more predictable framework for the development of such activities.[228]

---

[222] *Ibid.*, P. 25.
[223] *ADRIOS (Active Debris Removal/ In-Orbit Servicing)*: *Portugal Space (the Portuguese Space Agency)*. Available at: https://ptspace.pt/adrios/ (Accessed: 29 June 2023).
[224] *Ibid*.
[225] Interview conducted by ESPI on August 10th, 2023.
[226] *PERTE Aeroespacial* (2022) *Plan de recuperación transformación y resilienca,* OE5, p. 23.
[227] *Ibid.*, OE9 p.24.
[228] Interview conducted by ESPI on August 10th, 2023.

In conclusion, Spain's strategic focus, although not expressly mentioning OSAM, contains elements essential for OOS development, and Spain is positioning itself as a contributor and partner for European and international OSAM missions by developing key components and technologies.

Switzerland

The declared strategy of Switzerland for the space sector has been to concentrate on the development of its activities in some specific niches (e.g., atomic clocks, payload fairings). However, although some activities related to active debris removal are taking place, on-orbit servicing, assembly, and manufacturing is not yet officially considered as one of these niches.

One of the topics regularly pinpointed by Switzerland in its policy documents and in international *fora* is the need to preserve the sustainability of space activities. The **Swiss Space Policy 2023** identifies sustainability as one of the main trends affecting the space sector. In this context, the document refers to the current development of technical solutions to dispose of space debris, and explicitly mentions the Swiss start-up Clearspace, which develops active debris removal capabilities. Similarly, the publication **Switzerland in Space**, released in 2016, which aims at illustrating the importance of space and the role played by Switzerland, identifies ADR as a way to make the space environment more sustainable. However, there is no description of concrete measures to support the ADR sector. Despite this relatively low profile of OSAM in Swiss policies, an evolution can be noted, as on-orbit servicing was not even mentioned once in the previous space policy released in 2008.

At the 2023 session of the Scientific and Technical Subcommittee of UNCOPUOS, Swiss representatives were also quite vocal regarding the safety and sustainability of space activities, which was one of the main topics tackled during their statements. These concerns were from time to time actively linked to OSAM considerations, in particular ADR. A reference to the mission developed by Clearspace for ESA was made and it was emphasised that "*activities such as in-orbit servicing or active debris removal could be discussed from the angle of the safety of space operations*"[229] in the context of the Working Group on LTS 2.0.

But Switzerland is also aware and highlights the risks related to the technologies that are necessary for OSAM, in particular RPOs. At the UN Open-ended Working Group on Reducing Space Threats (UN OEWG), Swiss representatives stated that "*the depollution of the orbits requires techniques, such as orbital rendezvous and proximity operations (RPOs) and the capturing of objects, that could not only be used for peaceful but also for hostile purposes, and hence bear the risk of misinterpretation. Deliberate close rapprochement to foreign satellites without prior coordination, knowledge or consent may be interpreted as a hostile act and may encourage countries to equip satellites with defensive capabilities, which in turn would raise questions regarding the weaponization of outer space. Adopting transparency and safety measures is therefore key when conducting RPOs.*"[230] These concerns, raised by the dual use of RPO technologies, were reiterated several times. As a consequence, Switzerland expressed its support to the position of Germany and the Philippines, which proposed to characterise the following activities as irresponsible:

- Approaching and/or following ("*shadowing*") an active satellite without prior coordination.

[229] *Statement of Switzerland– point 12 Long-term sustainability of outer space activities* (2023) *Scientific and Technical Subcommittee - United Nations Committee on the Peaceful Uses of Outer Space.*
[230] *Statement of Felix Baumann, Ambassador* (2022) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*

- Conducting rendezvous operations with active satellites of another State without prior consultation and consent.
- Conducting proximity operations that impair the safe operation of another space asset, or during an orbital manoeuvre of the approached satellite without prior consultation, or after the affected State has requested consultations or a cessation of the manoeuvre.

In this context, Switzerland calls for more transparency in the conduct of such operations, the establishment of notification mechanisms, and better space situational awareness data, including through greater international cooperation, in order to alleviate the concerns created by rendezvous and proximity operations.

Switzerland therefore puts emphasis on the importance of sustainability in outer space, but it does not necessarily translate into a push for OSAM activities and the proposal of concrete measures, despite the development of ADR capabilities in the country. The security concerns raised by OSAM-related technologies are also a dimension through which Switzerland addresses this topic.

The table below provides an overview of capability developments carried out by Switzerland in the past five years:

Services	Projects and capabilities
Active Debris Removal	**Under development**
	The start-up **ClearSpace** signed a service contract with ESA of €86.2 million to rendezvous, capture and bring down for re-entry a debris, which is a Secondary Vespa payload adapter. The mission called ClearSpace-1 is scheduled to be launched in 2026. In 2023, the mission passed a programme review, meaning it passed the initial design phase.[231]
Manufacturing	**Announced**
	Prometheus Life Technologies is a Swiss start-up (venture between the University of Zurich and Airbus Defence and Space) that is looking to produce human tissue in microgravity and in space with the objective to contribute to drug development and testing, as well as regenerative medicine. The production process was tested and validated twice on the ISS.

Table 9: Switzerland's capabilities developments in OSAM

Sweden

At the policy level, Sweden does not currently have a dedicated OSAM policy. Both **the Swedish National Space Agency Strategy**, published in 2019, and the **Strategy for Swedish Space Activities** in 2017, do not mention OSAM activities.

Sweden highlights its willingness to guarantee a free and peaceful access to space, especially by underpinning their awareness towards managing orbital space debris, that could essentially threaten space infrastructures. Naturally, this may lead to OSAM activities, especially ADR missions

231

and developments, but no further information or roadmaps are presented in Sweden's national policies.

During the General Debate of the UN OEWG in 2022, the Swedish Ambassador and Head of Delegation, Anna Maj Hultgård described OOS and ADR as emerging markets, both important for a **sustainable** use of space. In parallel, the **dual use of those capabilities** was also mentioned: *"as they are dual use in their nature, it is important that [we] develop the right framework that can facilitate its use while still keeping perceived threats and the risk of conflict at a minimum"*. [232] Sweden also stated that *"rendezvous and proximity operations that are conducted in a non-transparent manner, without proper communication or consent"* can become **security threats** and affect **space safety**.[233] By saying so, Sweden showed its direct support to join other states in the UN OEWG, *"in voicing [our] opinion that consultations and prior consent when conducting rendezvous and proximity operations are necessary and should constitute a norm"*.[234]

Overall, limited information and advancements in the field of OSAM are provided in Sweden's policy documents.

United Kingdom

The United Kingdom does have any dedicated national policies related to OSAM. However, the topic is addressed under other national space policies, mainly within the **UK National Space Strategy**, of 2022, **The National Space Strategy in Action** of 2023, and the **UK Space Power Joint Doctrine Publication** *of* 2022, illustrating a wider interest in the topic.

In its National Space Strategy, the UK views OSAM as an *"emerging market"* leading to several opportunities and threats:

- **Economic opportunity:** the Strategy outlines that the UK *"will explore advanced in-orbit debris removal, servicing, refuelling and assembly technologies, bringing together industry, academia, and government to ensure the UK is ready to grasp the opportunities of the future space economy"*[235], and *"will work to establish early leadership in potential and emerging markets such as on-orbit servicing, space travel and habitation, and active debris removal"*.[236] The UK's willingness to gain a leadership position in OSAM is strengthened in a dedicated section where it mentions the emergence of new technologies and markets in the coming decades. Here, the UK emphasises on the benefits on those services (e.g., OSAM) on relatively medium-term capabilities (i.e., robotics, 3D printing), but also as part of a long-term vision (i.e., space travel and habitation, energy production, use of space resources).
- **Military threat and opportunity:** the Strategy mentions that the UK *"will be able to build and repair satellites in orbit, conduct commercial activities including producing fuel and materials in space to support robotic and crewed space activity, and conduct defence operations to protect and defend our interests in and from space"*.[237]

[232] *Statement by Ambassador Anna-Maj Hultgard* (2022) *General Debate, Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*
[233] Ibid.
[234] *Statement of Sweden – topic 8 Norms, rules and principles relating to information exchange and risk reduction notifications related to outer space activities as well as to consultative mechanisms (2022) Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*
[235] *National Space Strategy* (2021) *Gov.uk*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1034313/national-space-strategy.pdf (Accessed: 10 July 2023).
[236] *Ibid*.
[237] *Ibid*.

- **Sustainability opportunity:** the Strategy outlines that the UK is willing to lead the global effort to make space more sustainable and that it *"will build on UK early advantage in robotics and on-orbit servicing and manufacturing to establish global leadership in space sustainability"*.[238]

In 2023, the UK released the **National Space Strategy in Action**, which provides concrete steps on the delivery and implementation of the **National Space Strategy of 2022**. The strategy aims to, among other things, develop the *"capability to provide services to customers in space, and products made in space for use in space or on earth"* such as *"sustainability services; in space assembly and manufacturing; and space energy and resources."* This is considered as a way to develop resilient space capabilities, further underlying the perception of OSAM through the sustainability and security perspective in the UK. The strategy particularly highlights the UK's interest in developing ADR capabilities both through ESA and national missions, which directly stems from an interest to support responsible space behaviours, maintain a safe and sustainable operating environment, and cement the UK leadership in the new space economy, with the objective to gain *"first mover advantage"*. To do so, the UK is willing to *"engage, contain, and move or remove spacecraft and debris from orbit when desired or required"*, and to develop capabilities and expertise for RPOs so that OSAM missions become *"business as usual,"* as well as to *"prove in space novel technologies (such as in-space manufacturing)"*.[239] The strategy also addresses OSAM from a military perspective as it aims to *"continue to develop a range of operational concept demonstrators for Space Control to help sustain military advantage and freedom of action in space,"*

Similarly, in its **Joint Doctrine Publication**, the UK emphasises the potential use of OOS from a military standpoint, mostly perceiving it as a potential threat. In fact, it highlights numerous times the risks that may occur from rendezvous operations and proximity operations. For instance, it mentions that those operations could *"pose a threat as the intercepting satellite could potentially be used to manipulate, damage or even destroy its target"* under the cover of a debris mitigation programme.[240] On this matter, it puts forward that *"an object designed to remove debris could equally be used to damage or destroy a functioning satellite"*. Additionally, while the document underlines that no fielded ability to refuel satellites in orbit exist for now, there is still *"considerable research activity focusing on this area"* which may presume that an economic opportunity could result from it in the future and that the UK is considering it.

The UK's interest in OSAM is also reflected in the British Parliament and its reports. In the Scientific and Technology Committee of the House of Commons' report, OSAM is extensively mentioned, especially from an economic and sustainability point of view. It suggests that the government should seize the opportunity of becoming a *"global leader in the growing in-orbit and manufacturing market."* The report recalls the focus on ADR and sustainability that the UK adopted, and the role that the State should take to support this objective, outlining that *"the Government has taken positive steps towards supporting the establishment of space debris removal missions [...]. Space debris removal missions should remain a clear focus of Government support and facilitation for the foreseeable future"*.[241] While this parliamentary report does not constitute the official policy or position of the UK's government, it still provides an overview of the interests of parliamentarians as well as in the British public debate.

At the diplomatic level, UK representatives regularly deliver statements on the topic to underline the role of OSAM in support space sustainability and responsible behaviour. During the 2022 Legal Sub Committee of COPUOS, the UK stated that it is looking into prioritising and facilitating *"active*

238 *Ibid*.
239 *Ibid*.
240 *Joint Doctrine Publication 0-40 UK Space Power* (2022) *Ministry of Defence*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1111805/JDP_0_40_UK_Space_Power_web.pdf (Accessed: 10 July 2023).
241 *Ibid*.

debris removal missions to help clean up the orbital environment and ensure a future use of space for all."[242] In addition, the latest UN OEWG on Space Threat was also a forum for the UK to raise its concerns about the dual use of OSAM missions and their potential military threats. In this regard, the British delegation highlighted the necessity for more transparency and trust between countries, and more particularly during OSAM operations.[243] In 2022, it for instance questioned *"how is a state to determine whether the deployment of an on-orbit capability is a test, or preparation for an attack?."*[244] and mentioned that "t*urning to Rendezvous operations, these are integral to active-debris removal and on-orbit servicing. [...] these capabilities could also be repurposed to attack a satellite."*[245]

Overall, it can be noted that the UK is considering ADR as one of its priorities. It considers such missions and services as an opportunity to improve space sustainability as well to develop its industrial and commercial capabilities. Consulted stakeholders reported the UK is also looking into innovative projects such as space-based solar power, ultimately involving, and leading to increasing capabilities in the field of OSAM technologies.[246]

The table below provides an overview of capabilities developments carried out by the UK in the past five years:

Services	Projects and capabilities
	Under developement
Active Debris Removal	In 2021, a consortium led by **Surrey Satellite Technology Ltd** was awarded a study by the UK Space Agency as part of the Low Earth Orbit Pursuit for Active Debris Removal (LEOPARD) project to define concepts and mission requirements to de-orbit two non-cooperative British space systems in LEO. The objective is to launch a demonstration mission in 2025.[247] In 2021, the UK Space Agency commissioned a feasibility study to **ClearSpace** for a mission to remove two British space debris that have been non-functioning for more than a decade.[248] To follow-up, in 2022, the UK Space Agency awarded a contract to ClearSpace UK to conduct the design and design review of what is now called the Clearing the LEO Environment with Active Removal (CLEAR) mission, which will remove the two British space debris. The project also involves British companies as well as foreign companies based in the UK such as Alden Legal, AstroAgency, Critical Software, Deimos, MDA, Orbit Fab, Satellite Applications Catapult, and University of Surrey.[249]

[242] *Statement of the United Kingdom – item 11 Legal mechanisms to space debris and remediation measures* (2023) *Legal Subcommittee United Nations Committee on the Peaceful Uses of Outer Space.*
[243] *Statement by the United Kingdom – exchange of views on the outcome of the second session and outlook towards the third session* (2022) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*
[244] *Statement by the United Kingdom – topic 3 Current and future space-to-space threats by States to space systems* (2022) *Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours.*
[245] *Ibid.*
[246] Interview conducted by ESPI on August 10th, 2023.
[247] *SSTL to lead UK Space Agency project to study active de-orbit of Space Debris* (2021) *SSTL*. Available at: https://www.sstl.co.uk/media-hub/latest-news/2021/sstl-to-lead-uk-space-agency-project-to-study-active-de-orbit-of-space-debris (Accessed: 16 June 2023).
[248] *Leading space innovator ClearSpace opens for business in the UK* (2023) *ClearSpace*. Available at: https://clearspace.today/leading-space-innovator-clearspace-opens-for-business-in-the-uk/ (Accessed: 13 May 2023).
[249] *ClearSpace secures a major UK contract to help clean up space* (2023) *ClearSpace*. Available at: https://clearspace.today/clearspace-secures-a-major-uk-contract-to-help-clean-up-space/ (Accessed: 13 May 2023).

	In 2022, the UK Space Agency also awarded a contract to **Astroscale**[250] to design a satellite servicer to remove debris for the future Cleaning Outer Space Mission through Innovative Capture (COSMIC) mission, which will remove two outdated British satellites by 2026. The COSMIC mission will leverage the technology developed by Astroscale as part of the ELSA-M mission, which will be launched prior to COSMIS in 2024, to develop a robotic capture capabiltiy. Astroscale is working with other British companies and foreign companies with a base in the UK such as MDA UK, Thales Alenia Space UK, Nammo, GMV-NSL, NORSS, Goonhilly, Satellite Applications Catapult, and Willis Towers Watson.[251]
Space Logistics	**Under development** The British company **Lúnasa Space** is developing a Versatile and Intelligent Architecture (VIA), which is an OTV to transport satellites to their final orbital destination and provide life extension services. The VIA is expected to be able to relocate satellites to new orbits, provide attitude control to serviced satellites that do not have or lost manoeuvring capabilities.[252] The start-up **Skyrora** is also developing a Space Tug to conduct in-orbit logistics missions and deliver satellites to their final orbits.[253]
Assembly	**Under development** The **University of Surrey** – Surrey Space Centre is developing the Autonomous Assembly of a Reconfigurable Space Telescope (AAReST) to demonstrate the launch and assembly of a telescope in orbit in collaboration with the **California Institute of Technology** (CalTech) and **Indian Institute of Space Science and Technology**. Launch is expected in 2023.[254]

Table 10: The United Kingdom's capabilities developments in OSAM

4.1.2 Comparative assessment of doctoral research in OSAM in Europe

Beyond capabilities and missions developed by State actors and private companies, assessing the state of capabilities developments in the field of in-orbit servicing would not be complete without looking at doctoral research and development efforts in academia.

Therefore, this section consists of a mapping of research activities conducted by European universities in the field of in-orbit servicing, assembly, and manufacturing between 2018 and 2023.

[250] *Astroscale, securing space sustainability* (2023) *Astroscale*. Available at: https://astroscale.com/about-astroscale/about/ (Accessed: 13 May 2023).
[251] McPhail, T. (2022) *Astroscale forges ahead with UK Active Debris Removal Mission with support from UK space agency*, *Astroscale*. Available at: https://astroscale.com/astroscale-forges-ahead-with-uk-active-debris-removal-mission-with-support-from-uk-space-agency/ (Accessed: 15 May 2023).
[252] *Company spotlight: Lúnasa Space* (2023) *Satellite Applications Catapult*. Available at: https://sa.catapult.org.uk/blogs/company-spotlight-lunasa-space/ (Accessed: 29 April 2023).
[253] *Providing In-Space Services to Satellites and Spacecrafts In-Orbit - Space Tug: Skyrora*. Available at: https://www.skyrora.com/space-tug/#section-5 (Accessed: 07 June 2023).
[254] Kulu, E. (2023) *Aarest MirrorSat 1* , *Nanosats Database*. Available at: https://www.nanosats.eu/sat/aarest-mirrorsat1 (Accessed: 07 June 2023). r

Methodology

The mapping exercise explored the extent and depth of research conducted in the field of in-orbit servicing, assembly, and manufacturing in universities across Europe, by focusing exclusively on PhD theses conducted between 2018 and 2023 as well as university programmes dedicated to ISAM.

The mapping was conducted based on open-source information available online as well as direct contacts with European universities. Through a web scrapping method, 259 European universities engaged in space-related education in 33 countries were assessed against a set of keywords[255] pertaining to the field of in-orbit servicing, assembly, and manufacturing along with investigations of national theses repositories and academic databases. The scope of the mapping focused only on PhD theses and did not take into account bachelor and master's theses, as well as other academic publications or conference papers.

Yet, it is important to note that the interest in OSAM is not confined to doctoral research. While it was not the focus of the mapping, it seems that there is a great interest in OSAM from bachelor's and master's theses, and other academic publications such as but not limited to academic journals, university conferences, or articles submitted to the International Astronautical Congress (IAC), indicating a significant interest on OSAM in the wider academic community.

Limits to the methodology include the heterogenous availability of information available online regarding recent and current PhD theses conducted by universities as well as the availability and accessibility of information in languages not spoken by the ESPI research team. As a result, the mapping strived to be as comprehensive as possible, but is likely non-exhaustive.

Analysis

The mapping showcased that 50 PhD theses on on-orbit servicing, assembly, and manufacturing (OSAM) were conducted between 2018 and 2023 in Europe.

A significant majority of mapped PhD theses focuses on aerospace engineering and computer science. Only a few focus on legal issues. It does not seem that PhD in the field of political science, space science, or physics were conducted on the topic of OSAM despite some findings of PhD theses in physics but without apparent links to OSAM (e.g., entry of objects in the atmosphere not linked to deorbiting/ADR). Yet, this unbalanced breakdown of PhD theses per academic field still demonstrates the interdisciplinary aspects of OSAM.

Anthea Comellini, who was recently inducted into ESA's astronaut reserve, successfully defended her PhD thesis on On-orbit Servicing in 2021.

The mapping illustrated that **no European university programme is entirely dedicated to OSAM.** However, **some centres, programmes, or initiatives include OSAM and/or key enabling technologies among their activities**. Several centres conduct R&D related to OSAM such as but not limited to the Interdisciplinary Centre for Security, Reliability and Trust (SnT) at the University of Luxembourg, or the Surrey Space Centre at the University of Surrey.

One prominent example, which led to commercial developments, is the Space Center of the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. The EPFL Space Center was

[255] Keywords were searched in several languages and included: In-Orbit Servicing (IOS), Spacecraft Servicing, On-Orbit Servicing (OOS), Satellite Servicing, space Debris Removal Active Debris Removal (ADR), On-Orbit Satellite Life Extension, Satellite Refueling Space Tug, Space Tether, In-Orbit Assembly, In-Orbit Manufacturing On-Orbit Repair Autonomous Servicing, relocation, station-keeping, satellite inspection, space robotics, robotic Servicing of Geosynchronous Satellites (RSGS), Mission Extension Vehicle (MEV), In-space servicing missions, Satellite Repurposing.

established to promote space research and activities within EPFL and Switzerland. The activities of the EPFL Space Centre focus on education, research, and awareness raising. Its activities are divided between three themes: Space Technology and Innovation; Space Science and Engineering; and Sustainable Space and Diplomacy.[256] Therefore, its activities are inherently interdisciplinary. While its focus is not entirely dedicated to OSAM, many of its activities focus on OSAM. Some PhD theses were conducted in the past few years on space logistics and active debris removal.

The EPFL Space Center also enabled the creation of a spin-off start-up called ClearSpace, which is working on space debris and active debris removal. In 2019, ClearSpace was selected by ESA to conduct an ADR mission on a Vespa upper stage in 2026. ClearSpace's activities also led to side academic work from the EPFL Computational Solid Mechanics Laboratory (LSMS) on debris capture systems as well as from the EPFL ESL and CVLab on relative navigation and vision algorithms.[257]

Geographically, the mapping exhibits a clear concentration of research activity in France, Germany, Italy, and the United Kingdom. Within the UK, Scotland stands out as a significant contributor to the UK's research output, accounting for almost 50% of research on OSAM.

Overall, out of the 50 PhD analysed, **28% were or are being conducted in the United Kingdom, 18% of them were or are being conducted in France, and 14% of them were or are being carried out in Germany and 12% in Italy.** As a result, the concentration of OOS research within only 10 out of the identified 33 countries points to a significant disparity in the distribution of this specialised research across Europe. The vast majority of the OOS research is confined to less than a third of European countries.

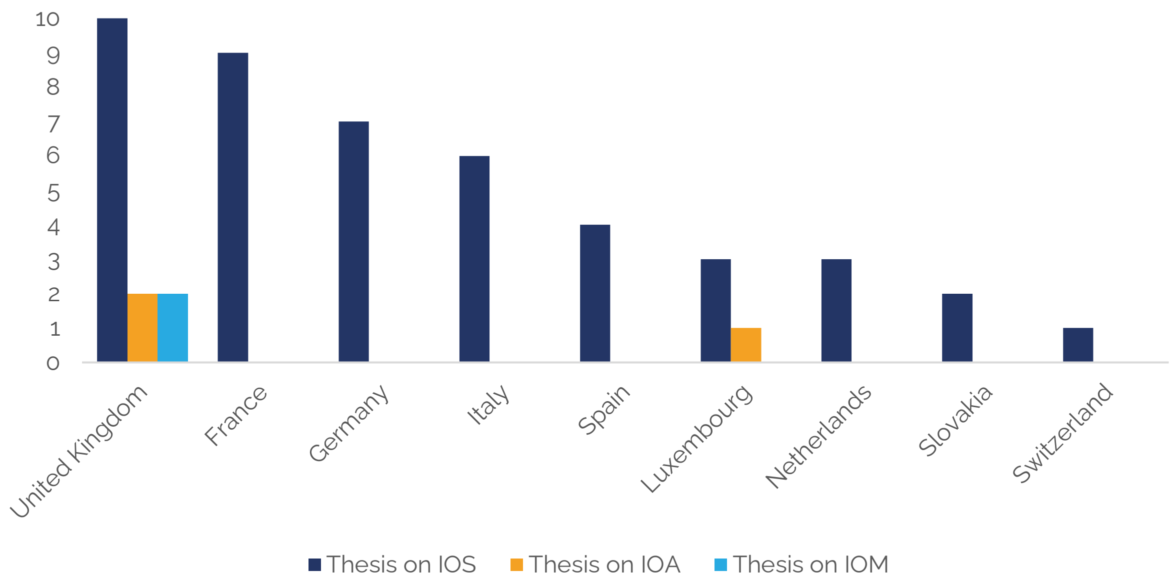

Figure 12: Number of PhDs in OSAM per country

Prominent universities where these PhDs were conducted include the University of Luxembourg (Luxembourg), the Technical University of Berlin (Germany), the Polytechnic University of Turin (Italy), ISAE SUPAERO (France), Université Toulouse III - Paul Sabatier (France) the University Carlos II of Madrid (Spain), and Delft University of Technology (Netherlands).

[256] *About Us* (no date) EPFL. Available at: https://espace.epfl.ch/about-us/espace/ (Accessed: 15 April 2023).
[257] EPFL Space Center – a center of excellence in space (2022) EPFL Available at: https://espace.epfl.ch/wp-content/uploads/2022/08/eSpace_Activities_2021.pdf (Accessed: 17 April 2023).

Naturally, countries in which PhD theses are written in the field of on-orbit servicing, manufacturing, and assembly are the European countries, which have the highest space budget and are making the highest financial contributions to the European Space Agency, which is mostly doing R&D. ESA is also providing funding or conducting R&D projects with universities in these countries in the field of OOS, which may stimulate the interest for doctoral research on a wider scale in these universities.

4.2 Assessing policy, regulatory, and capabilities development in the rest of the world

Beyond Europe, various spacefaring nations are developing capabilities and policy postures with regard to OSAM. Analysing their developments is essential to better understand, assess, and compare Europe's progresses in this field. This section provides an overview of current developments taking place in the following countries: Australia, Canada, China, India, Japan, Russia, South Korea, United Arab Emirates, and the United States. Countries are presented in alphabetical order and not in any order of hierarchy or importance.

Australia

Australia's space policy mostly focuses on space application (i.e., Earth Observation, Navigation, Communications), the development of the space industry in areas where Australia can have a competitive advantage, access to space, and Space Situational Awareness capabilities.

Australia does not have a dedicated policy for OSAM. However, **the Australian Civil Space Strategy 2019-2028** mentions on-orbit servicing as an area of opportunity for Australia to *"commercialise R&D that would grow and transform (our) space sector."*[258] However, it does not outline specific measures.

The **Australian Space Defence Strategy** mentions on-orbit servicing as a new business model for *"non-traditional state actors, smaller nations, and commercial companies."* The Strategy seems to see it both as a potential economic opportunity and a threat to sustainability in outer space by putting OSAM in the same category as mega constellations, which make orbits congested.[259]

The **Australian Decadal Plan for Australian Space Science** does not mention OSAM.

At the legal level, the **Space (Launches and Returns) Act 2018** contains provisions that compel space operators to integrate a debris mitigation strategy to obtain a launch permit, which can include on-orbit services. However, the Act does not explicitly mention active debris removal or other on-orbit services.[260]

At the diplomatic level, Australia does not seem to have addressed the topic of OSAM in its statements at UNCOPUOS or at the UN OEWG on Reducing Space Threats in the past years.

At the programmatic level, there are no specific programmes dedicated to on-orbit services in Australia. Yet, according to the **Australian Space Industry Capability report of 2017**, the Space

[258] *Advancing Space Australian Civil Space Strategy 2019 – 2028* (2019) *Australian Government, Department of Industry Science and Resources*. Available at: https://www.industry.gov.au/sites/default/files/2022-07/advancing-space-australian-civil-space-strategy-2019-2028.pdf (Accessed: 28 June 2023).
[259] *Australia's Defence Space Strategy: Air Force*. Available at: https://view.publitas.com/jericho/australias-defence-space-strategy/page/1 (Accessed: 28 June 2023).
[260] *Space (Launches and Returns) Act 2018* (2019) *Federal Register of Legislation*. Available at: https://www.legislation.gov.au/Details/C2019C00246 (Accessed: 28 June 2023).

Environment Research Centre has the potential to contribute to technological development for active debris removal.[261]

Overall, while OSAM is acknowledged in Australian public policies, it does not seem to be a main priority. However, Australia is putting the priority on the development of SSA capabilities (due to its ideal geographical position), which is a prerequisite for OSAM.

The following table provides a non-exhaustive overview of current projects in the field of OSAM in Australia:

Services	Projects and capabilities
Inspection	**Announced** The start-up **HEO Robotics** is developing the Software-as-a-Service solution HEO Inspect. The company collaborates with other space companies by either putting cameras on their satellites or by providing a software that enable the customer satellite operator to have the capability to take satellite images of the Earth as well as to turn the cameras to take photos of another spacecraft in orbit.[262] HEO Robotics is also partnering with the U.S. start-up Turion Space to develop the Droid spacecraft, which is expected to gather in-space SSA and have close inspection capabilities to provide commercial services by 2024.[263]
Space Logistics	**Under development** The start-up **Space Machines Company** is developing an OTV for last mile delivery services called Optimus. In 2023, Space Machine Company launched its OTV on a SpaceX rideshare mission and demonstrated space logistics with Optimus.[264] The company is also looking to expand to in-orbit servicing such as refuelling, life extension, deo-orbiting, inspection, repair, and assembly.[265]
Assembly	**Under development** The start-up **Sperospace** is developing a robotic arm as part of a project for the Australian Space Agency in order to demonstrate on-orbit assembly. The company is also developing a robotic end effector under a grant provided by ASA. In addition, Space Machine Company contracted Sperospace to

[261] *Australian Space Industry Capability* (2017) *Acil Allen Consulting*. Available at: https://www.industry.gov.au/sites/default/files/2019-03/australian_space_industry_capability_-_a_review.pdf (Accessed: 28 June 2023).
[262] *Heo Robotics puts eyes on satellites to make space safer* (2023) *Business News Australia*. Available at: https://www.businessnewsaustralia.com/articles/sydney-s-heo-robotics-putting-eyes-on-satellites-to-make-space-safer.html (Accessed: 29 April 2023).
[263] *Domain Awareness & Orbital Transport: Turion Space*. Available at: https://turionspace.com/ (Accessed: 30 May 2023).
[264] Roberts, P. (2022) *Space Machines to launch its Optimus in-space orbital transfer vehicle*, *Australian Manufacturing Forum*. Available at: https://www.aumanufacturing.com.au/space-machines-to-launch-its-optimus-in-space-orbital-transfer-vehicle (Accessed: 05 June 2023).
[265] *Fit for every mission*: *Space Machines Company*. Available at: https://www.spacemachines.co/technology (Accessed: 05 June 2023).

	develop and integrate a payload to test the effect of cold welding in space. The payload is expected to be launched in 2024.[266]
Manufacturing	**Announced**
	The start-up **Exodus Space Systems** is developing the Carousel Spacelab project, a small free flying centrifuge that is expected to allow in-space manufacturing.[267]

Table 11: Australia's capabilities developments in OSAM

Canada

Canada is a spacefaring nation with historical capabilities in the field of OSAM, in particular robotics and assembly through Canadarm and Canadarm2 as part of missions on the ISS.

Despite technical expertise in some OSAM-related technologies, Canada does not have a dedicated national policy for OSAM activities. Yet, the topic is addressed in Canadian space policy documents such as the Canadian **New Space Strategy of 2019**, and **Canada's Space Policy Framework of 2019**. Canada appears to see OSAM mostly from an economic and sustainability perspective.

The new Space Strategy underlines a vision of OSAM as an emerging domain and an economic opportunity for Canadian commercial space companies. It hopes to position its national companies as *"global leaders in the future on-orbit servicing market."* To do so, Canada is putting a strong emphasis on its legacy technology acquired thanks to Canadarm and is willing to leverage this know-how in other areas such as AI and deep-space robotic systems.

Canada also seems to perceive OSAM activities from a sustainability standpoint as per Canada's **Space Policy Framework**. It builds the link between the ISS Canadian robotic *"handyman"* Dextre and its impact on reducing space debris. It presents how this dexterous robot was able to both perform *"cutting-edge technology demonstrations"* and prove how *"robots could service and refuel satellites in space to extend their lifetimes and reduce orbital debris,"* from the exterior of a station. Similarly, the paper highlights Canadarm2 capability to assemble space infrastructures, or capture, dock and release visiting spacecrafts.

At the diplomatic level, Canadian delegations also regularly express their national views on OSAM, mainly from a **sustainability perspective** at UNCOPUOS in 2023. During all sessions, including the plenary sessions, and both the STSC and LSC, Canada was supporting and in favour of going beyond the LTS guidelines and the IADC guidelines through ADR missions. It considers that the issue of space debris should be addressed in a holistic way with both mitigation and retrieval. In addition, Canada is also supporting the development of standardised space systems so that they can be designed to be serviced, including interfaces for removal: *"[we] commend the European Space Agency's "net zero" space debris objective to improve end-of-life management of space objects, for example, by promoting "design for removal" requirements".*[268] During LSC sessions, Canada raised that legal issues are to be considered, especially when it comes to debris remediation or removal. According to them, *"the concepts of jurisdiction, control, responsibility, and liability in space law require*

[266] *Projects*: *Sperospace*. Available at: https://www.sperospace.com/projects (Accessed: 05 June 2023).
[267] *News* (2022) *Exodus Space Systems*. Available at: https://exodusspacesystems.com/news/ (Accessed: 05 June 2023).
[268] *Statement of Canada – item 7 Space Debris (2023) Scientific and Technical Subcommittee - United Nations Committee on the Peaceful Uses of Outer Space.*

examination in the context of remediation".[269] At the national level, the Canadian space law focuses on space debris mitigation but does not address OSAM.

At the programmatic level, the Canadian Space Agency (CSA) is supporting ongoing research and development for OSAM future capabilities. Canada takes part in the Lunar Gateway project, which is led by NASA and part of the Artemis programme. Canada is responsible for building the Canadarm3 by 2028, which will use advanced machine vision and AI to *"maintain, repair and inspect the Gateway, capture visiting vehicles, relocate Gateway modules, help astronauts during spacewalks, and enable science in lunar orbit".*[270] Within this project, CSA has a funding role, and already announced a financial support of $22,8 million to MacDonald, Dettwiller, and Associates Ltd. (MDA) for establishing the technical requirements of the project[271], and a $269 million to execute its second phase.[272] Canadarm3 project is expected to involve hundreds of Canadian companies.

Overall, Canada's posture regarding OSAM is almost entirely revolving on its contribution to the ISS as it is looking to build upon these legacy capabilities in maintenance and assembly to build new ones. Canada is mostly perceiving OSAM from a sustainability and economic point of view and does not seem to address the issues from the defence perspective.

The following table provides a non-exhaustive overview of current projects in the field of OSAM in Canada:

Services	Projects and capabilities
Repair	**Announced**
	Orbruta Space Solutions developed the Rendezvous, Proximity Operations, and Docking (RPOD) Kit, which is a turnkey solution to install on a satellite to ensure docking and make the spacecraft serviceable, including for satellite hardware upgrade and replacement.[273]
	Operational
	Dextre is a robot on board the ISS. It features seven joints with a retractable motorised wrench, a camera and lights, a retractable connector for power, data, and video connection with capabilities to support astronauts' activities, install and replace small equipment on the ISS, replace components, test tools that aim to develop on-orbit servicing.[274]
Assembly	**Operational**

[269] *Statement of Canada – item 3 General exchange of views* (2023) *Legal Subcommittee - United Nations Committee on the Peaceful Uses of Outer Space.*
[270] *About Canadarm3* (2023) *Canadian Space Agency*. Available at: https://www.asc-csa.gc.ca/eng/canadarm3/about.asp (Accessed: 16 July 2023).
[271] *Moon Exploration News - 2020* (2020) *Canadian Space Agency*. Available at: https://www.asc-csa.gc.ca/eng/astronomy/moon-exploration/news-2020.asp (Accessed: 16 July 2023).
[272] *Canada begins design phase of CANADARM3 for Lunar Gateway* (2022) *Government du Canada*. Available at: https://www.canada.ca/en/space-agency/news/2022/03/canada-begins-design-phase-of-canadarm3-for-lunar-gateway.html (Accessed: 13 July 2023).
[273] Equip your spacecraft for autonomous RPOD - Our Products & Services (no date) Obruta Space Solutions. Available at: https://www.obruta.com/products (Accessed: 13 May 2023).
[274] Canadian Space Agency (2022) About Dextre, *Canadian Space Agency*. Available at: https://www.asc-csa.gc.ca/eng/iss/dextre/about.asp (Accessed: 14 September 2023).

Canadarm2 is on board the ISS. It is 17-metre-long robotic arm enabled the assembly of the orbiting laboratory. It carries out maintenance on the ISS, move supplies, equipment, Dextre and astronauts, and can grapple vehicles and dock them to the ISS.[275]

Table 12: Canada's capabilities developments in OSAM

China

China is a major space power with significant capabilities in OSAM and policy objectives to further develop in this domain.

Chinese progress in OSAM stems from decisions dating back to 1992 in which the government decided to implement a manned space programme through a three-step approach. This strategy aimed at first developing capabilities to develop human spaceflight capabilities and conduct related experiments, followed by the development of EVA capabilities as well as space rendezvous and docking for both crewed and uncrewed spacecraft, to then launch its own space station.[276] The Chinese Manned Space Agency (CMSA) eventually developed the Tiangong space station and launch the first module Tianhe in 2021, the second module Wentian in 2022, and the third Module Mengtian in 2022. The station was assembled in orbit and completed in November 2022 after the final docking of the Mengtian module, thereby demonstrating assembly capabilities.[277]

The National Natural Science Foundation has been tasked by **the 14th Five-Year Plan (2021-2025)** to start working on the in-orbit assembly of a mega-spacecraft.[278] The country also plans a space-based solar power station, which will have capabilities for orbital assembly in phases 3 (2035) and 4 (2050) of the project. To this end, some researchers are also proposing the concept of a multirobot on-orbit assembly antenna.[279]

More generally, Chinese space policy appears to be increasingly focused on the development of new advanced technologies, on-orbit servicing, and space environment governance. In its latest **White paper**, on-orbit servicing, in particular active debris removal, is seen from an economic perspective and described a *"new business model for upscaling the space economy."*[280]

China's focus over the next five years will be on advancing OSAM technologies through the strengthening of space traffic control, the improvement of space debris monitoring systems (SSA), and the conduct of on-orbit maintenance. China aims to test technologies such as smart self-management of spacecraft, space mission extension vehicles (for life extension), innovative space propulsion, on-orbit service and maintenance of spacecraft, as well as space debris cleaning.[281] These objectives will contribute to the development of capabilities in the field of OSAM.[282]

China has been developing ADR capabilities. However, it seems difficult to assess the exact level of advancement of the Chinese space programme in this field. Indeed, in 2016, China launched the Aolong-1 satellite, also called Advanced Debris Removal Vehicle (ADRV), which was developed by

[275] *Ibid.*
[276] About CMS_CHINA manned space. Available at: http://en.cmse.gov.cn/aboutcms/ (Accessed: 14 September 2023).
[277] Jones, A. and Dobrijevic, D. (2021) *China's Space Station, Tiangong: A complete guide, Space.com*. Available at: https://www.space.com/tiangong-space-station (Accessed: 14 September 2023).
[278] Global Times. (2021) *China to study assembly mechanics of kilometer-level extra-large spacecraft*, *Global Times*. Available at: https://www.globaltimes.cn/page/202108/1232426.shtml (Accessed: 05 June 2023).
[279] Li, D. *et al.* (2022), *op. cit.*
[280] *Full text: China's space program:* A 2021 perspective. Available at: https://english.www.gov.cn/archive/whitepaper/202201/28/content_WS61f35b3dc6d09c94e48a467a.html (Accessed: 14 September 2023).
[281] 2022 China's Space Program: A 2021 Perspective. *The State Council Information Office of the People's Republic of China*, P. 7.
[282] *Ibid*. P. 20.

the Harbin Institute of Technology to demonstrate a debris capture with a robotic arm. However, according to the Secure World Foundation, SSA data demonstrated that Aolong-1 did not rendezvous with any space object, suggesting that the experiment was likely conducted in a simulated environment.[283]

China also seems to see OSAM through the military perspective. The China Aerospace Studies Institute (CASI) reported that courses materials of the Chinese Academy of Military Sciences described a *"Space Flight Combat Force"* that would be composed of space shuttles and space planes that would be able to conduct space operations including inspection, maintenance, refuelling and testing in orbit. While China is developing the suborbital space plane Shenlong, which is expected to be a similar system to that of the U.S. x-37B, it is not clear whether these courses materials translate programmatic objectives or simply theoretical prospective analyses.[284]

Overall, information about Chinese space activities is sometimes difficult to map but suggests clear policy and programmatic objectives in the field of OSAM, with particular emphasis on assembly, inspection, and ADR.

The following table provides a non-exhaustive overview of current projects in the field of OSAM in China:

Services	Projects and capabilities
Refuelling	**Under development**
	In 2021, the Shanghai Academy of Spaceflight Technology unveiled its Supplemental Service Vehicle at the Zhuhai Airshow in September. The system was presented as a commercial service spacecraft that can provide life extension services in GEO. The Vehicle can carry 1.3 tons of fuel and refuel satellites.[285]
	Operational
	The Tianzhou cargo spacecraft has the capability to dock with the Tiangong space station to refuel the space station with propellant and cargo.[286]
Active Debris Removal	**Under development**
	The Shenyang Institute of Automation of the Chinese Academy of Sciences (CAS) has been conducting research and development on ADR and in-orbit capture.[287]

[283] Global Counterspace Capabilities: An Open Source Assessment (2023) Secure World Foundation. Available at: https://swfound.org/media/207567/swf_global_counterspace_capabilities_2023_v2.pdf (Accessed: 13 May 2023).
[284] Military-civil fusion terminology: A reference guide - air university. Available at: https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/CASI%20Articles/2021-03-15%20MCF%20Lexicon.pdf?ver=ERteHVCsjK2IBa6__DAldw%3d%3d (Accessed: 14 September 2023).
[285] *'Space Oil Tank Truck' makes debut at airshow China, provides energy for satellites' long-term operation* (2021) *Global Times*. Available at: https://www.globaltimes.cn/page/202109/1235426.shtml (Accessed: 03 May 2023).
[286] Tianzhou 5 reconnects with Tiangong Space Station (no date) Chinadaily.com.cn. Available at: https://www.chinadaily.com.cn/a/202306/06/WS647e88bfa31033ad3f7baaf0.html (Accessed: 14 September 2023).
[287] *How scientist designed an 1U-sized deployable space manipulator for future* (2022) *Scienmag*. Available at: https://scienmag.com/how-scientist-designed-an-1u-sized-deployable-space-manipulator-for-future-on-orbit-servicing-assembly-and-manufacturing-2/ (Accessed: 01 June 2023).

	Demonstrated/Concluded
	Tianjin University developed a robotic arm that is expected to grab pieces of debris. The arm is composed of superelastic metal alloy of nickel and titanium. The university conducted tests on the ground for capturing non-cooperative objects.[288]
	Operational
	In 2021, China launched the Shijian-21 (SJ-21) mission, which is a debris removal satellite that was launched to GEO. In 2022, the Shijian-21 spacecraft docked with the Chinese Beidou-2 G2 satellites, relocated it above the GEO belt, beyond the traditionally used graveyard orbit. The servicer Shijian-21 had the capability to service other space systems.[289]
Inspection	**Operational**
	China has been developing RPO capabilities with the SJ-06F, Shiyan 7, SJ-15 satellites to manoeuvre across LEO. In GEO, China developed the SJ-17, TJS-3, and SJ-21, Shiyan-12 01, and Syhiyan-12 02 satellites that have the capability to conduct RPOs. It is not clear to what extend these satellites also have inspection capabilities.[290]
Assembly	**Under Development**
	The Changchun Institute of Optics, Fine Mechanics and Physics launched the Ultra-Large Aperture On-Orbit Assembly Project with the University of Surrey. This joint endeavour aims at building in orbit a 10m aperture space telescope.
	Demonstrated/Concluded
	In 2021 and 2022, China launched the three modules of the Chinese Space Station Tiangong and demonstrated assembly in orbit.
Manufacturing	**Demonstrated/Concluded**
	In 2020, China conducted an in-orbit 3D experiment of the Space-based Composite Material 3D Printing System in LEO.

Table 13: China's capabilities developments in OSAM

India

A review of Indian space policy documents and debate shows that on-orbit servicing, assembly and manufacturing is not a major topic for the country. None of the flagship programmes developed by India focuses on this kind of activities, and priority is given to space applications (Earth observation,

---

288 *China develops new tentacle-like robot to clear space debris* (2021) *chinadailyhk*. Available at: https://www.chinadailyhk.com/article/156990 (Accessed: 14 May 2023).
289 Jones, A. (2023) *China's shijian-21 towed dead satellite to a high graveyard orbit*, *SpaceNews*. Available at: https://spacenews.com/chinas-shijian-21-spacecraft-docked-with-and-towed-a-dead-satellite/ (Accessed: 14 April 2023).
290 *Global Counterspace Capabilities: An Open-Source Assessment* (2023) *Secure World Foundation* Op Cit.

telecommunications, and navigation), which can support the development of the country, as well as human spaceflight missions and science. OSAM is not part of the **Vision, Mission and Objectives of the Department of Space**[291] and is not mentioned in the achievements of the Department of Space between 2014 and 2022.[292]

Despite this situation, OSAM is sometimes touched upon in official documents. The **Indian Space Policy** released in 2023, which was created to support the development of the sector in the country, makes limited reference to this topic. In particular, the document calls for the establishment of measures to encourage non-governmental entities to "*provide end-to-end services for safe operations and maintenance in space.*"[293] In-situ resource utilisation, which may be seen as a component of on-orbit manufacturing, is also promoted. Indeed, ISRO is directed to "*undertake studies and missions on in-situ resource utilization, celestial prospecting and other aspects of extra-terrestrial habitability*".[294] Beyond these two elements, other elements of OSAM activities are overlooked.

Similarly, the policy document **Commitment towards a reformed space sector: Unlocking the space sector**[295], released in 2020 during the creation of the Indian National Space Promotion and Authorisation Centre (IN-SPACe) makes no reference to OSAM efforts while it explains how India will foster its private space sector to grab a bigger share of the global space economy.

Even though OSAM is not at the core of Indian space policy, Indian representatives have already addressed the topic in their declarations in multilateral *fora* but, here as well, in a very limited manner. Thus, at the UNCOPUOS Legal Subcommittee taking place in 2023, the Indian delegation demonstrated awareness on the matter by asserting that *"Active debris remediation technology, while still in its developmental stage, presents several legal challenges that are yet to be addressed on a broader, international scale. Ensuring safe and responsible debris remediation and removal measures will therefore require effective legal and policy approaches".*[296] However, no other mention of OSAM was made by India during the three sessions of the COPUOS of 2023.

Overall, activities of the country in on-orbit servicing, assembly and manufacturing are rather limited, with the exception of the development of technologies that can be useful for human spaceflight, given the ambition of the country to launch its own manned mission in the short-term.

Japan

Japan is a major spacefaring nation in Asia with significant capabilities and a clear interest in OSAM. Activities in this domain are mostly centred around one company, which is Astroscale with a focus on refuelling, active debris removal, and attitude control/orbit correction.

At the policy and legal level, several documents take OSAM into account and govern these operations. Indeed, **the Guidelines on licensing for the management of satellites performing in-orbit services** provides concepts and specific measures to ensure transparency of the technology

[291] *Vision, Mission and Objectives of the Department of Space. Indian Space Research Organisation*. Available at: https://www.isro.gov.in/Vision-Mission-Objectives.html (Accessed: 10 July 2023).
[292] *Year-End Review -2022: Department of Space* (2022) *Department of Space*. Available at: https://pib.gov.in/PressReleseDetail.aspx?PRID=1887687 (Accessed: 10 July 2023).
[293] *Indian Space Policy* (2023) ISRO. Available at: https://www.isro.gov.in/media_isro/pdf/IndianSpacePolicy2023.pdf (Accessed: 17 July 2023).
[294] *Ibid*.
[295] *Commitment towards a reformed space sector: Unlocking the space sector* (2020) *ISRO*. Available at: https://static.pib.gov.in/writereaddata/userfiles/unlocking_the_space.pdf (Accessed: 20 July 2023).
[296] *Statement of Inda – item 11 General Exchange of information and view on legal mechanisms relating to space debris mitigation measures, taking into account the work of the Scientific and Subcommittee* (2023) *Legal Subcommittee - United Nations Committee on the Peaceful Uses of Outer Space.*

to the international community for the purpose of providing satellites and other in-orbit services that rendezvous with or operate in close proximity to other space objects. The guidelines apply to various phases, namely rendezvous, proximity operations, final approach and capture, service, and separation phases.[297] In addition, the **Satellite Management Plan** clarifies the status of the target object in orbit, the status of the spacecraft on which rendezvous and other operations are to be performed, the launch configuration, the conditions for ensuring stable operations during capture and docking, and the decision criteria for the transition to the movement phase.

Also, as a signatory of **the Artemis Accord**, Japan adopted the **Act on the Promotion of Business Activities for the Exploration and Development of Space Resources**, or **Space Resources Act of Japan** to enable private stakeholders to exploit space resources and govern these activities (e.g., permits, ownership, etc.).[298]

In March 2022, Japan published the **Mid-to Long-term Policy on Efforts for Rule-Making on the Use of Earth Orbit,** which address collision avoidance, Space Situation Awareness, debris mitigation and large constellations.

Furthermore, the **Basic Plan on Space Policy** plans for the development of ADR and seems to perceive this technology as an economic opportunity. To implement the **Basic Plan**, JAXA has started the Commercial Removal of Debris Demonstration (CRD2) programme with the aim of establishing ADR as a new business field and developing a new market where the private sector can play an active role.[299]

In this spirit, the Japanese Government is highly supporting the private company Astroscale to foster the creation of an OSAM market. For instance, Astroscale and JAXA are developing systems together under the **JAXA Space Innovation through Partnership and Co-creation (J-SPARC) programme**, which enables space companies to co-create systems, including but not limited to OSAM, to eventually commercialise them.[300] In addition, the Japanese Ministry of Economy, Trade, and Industry announced it is financially supporting the R&D efforts of Astroscale on robotic arms and robotic hands technologies that can be used to conduct ADR missions and other in-orbit services..[301] Unlike other countries such as the U.S., France, or the UK, which are supporting a wide range of start-ups in hope that a few will truly develop and access the market, Japan seems to bet on a few commercial and R&D actors only.

At the diplomatic level, OSAM is not the main focus of Japanese delegations' statements at COPUOS, but it is regularly mentioned, mostly from the perspective of space sustainability, underlining the efforts of Japan in developing ADR and related capabilities and emphasising on the adoption of its national guidelines on OOS.[302]

At the academic level, several universities are involved in the R&D of OSAM, in cooperation or not with JAXA. For instance, the University of Tokyo is conducting research aiming at the realisation of "intelligent" space systems. One of the main research areas is spacecraft control problems including

[297] Cabinet Office (2021). Available in Japanese at: 軌道上サービスを実施する人工衛星の管理に係る許可に関するガイドライン) (Accessed: 07 July 2023)

[298] *Japan: Space Resources Act Enacted* (2021) *The Library of Congress*. Available at: https://www.loc.gov/item/global-legal-monitor/2021-09-15/japan-space-resources-act-enacted/ (Accessed: 06 July 2023).

[299] Cabinet Office (2022). Available in Japanese at: 宇宙基本計画工程表 (Accessed: 07 July 2023)

[300] *Astroscale Japan and JAXA launch co-creation project for Satellite Refuelling Service Concept* (2022) *JAXA*. Available at: https://global.jaxa.jp/press/2022/12/20221207-1_e.html (Accessed: 06 June 2023).

[301] Howlett, A. (2021) *Astroscale advances on-orbit servicing technologies with Mitsubishi Heavy Industries and the Government of Japan*, *Astroscale*. Available at: https://astroscale.com/astroscale-advances-on-orbit-servicing-technologies-with-mitsubishi-heavy-industries-and-the-government-of-japan/ (Accessed: 12 June 2023).

[302] *Statement of Japan - item 6, 66th session: Scientific and Technical Subcommittee - United Nations Committee on the Peaceful Uses of Outer Space.*

rendezvous-docking control, retrieval of non-cooperative tumbling objects, formation flight, and space robotics.[303] The Tokyo Institute of Technology is exploring new space systems focusing on robotics and satellites including in-orbit technology.[304] The Kyushu University is exploring space debris.[305] The Kyushu Institute of Technology is studying the capture of tumbling space debris.[306]

Overall, a lot of technological advancements and growing partnerships between governments, industry and academia have taken place in Japan. The country updated its policy and regulatory framework to address the evolving domain of OSAM. It appears that Japan's initiatives are mostly oriented towards space sustainability and economic growth.

The table below provides a non-exhaustive overview of current capabilities being developed in Japan:

Services	Projects and capabilities
Refuelling	**Announced** In 2022, **Astroscale** and **JAXA** announced that they are working together on in-orbit refuelling as part of the JAXA Space Innovation through Partnership and Co-Creation (J-SPARC). They are conducting a one-year feasibility study on satellite refuelling services. Astroscale is exploring refuelling mission concepts for satellites designed to be services as well as satellites not designed to be serviced by leveraging RPO technology demonstrated as part of the ELSA-d mission and applying robotics technology still under development. JAXA is studying the technical feasibility of a refuelling system and assessing ground test equipment for fuel transfer evaluation.[307]
Active Debris Removal	**Announced** **Astroscale** and **GITAI** were selected to lead the development of international standards and further promote space development and utilisation for the Ministry of Economy, Trade and Industry (METI) to research and develop extra-vehicular general-purpose robotic arm and hand technologies.[308] JAXA selected the Astroscale company as a commercial partner for Phase I, and the project (ADRAS-J) was kicked off in March 2020.[309] ADRAS-J is scheduled for lift-off on a Rocket Lab Electron rocket from Launch Complex

[303] *Research: Intelligent Space Systems Laboratory*. Available at: https://www.space.t.u-tokyo.ac.jp/nlab/about_e.html (Accessed: 08 May 2023).
[304] *Lab for space robotics: Nakanishi Lab*. Available at: http://www.srobot.mech.e.titech.ac.jp/ (Accessed: 08 May 2023).
[305] *Space Systems Dynamics Lab: Hanada lab (Space Systems Dynamics Lab at Kyushu University)*. Available at: https://ssdlab.info/ (Accessed: 08 May 2023).
[306] *Research: Research: Space robotics lab., Kyutech*. Available at: http://www.mech.kyutech.ac.jp/srl/research_e.html (Accessed: 20 June 2023).
[307] *Astroscale Japan and JAXA launch co-creation project for Satellite Refuelling Service Concept* (2022) *Astroscale*. Available at: https://astroscale.com/astroscale-japan-and-jaxa-launch-co-creation-project-for-satellite-refuelling-service-concept/ (Accessed: 01 May 2023).
[308] *Astroscale and Ministry of Economy, Trade and industry renew robotic arm and Hand Technology Development Contract* (2022) *Astroscale*. Available at: https://astroscale.com/astroscale-and-ministry-of-economy-trade-and-industry-renew-robotic-arm-and-hand-technology-development-contract/ (Accessed: 06 April 2023).
[309] *JAXA concludes partnership-type contract for phase I of its commercial removal of debris demonstration (CRD2)* (2020) *JAXA*. Available at: https://global.jaxa.jp/press/2020/03/20200323-1_e.html (Accessed: 13 April 2023).

1 in Mahia, New Zealand in 2023.[310] Once deployed to a precise orbit by Electron's Kick Stage, the ADRAS-J satellite is designed to rendezvous with a Japanese upper stage rocket body, demonstrate proximity operations, and obtain images, delivering observational data to better understand the debris environment.[311] In August 2022, Astroscale and Kawasaki Heavy Industries, Ltd. were selected as the contracting parties for the Front-Loading Technology Study in Phase II.[312] This study will focus on the ground test of development hardware and software that are key for two critical areas of the Phase II mission: close proximity operations and the capture mechanism design.[313]

GITAI was selected by the New Energy and Industrial Technology Development Organization (NEDO) for the development of a robotic arm with high performance and maintainability for an extravehicular environment.[314]

In academia, in 2021, **Shizuoka University** was developing nanosatellite to demonstrate space debris capture technology under JAXA's Innovative Satellite Technology Demonstration Programme. The mission was to extend a tether 1km into space on which a robot (Climber) would move and conduct a debris capture experiment with nets. However, the project failed due to the Epsilon 6 rocket's launch failure in October 2022. The laboratory is still developing on-orbit technologies.[315]

Under development

Astroscale also plans to launch the ELSA-m In-orbit Demonstration mission in 2024 by removing debris of a constellation of satellites. ELSA-m is expected to be a servicer equipped with both chemical and electric propulsion and will be capable to conduct RPOs and inspections, docking, and debris capture to push satellites back into the atmosphere.[316]

JSAT partnering with JAXA, Institute of Physical and Chemical Research (RIKEN), Nagoya University (Prof. Sasoh), and Kyushu University (Hanada Lab.) initiated the design and development of the world's first satellite to

[310] *Astroscale selects rocket lab to launch phase I of JAXA's Debris Removal Demonstration Project* (2021) *Astroscale*. Available at: https://astroscale.com/astroscale-selects-rocket-lab-to-launch-phase-i-of-jaxas-debris-removal-demonstration-project/ (Accessed: 14 April 2023).

[311] *Astroscale selected as commercial partner for JAXA's commercial removal of debris demonstration project* (2020) *Astroscale*. Available at: https://astroscale.com/astroscale-selected-as-commercial-partner-for-jaxas-commercial-removal-of-debris-demonstration-project/#:~:text=(%E2%80%9CAstroscale%E2%80%9D)%2C%20the,project%2C%20a%20groundbreaking%20step%20by (Accessed: 13 April 2023).

[312] 契約相手方の選定結果の公示 (2022) JAXA, (Accessed: 13 April 2023)

[313] *Astroscale selected as contract partner for front-loading technology study in Phase II of Jaxa's commercial removal of debris demonstration project* (2022) *Astroscale*. Available at: https://astroscale.com/astroscale-selected-as-contract-partner-for-front-loading-technology-study-in-phase-ii-of-jaxas-commercial-removal-of-debris-demonstration-project/ (Accessed: 14 April 2023).

[314] *GITAI was selected by NEDO for Program to Support Ventures for Developing Space Components* (2020) *GITAI*. Available at: https://gitai.tech/2020/10/07/gitai-was-selected-by-nedo-for-program-to-support-ventures-for-developing-space-components/ (Accessed: 14 April 2023).

[315] 宇宙ごみ、人工衛星が捕獲　静岡大、開発計画を発表　(2021)　あなたの静岡新聞. Available at: https://www.at-s.com/news/article/topics/shizuoka/856574.html (Accessed: 17 April 2023).

[316] *Elsa-m - Astroscale, securing space sustainability: Astroscale*. Available at: https://astroscale.com/elsa-m/ (Accessed: 29 April 2023).

	remove space debris using laser-based methods in June 2022 under J-SPARC programme. The project is scheduled to be finalised by 2026.[317]
	Demonstrated
	In 2021, **Astroscale** successfully conducted an in-orbit demonstration using its The End-of-Life Services by Astroscale-demonstration (ELSA-d) spacecraft. The demonstration aimed at proving the feasibility and ability of ELSA-d to dock another spacecraft, which validated the capture system, the on-board sensors, and the cameras.[318]
Relocation and Orbit Correction	**Announced**
	Before being acquired by **Astroscale,** Effective Space Solutions (Israel) was developing the Space Drone, which was supposed to provide station-keeping and attitude control services in GEO. It was scheduled to be launched in 2020 on a Proton-M rideshare mission. However, despite a contract with a customer, Astroscale decided to cancel the mission and to integrate the Space Drone into Astroscale's servicing platform.[319] In December 2022, NASA issued a request for information (RFI) to look for potential concepts to raise the orbit of the Hubble Space Telescope, **Astroscale** (Japan) and Momentus (United States) replied to the RFI suggested that Momentus' orbital service vehicle equipped with Astroscale servicing technology could conduct a RPO and dock the Hubble and relocate it 50 km higher. It is also envisioned that the vehicle could be used for ADR.[320]
	Under development
	Astroscale is developing the Life Extension In-Orbit (LEXI) services, which is capable of providing station-keeping and altitude control services by positioning electric thrusters into the serviced spacecraft with the help of robotic arms. LEXI also has the capability to relocate pieces of debris and satellites to graveyard orbits or other GEO orbital slots. LEXI is able to provide inclination correction services.[321]

Table 14: Japan's capabilities developments in OSAM

Russia

Russia is a major space power and has developed space capabilities since the dawn of the space age, including in the field of OSAMFrom the 1970s, its goals has been to support its space stations

[317] 世界初、宇宙ごみをレーザーで除去する衛星を設計・開発: *Sky Perfect JSAT Group*. Available at: https://www.skyperfectjsat.space/news/detail/sdgs.html (Accessed: 29 April 2023).
[318] McPhail, T. (2022) *Astroscale's Elsa-D mission successfully completes complex rendezvous operation, Astroscale*. Available at: https://astroscale.com/astroscales-elsa-d-mission-successfully-completes-complex-rendezvous-operation/ (Accessed: 14 May 2023).
[319] *Space drone 1, 2*: *Gunter's Space Page*. Available at: https://space.skyrocket.de/doc_sdat/space-drone-1.htm (Accessed: 04 June 2023).
[320] Foust, J. (2023) *Astroscale and Momentus offer concept for reboosting Hubble, SpaceNews*. Available at: https://spacenews.com/astroscale-and-momentus-offer-concept-for-reboosting-hubble/ (Accessed: 28 May 2023).
[321] *What is life extension (LEX)?* (2021) *Astroscale*. Available at: https://astroscale-us.com/wp-content/uploads/2021/09/LEXI-Fact-Sheet_September-21.pdf (Accessed: 12 May 2023).

(supply, refuel, repair, etc.). Most capabilities stem from developments that started at the time of the Soviet Union and continued later on. Russia has mature capabilities in the areas of refuelling, inspection, relocation, repair, assembly, and manufacturing.

At the policy level, Russia does not have a dedicated policy for OSAM. Nonetheless, according to the **Russian Federal Space Programme 2016-2025**, assembly seems to be a main priority as Russia considers the possibility to retrieve the Russian components of the ISS to build another Russian space stations once the ISS will seize to function.[322] However, OSAM is not necessarily explicitly referenced in the policy document.

The **Presidential Decree Fundamentals of the Russian Federation's State Policy in the Field of Space Activities for the Period up to 2030 and beyond** does not mention OSAM as it rather focuses on organisational aspects.

Roscosmos' Corporation Development Strategy until 2025 and towards 2030, which was unveiled in 2021, primarily aims to ensuring the strategic security and independence of Russia with space forces and means; ensuring the improvement of the quality of life, the infrastructural unity of the country and the digital transformation of the economy; obtaining new knowledge about the Universe and the origin of life on Earth; access to unlimited space resources.[323] The last objective may include some objectives related to in-space manufacturing.

At the legal level, the Russian space law does not contain provisions regarding on-orbit servicing.

At the diplomatic level, Russian delegations to UNCOPUOS address OSAM while not being their main priority or talking point. In this domain, they mostly focus on ADR and the implementation and evolution of the LTS guidelines. Russia considers that some issues were ignored in the LTS guidelines and should be addressed including active debris removal, the *"safe in-orbit destruction of objects in space"*, and the *"appropriate solutions for ADR and the destruction of unregistered space objects"*.[324] However, no specific propositions seem to have been made on how ADR should be addressed.

Overall, it is worth noting that it remains to be seen how the war in Ukraine and its consequences (notably sanctions, the end of international cooperation projects, and the loss of many skilled engineers) will impact the Russian space programme as well as its capabilities and ability to develop future space systems and carry out future OSAM missions. In addition, the Federal Space Programme underwent budget cuts of about 150 billion roubles due to the economic crisis caused by COVID-19.[325]

The following table provides a non-exhaustive overview of current projects in the field of OSAM in Russia:

Services	Projects and capabilities
Refuelling	**Announced**
	Roscosmos also announced the Nucleon mission, which aims to create a space tug with nuclear propulsion that is expected to launch in 2030 to the

[322] *Russian Federal Space Programmes 2016-2025* (2016) *The Russian Government.*
[323] Космос - ТАСС. Available at: https://tass.ru/kosmos (Accessed: 14 September 2023).
[324] United Nations Office for Outer Space Affairs, COPUOS 2023: Statements. Available at: https://www.unoosa.org/oosa/en/ourwork/copuos/2023/statements.html (Accessed: 14 September 2023).
[325] ТАСС. Федеральную Космическую Программу До 2025 Года Урезали На 150 Млрд Рублей. (2022) Available at: https://tass.ru/kosmos/9280803 (Accessed: 05 May 2023).

	Moon, Venus, and Jupiter. The space tug is expected to be refuelled with xenon propellant.[326]
	Operational
	Russian spacecraft such as the Progress MS vehicle have been regularly refuelling the ISS with cargo and propellant.
Recharging	**Announced**
	The Military Space Academy A.F. Mozhaisky and the Russian company RSC Energia developing what they called a *"space gas station"*, which would provide in-orbit recharging services through power beaming.[327] During the Army-2019 exhibition, the Academy unveiled a concept project with repeaters of electricity received from Earth or from sunlight in orbit that would be able to transfer electricity to other space systems through laser beams,
Repair	**Announced**
	In 2022, Roscosmos unveiled its plans to reuse the Russian segment of the ISS to build another space station called ROS. In 2023, RSC Energia announced that the future Russian Orbital Station would be able to repair, refuel, and replace parts of satellites. Satellites would be delivered to the station with a tug to be serviced by manipulators or by astronauts, then serviced satellites would be transported to their targeted orbital destination.[328]
Assembly	**Announced**
	Russian plans to build a future space station, named ROS, with the Russian module of the ISS is expected to be a four-module station that will be launched in two phases and that would have the capacity to host four astronauts. At the time, Roscosmos announced it planned a first launch in 2025-26 and a second launch in 2030-35.[329] Russia recently suggested to build a scientific module on ROS for BRICS countries and African countries, but no foreign partners agreed to participate to ROS yet.[330]
	Operational

[326] *By the end of 2020, Roscosmos will sign a contract for the creation of the Nuclon nuclear spacetug* (2020) *Aviation EXplorer*. Available at: https://www.aex.ru/news/2020/9/16/216791/ (Accessed: 05 May 2023).
[327] Дмитрий Литовкин (2020) В России работают над созданием «орбитальных бензоколонок». Независимая. Available at: https://nvo.ng.ru/realty/2020-05-29/5_1094_satellites.html (Accessed: 29 April 2023).
[328] Большая часть обслуживания спутников на РОС будет проводиться с помощью манипуляторов (2023) ТАСС. Available at: https://tass.ru/kosmos/18503093 (Accessed: 05 May 2023).
[329] Rahmani, M. (2022) *Russia unveils model of its new Space Station Ross*, *Mehr News Agency*. Available at: https://en.mehrnews.com/news/190303/Russia-unveils-model-of-its-new-space-station-Ross (Accessed: 03 May 2023).
[330] Роскосмос пока не получил отклик по участию других стран в проекте РОС (2023) ТАСС. Available at: https://tass.ru/kosmos/18503867 (Accessed: 05 May 2023).

		The Strela Cranes, which is on the ISS is used to assist astronauts during EVA to capture objects, assemble them, or repair components on the station.
Manufacturing	**Demonstrated/Concluded**	
		The company 3-D Bioprinting Solutions developed a biomedical 3D printer named Organaut, which was launched to the ISS in 2018 to conduct a magnetic bioprinting experiment by printing cartilage and thyroid glands of mice. The printer is expected to stay operational until the end of 2023. RSC Energia and the Tomsk Polytechnic University partnered to send a 3D printer to the ISS in order to print additional satellites on orbit.[331] In June 2022, the 3D printer was launched to the ISS on Progress MS-20 and tested to produce items using polymeric materials.[332]

Table 15: Russia's capabilities developments in OSAM

South Korea

While OSAM does not seem to be a main priority for the Korean government, the policy framework and the projects of the Korea Aerospace Research Institute (KARI) appear to highlight initial interests in OSAM, in particular Active Debris Removal and in-space manufacturing.

Indeed, KARI's **Future Vision 2050** was released in 2019 and defined a set of 19 strategic goals in four areas of space activities, namely (1) space transportation, (2) space exploration for securing space and space science research, (3) aerospace capabilities to respond to future environmental changes, (4) and aerospace to contribute to the prosperity of mankind. Within the goal of space exploration for securing space and space science research, the **Vision 20250** aims to *"realizing the economic feasibility of space exploration and securing future strategic resources by utilizing space resources."*[333] While the strategy does not provide additional detail, this objective may include on-orbit manufacturing and may indicate an interest from the Korean government for the in-space economy and OSAM. According the Sangwoo Shin from the Korea Space Policy Research Center (SPREC) *"Internally, entities such as the Korea Aerospace Research Institute (KARI) are just beginning to review and consider this endeavour. One interesting point is that as interest in space utilization in the defence sector increases, it is understood that related research is being conducted."*[334]

Older policy documents such as the **Basic Plan for Promotion of Space Development 2018-2022** and KARI's 2021 **Space Development Implementation Plan** did not mention OSAM. However, newer policy documents reflect an interest for OSAM from the Korean Government. **The Basic Plan for Promotion of Space Development "Realisation of a space economy powerhouse by 2045"**, which was released in 2022, plans for the development of the *"on-orbit service, space tourism, and space station service industries"* as part of its measures. The plan aims to be looking to create the market through active public-private cooperation. Specific timelines for such developments are expected to be disclosed through the **National Space Technology Roadmap**.[335]

At the legal level, the **Space Development Promotion Act** of 2005 aims to *"facilitate the peaceful use and scientific exploration of outer space and to contribute to national security, the sound growth*

---

[331] *Institute for Defense Analyses* (2020), *op. cit.*
[332] Космонавты испытали на МКС первый российский 3D-принтер (2022) Интерфакс Available at: https://www.interfax-russia.ru/siberia/main/kosmonavty-ispytali-na-mks-pervyy-rossiyskiy-3d-printer (Accessed: 05 June 2023).
[333] *Development direction and strategic goals of Future Vision 2050*: *About KARI Future Vision 2050*. Available at: https://www.kari.re.kr/eng/sub01_06.do (Accessed: 13 June 2023).
[334] Interview conducted by ESPI on July 21st, 2023.
[335] Interview conducted by ESPI on August 30th, 2023.

of the national economy, and the betterment of citizens' lives by systematically promoting the development of outer space and by efficiently using and managing space objects." [336] While its scope can serve to govern on-orbit servicing, OSAM is not explicitly mentioned or dealt with. The Act does not provide rules for deorbiting or disposing of space objects at the end of life. Nonetheless, the Ministry for ICT introduced a draft recommendation in 2020 concerning *"spacecraft development and operation to reduce space debris".* The recommendation mostly reflects the IADC guidelines as well as discussions from UNCOPUOS and requires operators to have a plan for debris mitigation for their missions. The draft recommendation does not explicitly mention servicing or ADR, but its obligations may create a favourable environment to develop such technologies.

At the diplomatic level, Korean delegations to UNCOPUOS or the UNOEWG on Space Threats do not seem to have addressed the topic of OSAM in their official statements despite addressing debris issues. Yet, it is interesting to mention that the Ministry of Foreign Affairs of Korea recently supported the organisation of UN conferences on responsible space behaviour in space,[337] in which OSAM was briefly mentioned. It welcomed the 21st Korea-UN Joint Conference on Disarmament and Non-proliferation issues,[338] which also partly addressed debris mitigation and space operations. While it does not constitute an official policy or programmatic position on OSAM, it provides an overview of the increasing interest of Korea in space sustainability issues.

Sangwoo Shin further explained that *"Korea is currently in the initial phase of research and development. The government has embarked on conducting technology verification at the small satellite level, and is planning services later."*[339] Indeed, at the Advanced Maui Optical and Space Surveillance Technologies Conference in Hawaii, USA in 2019, KARI representatives mentioned that they started to study the possibility to conduct deorbiting missions at the end of life to comply with IADC guidelines. Korea is looking to remove KOMPSAT-2, which is a LEO satellite that seized its activities in 2015. However, the mission is only in early development is not yet scheduled. [340]

There are interests from start-ups in developing OSAM solutions in Korea. However, similarly to most countries, these solutions are not operational nor available on the market yet. Sangwoo Shin considers that *"while some companies, particularly startups, have announced plans related to space debris removal technology development, it appears they have not yet reached the commercialization stage. Therefore, it is projected that market evolution will manifest once the government establishes its technology development and specific investment policies."*[341]

KARI is carrying out research on ADR technologies and developed a ground-based test bed to demonstrate RPOs by small satellites as well as algorithms. On-orbit tests are scheduled to take place.[342]

[336] *Space Development Promotion Act* (2020) *Korea Legislation Research Institute*. Available at: https://elaw.klri.re.kr/eng_service/lawView.do?hseq=57094&lang=ENG (Accessed: 12 July 2023).
[337] *Advancing Space Security Through Norms, Rules and Principles of Responsible Behaviours* (2022) *UNIDIR*. Available at: https://documents.unoda.org/wp-content/uploads/2022/09/UNIDIR_Advancing-space-security-summary.pdf (Accessed: 09 July 2023).
[338] *Summary Report of the 21st Republic of Korea-United Nations Joint Conference on Disarmament and Non-proliferation Issues* (2022). Available at: https://docs-library.unoda.org/Open-Ended_Working_Group_on_Reducing_Space_Threats_-_(2022)/Summary_Report_of_the_21st_ROK-UN_Conference.pdf (Accessed: 12 July 2023)
[339] Interview conducted by ESPI on July 21st, 2023.
[340] Seong, J., Jung, O. and Chung, D.W. (2019) *KARI Recent Activities on SSA & STM*, *NASA/ADS*. Available at: https://ui.adsabs.harvard.edu/abs/2019amos.confE..37S/abstract (Accessed: 17 July 2023).
[341] Interview conducted by ESPI on July 21st, 2023.
[342] *Ibid*.

United Arab Emirates

The UAE is an emerging spacefaring nation, which recently established its space agency and drafted its first space policy documents. The UAE already defined clear objectives for its space economy as well as in the field of space exploration.

The UAE does not have a dedicated OSAM policy, but OSAM is referenced repeatedly in its space policies. **It seems to perceive on-orbit servicing, assembly, and manufacturing as an economic opportunity in its space policies.** This is consistent with the Emirates' overall space policy objectives, which are to diversify its economy from reliance on fossil fuels and generate economic growth, as well as to develop the private space sector.[343]

Indeed, the **National Space Strategy 2030** mentions Active Debris Removal as a new business opportunity *"with the possibility of adding a commercial aspect".* The strategy also mentions *"satellites services"* and *"space manufacturing"* as new business models along with ADR, without specifying whether it really covers on-orbit servicing and on-orbit manufacturing. The strategy puts some economic interests in on-orbit manufacturing, detailing that it aims to *"attract the private sector into space exploration activities including space resources utilization"*. In addition, the National Space Strategy mentions *"assembly in space"* and acknowledges it as a future trend in the global space sector value chain. However, the strategy does not outline specific measures in this domain.[344]

Similarly, **the Space Investment Promotion Plan of 2020,** which aims to support the Emirati space sector and promote the diversification of the economy, also mentions debris mitigation and removal, satellite servicing, manufacturing in microgravity and in space as well as space mining as new business models with a commercialization potential. OSAM is mentioned as an area, which can be funded by private investments. However, the document does not define specific policy or economic measures related to the development of OSAM. The Plan only outlines processes and approaches for private investments in the UAE space sector, which can apply to OSAM just as any other domain or application.

The **National Space Policy of 2016** does not mention on-orbit servicing but refers to on-orbit manufacturing in several instances. It highlights that the UAE aims to develop programmes in the fields of *"ancillary industries and the of robots and three-dimensional printing and manufacturing in space"* as well as *"exploration, mining, extraction and utilization of resources in space".* These activities are seen as a way to increase the Emirates' soft power and status in the space domain as well as a domain to foster space entrepreneurship and commercial space projects.[345]

Furthermore, the UAE released the **Mohammed bin Rashid Space Centre Strategy 2021-2031**, which is the centre's ten-year roadmap. The strategy focuses on space exploration and technology and covers six key programmes: Hope Probe, Mars 2117, the UAE Astronaut Programme, the UAE Satellite Programme, and the UAE Space Sector Sustainability Programme, as well as the Emirates Lunar Mission. While the strategy is not public, the project of Mars 2117, which aims to develop the capabilities to establish humans to Mars within the next 100 years includes the development of the Mars Scientific City, which includes research on food, energy and water, agriculture as well as a laboratory to simulate Mars' environment. This project may integrate aspects related to in-space

[343] *Emerging Spacefaring Nations* (2021) *ESPI*. Available at: https://www.espi.or.at/wp-content/uploads/2022/06/ESPI-Report-79-Emerging-Spacefaring-Nations-Full-Report.pdf (Accessed: 28 June 2023).
[344] *National Space Strategy* (2019) *UAE Space Agency.* Available at: https://space.gov.ae/Documents/PublicationPDFFiles/POLREG/2030-National-Strategy-Summary-EN.pdf (Accessed: 28 June 2023).
[345] *UAE National Space Policy* (2016) *UAE Government*. Available at: https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf (Accessed: 28 June 2023).

manufacturing. At the programmatic level, there are no dedicated programmes for the development of sovereign OSAM capabilities in the UAE. Yet, the UAE has clear ambitions in the field of space exploration, which might require the country to develop some OSAM capabilities or key enabling technologies in the future.

At the legal level, **Federal Law No. 12 of 2019** on the Regulation of the Space Sector establishes the UAE's legal and regulatory framework for the space sector and regulates the commercial exploitation and use of space resources, which may facilitate the development of in-space manufacturing activities. However, OSAM is not explicitly mentioned in the law. Yet, Article 4 states that the law regulates the *"removing or disposing of a space object from the orbit"* but does not provide specific rules for deorbiting spacecraft after the end of life or for the provision or operations of ADR activities.[346]

At the diplomatic level, the Emirati delegation does not seem to have addressed the topic of on-orbit services during UNCOPUOS sessions in the past three years. However, the UAE addressed the subject within the UN OEWG on Reducing Space Threats by taking an economic approach and by suggesting the creation of a *"finance programme to look into solutions that helps in the removal of debris"*.[347]

Overall, the UAE acknowledges the development of OSAM as an emerging market and perceives it as a potential economic opportunity. The threats posed by debris seem to be perceived from an economic perspective as well. However, Emirati public policy documents do not outline dedicated measures to seize this potential. Therefore, OSAM does not seem to be among the UAE's main priorities, which mostly focus on the development of its national space industry and sovereign space capabilities (EO, Telecommunications, navigation) as well as space exploration.

United States of America

The United States has significant experience in OSAM, which it started five decades ago with the need to support space stations (supply, refuel, repair, etc.). As a result, the United States is the country where on-orbit servicing, assembly and manufacturing activities are the most advanced. U.S. authorities plan to increase their efforts in this domain in order to serve sustainability, economic but also national security objectives, consistent with the U.S. approach of *"space dominance"* in all space applications.

The United States is the only country that drafted strategies dedicated to on-orbit servicing, assembly and manufacturing: the **In-Space Servicing, Assembly and Manufacturing National Strategy**, released in April 2022, and the **National In-Space Servicing, Assembly and Manufacturing Implementation Plan** of December 2022. These policy documents take note of the advantages of OSAM activities for the sustainability of the outer space environment, their positive impact on the output or lifetime of space systems, as well as their expected economic benefits in several domains (e.g., remote sensing, climate science, human exploration). The **ISAM National Strategy** also identifies six goals related to OSAM that the United States will pursue. These are:[348]

- *"Advancing ISAM research and development*

[346] (2019) *Federal law no. (12) on the Regulation of the Space Sector.* Available at: https://www.moj.gov.ae/assets/2020/Federal%20Law%20No%2012%20of%202019%20on%20THE%20REGULATION%20OF%20THE%20SPACE%20SECTOR.pdf.aspx (Accessed: 28 June 2023).

[347] *United Arab Emirates submission on The Tools and Mechanisms for Reducing Space Threats* (2023) UN *OWEG on reducing space threats through norms, rules and principles of responsible behaviours.* Available at: https://docs-library.unoda.org/Open-Ended_Working_Group_on_Reducing_Space_Threats_-_(2022)/A_AC294_2023_WP16_United_Arab_Emirates.pdf (Accessed: 03 July 2023).

[348] *In-space servicing, assembly, and Manufacturing National Strategy* (2022) *National Science and Technology Council*. Available at: https://www.whitehouse.gov/wp-content/uploads/2022/04/04-2022-ISAM-National-Strategy-Final.pdf (Accessed: 03 July 2023).

- *Prioritising the expansion of scalable infrastructure*
- *Accelerating the emerging ISAM commercial industry*
- *Promoting international collaboration and cooperation to achieve ISAM goals*
- *Prioritising environmental sustainability as we move forward with ISAM capabilities*
- *Inspiring a diverse future workforce as a potential outcome of ISAM innovation"*

For each goal, the Strategy and the Implementation Plan associate concrete actions related to the coordination of actors (academia, industry, international partners) involved in ISAM activities, the procurement of ISAM capabilities from the U.S. government, and the elaboration of norms and standards. For instance, the **National ISAM Implementation Plan** underlines that there is a need to study ISAM capability needs and technology gaps, to balance government and industry roles and responsibilities or to revise the policy for on-orbit imaging devices used for RPOs. All these measures aim at furthering the development of OSAM activities in the United States, including through the establishment of a strong commercial base.

OSAM activities (ADR in particular) are perceived as a key tool to ensure the sustainability of the space environment. However, the perception of ADR has evolved over time. While the **National Space Policy** of 2020 described it as a "*potential long-term approach*"[349], later documents give a more prominent position to ADR. The **National Orbital Debris Research and Development Plan**, released in January 2021, dedicates a whole section to the remediation of debris (i.e.. ADR) and the repurposing/recycling of space debris. Compared to the **National Space Policy**, the document improves the status of ADR as it states that *"Consistent with SPD-3*[350]*, the United States should pursue ADR as a necessary long-term approach to ensure the safety of flight operations in key orbital regimes."*[351] Although this stronger focus may be due to the fact that this document is more specific than a general space policy, one can also identify a noticeable shift of mindset, through which the United States now considers ADR a major tool to ensure the sustainability of space activities, which leads to increased investment in this domain. As a consequence, the **National Orbital Debris Implementation Plan** (June 2022), which aims at implementing the previous document, calls for further research related to ADR, in order to better understand the risks and opportunities (economic, technological, policy-related) brought by this technology. Beyond ADR, the **Implementation Plan** recognises that other technologies also contribute to the remediation of debris, such as *"technologies related to on-orbit servicing, and rendezvous and proximity operations including the operation of grappling mechanisms, object manipulators, and capture devices"*.[352]

A U.S. representative at the 2023 UNCOPUOS Scientific and Technical Subcommittee stated that *"The United States will work with commercial and international partners to pursue active debris removal as a necessary long-term approach to ensure the safety of flight operations in key orbital regimes"*[353] while also underlining that *"International efforts on active debris removal should not detract from continuing to advance international cooperation on space debris mitigation"*.[354] ADR is therefore perceived as one tool among others to manage the risks created by space debris, but not as a one-size-fits-all solution. Nevertheless, international counterparts were told that "*the United States is beginning to fund development of some concepts to remove space debris, performing*

[349] *National Space Policy of the United States of America* (2020) *Office of Space Commerce, p. 15*
[350] Space Policy Directive-3 (SPD-3) is a Presidential Memorandum issued in June 2018 and directing the establishment of a National Space Traffic Management Policy
[351] *National Orbital Debris Research and Development Plan* (2021) *Executive Office of the President of the United States*, *p. 11.*
[352] *National Orbital Debris Implementation Plan* (2022) *Executive Office of the President of the United States*, *p. 6.*
[353] *Statement of the United States (2023) Scientific and Technical Subcommittee - United Nations Committee on the Peaceful Uses of Outer Space.*
[354] *Ibid*.

economic and social research related to the value of remediation, and identifying the most cost-efficient approaches to remediate the risks posed by orbital debris".[355]

The United States has also identified OSAM as a sector with high potential for its economy and has therefore **repeatedly expressed its willingness to support the development of OSAM activities and U.S. commercial companies in this domain**. In this context, U.S. authorities are willing to work with private actors and procure commercial OSAM solutions to meet their needs. This is clarified in the 2020 **National Space Policy,** which states that leveraging satellite servicing and on-orbit manufacturing can be done through *"inventive, nontraditional arrangements for acquiring commercial space goods and services to meet United States Government requirements"*[356]. U.S. authorities acknowledge that, for a real OSAM ecosystem to emerge, the U.S. framework and regulations should be adapted through the development of "*commercial operating guidelines*"[357] and "*licensing requirements*".[358] The **Space Priorities Framework** of 2021 even asserts that *"U.S. regulations must provide clarity and certainty for the authorization and continuing supervision of non-governmental space activities, including for novel activities such as on-orbit servicing, orbital debris removal, space-based manufacturing, commercial human spaceflight, and recovery and use of space resources"*.[359]

The United States considers that OSAM activities could also indirectly benefit from the development of other commercial space markets, eventually contributing to the U.S. economy. One such sector that could drive OSAM is research and development in LEO or, more generally, commercial LEO destinations. For instance, the **National LEO Research and Development Strategy** explains that, should a market for space-based research develop, it would require in-space assembly; similarly, some of these LEO platforms could be dedicated to specific activities, such as in-space production. The Strategy also defines clear action for in-space manufacturing, stating that the U.S. government will *"support the development of commercial R&D and in-space manufacturing before and after the retirement of the ISS"*.[360] The development of OSAM is therefore also related to the success of other markets, which is an opportunity but also a factor of uncertainty.

Indeed, the United States recognises that there is still a lot of uncertainty surrounding OSAM activities, notably regarding their actual usage (i.e., use cases and business cases). Even for ADR, despite the hopes placed in this approach, U.S. policies acknowledge that several factors are still unknown, such as the size of the market, the cost-disadvantage of this method, the risks related to the inadvertent generation of debris, or other economic, legal and policy issues. Therefore, U.S. authorities call for more research and development regarding this technology to better understand, in particular, its cost and efficiency.

Finally, the security and military dimension of OSAM is also addressed by the United States. **The dual-use nature of such activities is well recognised by U.S. authorities.** Thus, as a reply to the UN General Assembly Resolution 75/36, the United States submitted a **document** to the UN Secretary General stating that "*both on-orbit servicing and active debris removal satellites would require various mechanisms to grab or attach themselves to their target satellites. Some on-orbit demonstrations have included the use of a net, harpoon or magnet to accomplish this task. Robotic arms could also be used for this type of activity. This capability to grapple another satellite is inherently dual-use – such a capability could be used to repair or service another satellite, or to degrade or*

[355] *Ibid*.
[356] *National Space Policy of the United States of America* (2020) *Office of Space Commerce*, p. 20.
[357] *Ibid*., p. 23.
[358] *Ibid*., p. 23.
[359] *United States Space Priorities Framework* (2021) *The White House Washington*, p. 5.
[360] *National Low Earth Orbit Research and Development Strategy* (2023) *Executive Office of the President of the United States*, p. 7.

destroy another satellite'.[361] Technologies that are necessary for the conduct of OSAM activities are thus seen as potential anti-satellite weapons.

In practice, OSAM is not significantly present in official documents of the Department of Defence or the U.S. Space Force, with the exception of the **Space Capstone Publication** (the doctrine of the Space Force). This document considers that one of the core competencies of spacepower[362] is space mobility and logistics (SML), which refers to *"the movement and support of military equipment and personnel into the space domain, from the space domain back to Earth, and through the space domain"*.[363] **As part of SML applications, *"orbital sustainment"* is inextricably linked to OSAM** as it *"will allow military space forces to replenish consumables and expendables on spacecraft that cannot be recovered back to Earth. Orbital sustainment will also enable spacecraft inspection, anomaly resolution, hardware maintenance, and technology upgrades."*[364], with the objective to help extend mission life. The **Space Doctrine Publication 3.0 – Operations**, released in July 2023, goes further in the description of these concepts. It makes space mobility and logistics an operational area, with mobility including "*post-launch transport of space vehicles between orbits, within orbits, and augmented maneuvering to enhance mission effectiveness or maneuvering related to reconstitution, operational degradation or loss, and end-of-life actions"*.[365] The publication even anticipates that *"In the future, logistics on-orbit may include spacecraft servicing, disposition, debris management capabilities, refuelling, and in-space component installation"*.[366] OSAM is therefore fully integrated into the expected operations of the U.S. Space Force.

Despite the relative absence of OSAM in U.S. space defence policies and strategies, **military leaders are increasingly voicing their interest in such capabilities.** For instance, during events held in 2023, the Vice-Chief of Space Operations David Thompson characterised satellite servicing and in-orbit logistics as *"core capabilities"* while the deputy commander of the U.S. Space Command, John Shaw, emphasised the benefits that these capabilities would bring in terms of manoeuvring as a response to threats. In addition, the Space Force is already implementing some measures as it is *"investing in early-stage technologies and laying out a strategy to buy commercial services to refuel and service satellites in geostationary orbit by the early 2030s"*.[367] This trend towards the use of OSAM capabilities for military purposes is supported by the U.S. Congress, which provided $30 million in the 2023 Space Force budget to further explore on-orbit servicing technologies.[368] Finally, in a concrete move to support these activities, the Space Force launched the Orbital Prime programme, which will develop ADR in order to foster the foundational technologies that enable OSAM. The objective is to demonstrate an on-orbit capability in two to four years.[369]

In conclusion, **the United States has a consistent position which aims at supporting the development of OSAM activities for sustainability, economic and national security reasons.** The significance of this topic is considered high enough for the U.S. authorities to develop policy documents dedicated to this field, being the only country in the world to prepare such documents and release them publicly. In addition, the interest of the military actors in furthering their use of

---

[361] *United States of America, National Submission to the United Nations Secretary General Pursuant to UN General Assembly Resolution 75/36 Reducing space threats through norms, rules and principles of responsible behaviours*, p. 4.
[362] "Spacepower" is a concept used in the U.S. Space doctrine and presented as "the totality of a nation's use of space capabilities in pursuit of national prosperity and security".
[363] *United States Space Force, Space Capstone Publication – Spacepower* (2020) *Space Force,* p. 37.
[364] *Ibid*.
[365] *Space Doctrine Publication 3.0 – Operations* (2023) *Space Force.*
[366] *Ibid*.
[367] Erwin, S. (2023) *Space force eager to harness satellite-servicing technologies*, *SpaceNews*. Available at: https://spacenews.com/space-force-eager-to-harness-satellite-servicing-technologies/ (Accessed: 13 July 2023).
[368] *Ibid*.
[369] *Space prime*: *SpaceWERX*. Available at: https://spacewerx.us/space-prime/ (Accessed: 15 July 2023).

OSAM capabilities means that anchor customers such as the Department of Defense and the U.S. Space Force, will likely play a crucial role in supporting the U.S. industrial base.

The following table provides a non-exhaustive overview of current projects in the field of OSAM in the United States:

Services	Projects and capabilities
	Announced
Refuelling	**Orbit Fab** unveiled the Rapidly Attachable Fluid Transfer Interface (RAFTI), which is its satellite refuelling interface design, as well as the RAFTI Open Licence, which specifies the mechanical, electrical, and functional requirements of RAFTI. The RAFTI system includes two components: the Service Valve (SV), which serves as a fill/drain valve for on-orbit refuelling, a docking adapter, and a secondary servicing connection to facilitate missions that use robotic arms; and the Space Coupling Half (SCH), which is a double-action latch mechanism that enables both primary docking and secondary attachment of two spacecraft.[370] Orbit Fab announced it will offer an Open License for RAFTI and will share its intellectual property with other commercial space companies to foster the development of on-orbit operations.[371] Orbit Fab signed a Cooperative Research and Development Agreement (CRADA) with the U.S. Air Force Research Laboratory (AFRL), Space Vehicle Directorate, and the Spacecraft Technology Division to share technical details about is RAFTI system with the Air Force. The Air Force will give Orbit Fab access to its facilities and will review its refuelling technologies, advise on requirements and designs to ensure that Orbit Fab can provide services to defence customers.[372] Orbit Fab later signed a $12 million contract with the Department of Defence to equip military satellites with Orbit Fab's RAFTI interface and provide on-orbit refuelling. Orbit Fab signed a contract with Astroscale to enable the Japanese company to dock its own LEXI satellite servicer to Orbit Fab's fuel depot in order to be refuelled. Orbit Fab's RAFTI device will be installed into the LEXI servicer to ensure that refuelling is possible. The contract was considered by the two companies as the "*first on-orbit satellite fuel sale agreement*". [373] Orbit Fab also signed a partnership with ClearSpace to equip ClearSpace's debris-removing satellites with Orbit Fab's RAFTI on-orbit refuelling interface.[374]

[370] *Orbit Fab: Spacecraft refuelling* (2023) *Orbit Fab*. Available at: https://www.orbitfab.com/products (Accessed: 27 April 2023).
[371] *Ibid*.
[372] *Orbit Fab, U.S. Air Force Sign CRADA for on-orbit refuelling* technology (2023) *Orbit Fab*. Available at: https://www.orbitfab.com/cradapress (Accessed: 28 May 2023).
[373] Jewett, R. (2022) *Astroscale US taps orbit Fab to refuel servicing satellites: Via Satellite*. Available at: https://www.satellitetoday.com/in-space-services/2022/01/12/astroscale-us-taps-orbit-fab-to-refuel-servicing-satellites/ (Accessed: 28 April 2023).
[374] *Orbit Fab Part of UK team making debris removal operations sustainable through* refuelling (2023) *Orbit Fab*. Available at: https://www.orbitfab.com/news/clear-mission/ (Accessed: 16 May 2023).

Astroscale U.S., a subsidiary of the Japanese company Astroscale, announced in September 2023 a contract with the U.S. Space Force. Through this initiative, the Space Force and the company will co-invest in the development of an on-orbit refueling vehicle, for an amount of $25.5 million and $12 million respectively. This prototype vehicle will have to be delivered in 24 months by Astroscale. The spacecraft, called Astroscale Prototype Servicer for Refueling (APS-R), will be equipped with the RAFTI port from Orbit Fab. It is not yet clear whether an in-orbit demonstration of the spacecraft is envisaged.[375]

Under development

In 2020, as part of a Tipping Point solicitation,[376] NASA selected several companies for on-orbit refuelling and propellant depot demonstrations projects that, among other things, aim to develop and test technologies enabling long-term cryogenic fluid management. Among them, **Lockheed Martin** was awarded $89.7 million to conduct a dozen tests of cryogenic fluid management technologies in five years. **SpaceX** was awarded $53.2 million to demonstrate the transfer of 10 tons of cryogenic propellant between tanks on Starship. **United Launch Alliance** was awarded $86.2 million for a demonstration of a smart propulsion cryogenic system to test tank pressure control, tank-to-tank transfer, and propellant storage. **Eta Space** was awarded $27 million for a demonstration of a small cryogenic oxygen fluid management system to collect fluid management data in space for a period of nine months. These demonstrations will contribute to the development of capabilities to transfer propellants between spacecraft.[377]

NASA plans to launch the On-orbit Servicing, Assembly, and Manufacturing-1 (OSAM-1) mission, which will aim to rendezvous with the Earth observation satellite Landsat-7 in LEO to conduct in-orbit refuelling and relocate the satellite to a new orbit. Some part of the mission will be fully autonomous, and some operations and manoeuvres will be carried out by operators sending commands to the servicer.[378]

The **U.S. Space Force** is also developing on-orbit refuelling capabilities to support military missions. The Space Force announced it plans to launch the Tetra-5 mission in 2025, which will include three small satellites that will demonstrate docking with a propellant tanker to conduct on-orbit refuelling of these satellites in GEO. To conduct that demonstration, the Space Enterprise Consortium (SpEC), which aims at facilitating the entry of non-

[375] Erwin, S. (2023) *U.S. Space Force and Astroscale to co-invest in a refueling satellite, SpaceNews.* Available at: https://spacenews.com/u-s-space-force-and-astroscale-to-co-invest-in-a-refueling-satellite/ (Accessed: 26 September 2023)

[376] *Utilizing Public-Private Partnerships to Advance Tipping Point Technologies* (2020) *NSPIRES*. Available at: https://nspires.nasaprs.com/external/solicitations/summary!init.do?solId=%7B73A65D34-DD48-D3ED-9EFC-58771C88BC53%7D&path=open (Accessed: 25 April 2023).

[377] Hall, L. (2020) *NASA tipping point selections*, *NASA*. Available at: https://www.nasa.gov/directorates/spacetech/solicitations/tipping_points/2020_selections (Accessed: 25 April 2023).

[378] Atkinson, N. and Today, U. (2022) *NASA's newest invention could solve a major space exploration problem, Inverse*. Available at: https://www.inverse.com/science/nasa-osam-1-satellite-repair-in-orbit (Accessed: 25 April 2023).

	traditional defence contractors into government contracting, awarded $50 million to **Orion Space Solutions**.[379] **Northrop Grumman** is developing the Mission Robotic Vehicle (MRV), which is expected to install Mission Extension Pods (MEPs) into client satellites to provides services including refuelling. It is scheduled to be launched in 2024.[380]
	Demonstrated/Concluded
	In 2018, **NASA** demonstrated cryogenic liquid methane transfer in micro-gravity on the ISS as part of the Robotic Refuelling Mission (RRM) 3. **Orbit Fab** conducted a successful experiment on the ISS in 2019, which demonstrated water transfer between two satellite testbeds[381], Orbit Fab successfully launched the Tanker-001 Tenzing in 2021. It is a microsatellite that can be regarded as the world's first on-orbit fuel depot, which stores the green propellant High-Test Peroxide (HTP) and can refuel other spacecrafts in-orbit.[382]
	Operational
	Orbit Fab launched a propellant tanker (Tanker-002) to GEO on a Falcon 9 rocket lunar lander mission in June 2023. The tanker was launched as a secondary payload on the Intuitive Machines' IM-2 lunar lander mission. Tanker-002 will be able to store propellant for a period of 15 years and will store around 90 kg of hydrazine. Tanker-002 is expected to provide in-orbit refuelling in GEO. The tanker will be manoeuvrable enough to park hundred kilometres away from the GEO belt when it is not operating to avoid collisions.[383]
Active Debris Removal	**Announced**
	NASA announced that it plans on developing a space tug to deorbit the ISS. The planned budget is expected to be of $1 billion.[384] NASA issued a request for information (RFI) to companies to deorbit the station by relying on thrusters to control the attitude and push it into the atmosphere. The ISS is expected to be operational until 2030.[385]

[379] Erwin, S. (2023) *Space force looking at what it will take to refuel satellites in orbit, SpaceNews*. Available at: https://spacenews.com/space-force-looking-at-what-it-will-take-to-refuel-satellites-in-orbit/ (Accessed: 26 April 2023).
[380] *Mission Robotic Vehicle (MRV) - Northrop Grumman*. Available at: https://www.northropgrumman.com/wp-content/uploads/Mission-Robotic-Vehicle-MRV-fact-sheet.pdf (Accessed: 25 April 2023).
[381] Foust, J. (2023) *Orbit Fab demonstrates satellite refuelling technology on ISS, SpaceNews*. Available at: https://spacenews.com/orbit-fab-demonstrates-satellite-refuelling-technology-on-iss/ (Accessed: 26 April 2023).
[382] *Orbit Fab: Spacecraft refuelling* (2023) *Orbit Fab*. Available at: https://www.orbitfab.com/products (Accessed: 27 April 2023).
[383] Erwin, S. (2023) *Orbit Fab to launch propellant tanker to fuel satellites in geostationary orbit, SpaceNews*. Available at: https://spacenews.com/orbit-fab-to-launch-propellant-tanker-to-fuel-satellites-in-geostationary-orbit/ (Accessed: 28 April 2023).
[384] Foust, J. (2023) *NASA planning to spend up to $1 billion on Space Station deorbit module, SpaceNews*. Available at: https://spacenews.com/nasa-planning-to-spend-up-to-1-billion-on-space-station-deorbit-module/ (Accessed: 21 May 2023).
[385] Foust, J. (2023) *NASA asks industry for input on ISS deorbit capabilities, SpaceNews*. Available at: https://spacenews.com/nasa-asks-industry-for-input-on-iss-deorbit-capabilities/ (Accessed: 27 May 2023).

	Under development
	The start-up **Kall Morris** is developing ADR capabilities with the MK1 Laelaps satellite, which is expected to rendezvous with a piece of debris, grab it, and remove it. To do so, Kall Morris developed REACCH, which is a mechanically articulated end effector to capture space objects.[386] The start-up **OrbitGuardians** is developing a mission plan, which aims at deorbiting about 40 space debris. Its solution is expected to be able to deorbit small, medium, and large objects along with inspection, in-space SSA, and orbit positioning capabilities.[387] The start-up **Starfish Space** is developing ADR capabilities through the development of the Neutilius capture mechanism, which can dock with serviced satellites to remove debris.[388]
Inspection	**Announced**
	The U.S. start-up **OrbitGuardians** announced it is developing on-orbit inspection solutions among other on-orbit services. No inspection mission seems to be scheduled at the moment.[389] The start-up **Turion Space** announced it is developing inspection capabilities by partnering with the Australian start-up HEO Robotics and being part of their network.
	Under development
	DARPA's Robotic Servicing of Geosynchronous Satellites (RSGS) programme is expected to enable inspection in GEO.[390] To support RSGS's mission, Northrop Grumman's Mission Robotic Vehicle, which is scheduled to be launched in 2024, will be used.[391] The U.S. start-up **Orion Space Solutions** is developing on-orbit inspection capabilities. It was selected by the U.S. Space Force to contribute to the Tetra-5 mission with inspection capabilities in GEO.[392] The U.S. start-up **SCOUT Space** is developing on-orbit inspection services. Its solution is to develop the *"SCOUT Sat"* constellation, which will be composed of small satellites that have the capability to conduct RPO and

[386] *Current projects – KMI: Kall Morris Incorporated*. Available at: https://www.kallmorris.com/current (Accessed: 05 June 2023).
[387] *OrbitGuardians: Affordable ADR, Inspection, SSA, & Positioning Services, OrbitGuardians*. Available at: https://orbitguardians.com/services (Accessed: 01 June 2023).
[388] *Services: Starfish space: Giving life to on-orbit services: Starfish Space*. Available at: https://www.starfishspace.com/satellite-servicing (Accessed: 27 May 2023).
[389] *OrbitGuardians: Affordable ADR, Inspection, SSA, & Positioning Services, OrbitGuardians*. Available at: https://orbitguardians.com/services (Accessed: 01 June 2023).
[390] Erwin, S. (2023) *DARPA's robot could start servicing satellites in 2025, SpaceNews*. Available at: https://spacenews.com/darpas-robot-could-start-servicing-satellites-in-2025/ (Accessed: 11 May 2023).
[391] *Mission Robotic Vehicle (MRV) Satellite Technology* (2022) *Northrop Grumman*. Available at: https://www.northropgrumman.com/space/mission-robotic-vehicle-mrv-satellite-technology/ (Accessed: 28 April 2023).
[392] Erwin, S. (2023) *Orion space wins U.S. Space Force contract for on-orbit services experiment, SpaceNews*. Available at: https://spacenews.com/orion-space-wins-u-s-space-force-contract-for-on-orbit-services-experiment/ (Accessed: 01 June 2023).

	inspections, which an expected capability to reach any targeted spacecraft in six hours. Scout Space is also developing *"Sentry"* satellites, which will have on-board cameras for both in-space SSA and real-time surveillance.[393] SCOUT Space was also awarded a contract from the U.S. Air Force to integrate inspection data to demonstrate that space-based and ground-based data can improve debris tracking and collision predictions.[394]
	Concluded/Demonstrated
	In 2021, **SCOUT Space** launched a payload named SCOUT-Vision payload on Orbit Fab's Tenzing Tanker-001. SCOUT-Vision was a demonstration of on-orbit inspection capability and in-space SSA.[395]
	Operational
	The United States developed the Geosynchronous Space Situational Awareness Program (GSSAP), which consists of six small satellites, to manoeuvre across GEO; the Automated Navigation and Guidance Experiment for Local Space (ANGELS) programme; and the EAGLE satellite, and its sub-system Mycroft (USA 287), which has the capacity to conduct RPOs and for some of them inspections.
Relocation/Orbit Correction	**Announced**
	In September 2022, **NASA** contracted a study to SpaceX to study the possibility to reboost the altitude of the Hubble Space Telescope and explore the possibilities to service it, which has been slowly descending since it was last serviced by the Space Shuttle. The idea would be to potentially use Crew Dragon by docking with Hubble and reusing a capture mechanism from the Shuttle mission of 2009 to raise Hubble's altitude.[396] In December 2022, NASA issued a request for information (RFI) to look for potential concepts to raise the orbit of the Hubble Space Telescope, Astroscale (Japan) and Momentus (United States) replied to the RFI, suggesting that Momentus' orbital service vehicle equipped with Astroscale servicing technology could conduct a RPO, dock with Hubble and relocate it 50 km higher. It is also envisioned that the vehicle could be used for ADR.[397] Therefore, there are interests from both the public and private sector in further developing capabilities for orbit relocation and repositioning.
	Under Development

[393] Kulu, E. *Scout space (Eight Continent Technologies), Factories in Space*. Available at: https://www.factoriesinspace.com/scout-space (Accessed: 20 May 2023).
[394] Erwin, S. (2023) *Startups developing Space Traffic Monitoring System to help manage growing debris problem, SpaceNews*. Available at: https://spacenews.com/startups-developing-space-traffic-monitoring-system-to-help-manage-growing-debris-problem/ (Accessed: 19 April 2023).
[395] *Orbit Fab and scout work to host first commercial inspection payload for Space Situational Awareness* (2021) *Satellite Evolution*. Available at: https://www.satelliteevolution.com/post/orbit-fab-and-scout-work-to-host-first-commercial-inspection-payload-for-space-situational-awareness (Accessed: 01 May 2023).
[396] Foust, J. (2023) *NASA and SpaceX to study possible private Hubble Servicing mission, SpaceNews*. Available at: https://spacenews.com/nasa-and-spacex-to-study-possible-private-hubble-servicing-mission/ (Accessed: 04 May 2023).
[397] Foust, J. (2023) *Astroscale and Momentus offer concept for reboosting Hubble, SpaceNews*. Available at: https://spacenews.com/astroscale-and-momentus-offer-concept-for-reboosting-hubble/ (Accessed: 28 May 2023).

Northrop Grumman is developing the Mission Robotic Vehicle (MRV), which will have the capabilities to relocate other space systems as well as to conduct inspection, repair, active debris removal, refuelling, and docking with non-serviceable spacecraft.[398] The first MRV mission is scheduled to be launched to GEO in 2024 along with three Mission Extension Pods, which are small propulsion devices. The MRV is expected to rendezvous and dock with a customer satellite to install the pods before moving to a different target. MRV is developed in cooperation with DARPA for the Robotic Servicing of Geosynchronous Satellites (RSGS) mission. MRV is equipped with a robotic arm, which was developed by the **U.S. Naval Research Laboratory** thanks to funding from DARPA. In 2020, DARPA and Northrop Grumman signed an agreement to install DARPA's robotic arm on the MRV in exchange of access to DARPA's technology demonstration and programme data.[399]

The start-up **Atomos** is developing OTVs to transport satellites to their final destination and is also looking to provide relocation services by the mid-2020s. Atomos OTVs are expected to provide relocation, disposal to graveyard orbits and life extension services.[400]

Demonstrated/Concluded

In 2019, **Northrop Grumman** (which was initially Orbital ATK) launched the Mission Extension Vehicle-1 (MEV-1) mission. Following several on-orbit tests, MEV-1 was launched to service Instelsat's IS-901 satellite and provide relocation services.[401] To do so, Intelsat raised the altitude of IS-901 so as to match the one of the MEV-1 servicer. MEV-1 rendezvous and docked with IS-901 by using the liquid apogee engines to grab Instelat's satellite as it was not designed to be serviced. MEV-1 took over the propulsion and attitude control functions of the serviced satellite and relocated it to a graveyard orbit. The demonstration mission was conducted in graveyard orbit to avoid collisions with active satellites in GEO. MEV-1 eventually proceeded to relocate IS-901 to its intended orbital slot in GEO. In 2024, IS-901 is expected to be placed into graveyard orbit after its end of life.[402]

Operational

In 2020, **Northrop Grumman** launched the Mission Extension Vehicle-2 (MEV-2) to service Intelsat's 10-02 satellite. MEV-2 directly docked 10-02 in GEO and will remain docked to the satellite for a period of five years to provide attitude control and station-keeping.

Repair	**Under development**

[398] *Mission Robotic Vehicle (MRV) - Northrop Grumman.* Available at: https://www.northropgrumman.com/wp-content/uploads/Mission-Robotic-Vehicle-MRV-fact-sheet.pdf (Accessed: 25 April 2023).
[399] *MRV mission set to be launched by Northrop Grumman in 2024* (2022) *Link Communications Systems*. Available at: https://tinyurl.com/56n259w9 (Accessed: 14 May 2023).
[400] *Get to your place in space*: *Atomos space*. Available at: https://atomosspace.com/capabilities (Accessed: 09 May 2023).
[401] *MeV 1, 2, 3: Gunter's Space Page*. Available at: https://space.skyrocket.de/doc_sdat/mev-1.htm (Accessed: 23 May 2023).
[402] *Mev-1: A look back at the groundbreaking journey* (2020) *Intelsat*. Available at: https://tinyurl.com/92z6y6wr (Accessed: 02 June 2023).

	DARPA's Robotic Servicing of Geosynchronous Satellites (RSGS) programme aims to enable on-orbit inspection and on-orbit servicing in GEO, including on-orbit repair. DARPA, in collaboration with **Space Logistics** (Northrop Grumman) and the **U.S. Naval Research Laboratory**, is developing a servicer satellite equipped with two precision robotic arms consisting of seven high-strength joints that will be able to rendezvous and capture a satellite to conduct repair and refuel missions. The system also includes several robotic tools, checkout and calibration equipment, stowage ports, cameras, lighting, avionics boxes with robotics control flight software.[403] The objective is to conduct tests in 2023, launch in 2024 to conduct an on-orbit demonstration in order to start servicing activities in 2025. The servicer will be owned and operated by Space Logistics but will provide services to the DoD and commercial customers.[404]
	Announced
Recharging	The start-up **Litepulse** is looking to develop power stations in space that would harness energy from the sunlight to transfer it to other space systems in LEO. The company is also looking to provide power to future facilities on the Moon.[405]
	Under development
Assembly	**NASA** launched the Precision Assembled Space Structures (PASS) project which aims at building a 20m telescope structure on the ground and, therefore, "*provide confidence in assembly as a viable approach to future space systems*."[406] The project is running from October 2020 to September 2023. The Commercial Infrastructure for Robotic Assembly and Services (CIRAS) programme aims to attach and detach a solar array, demonstrating assembly and reuse capabilities on an integrated ground test using an air-bearing laboratory. It is led by **Northrop Grumman** and the final demonstrations of the first phase of the project took place in January 2018. **Tethers Unlimited** has been developing the SpiderFab concept, which will be able to manufacture and assemble structures in orbit.[407] The project is financially supported by NASA, which helped kickstart it with $500,000 in

[403] *DARPA's Robotic In-Space Mechanic Aces Tests, on Track for Launch* (2022) *DARPA RSS*. Available at: https://www.darpa.mil/news-events/2022-11-08 (Accessed: 06 June 2023).
[404] Marks, P. (2023) *Space Robots prepare to grapple and repair satellites in orbit*, *ACM*. Available at: https://cacm.acm.org/news/269731-space-robots-prepare-to-grapple-and-repair-satellites-in-orbit/fulltext. (Accessed: 19 April 2023).
[405] *The Northstar path for a sustainable future in Space* (2023) *Litepulse*. Available at: https://www.litepulse.com/northstar (Accessed: 23 April 2023).
[406] *Precision Assembled Space Structures* (*PASS*) (2020) *NASA TechPort*. Available at: https://techport.nasa.gov/view/116258 (Accessed: 15 May 2023).
[407] Dunbar, B. (2016) *Spiderfab: Process for on-orbit construction of kilometer-scale apertures*, *NASA*. Available at: https://www.nasa.gov/directorates/spacetech/niac/2012_phase_I_fellows_hoyt_spiderfab.html (Accessed: 12 May 2023).

	2013 after having provided $100,000 in 2012 for R&D.[408] Demonstrations of SpiderFab have been performed in laboratory on Earth.[409]
	Demonstrated/Concluded
	In 2020, **NASA** conducted the Optical Testbed and Integration eXperiment on the ISS as part of a project to advance the robotic assembly of optical systems. NASA's ARMADAS (Automated Reconfigurable Mission Adaptive Digital Assembly System) is conducted by the Ames Research Center. It develops and demonstrates autonomous assembly of *"digital materials"* and structures based on building blocks.[410] A ground-based demonstration took place in 2022.
Manufacturing	**Under development**
	In 2020, **NASA** launched the On-Orbit Servicing, Assembly and Manufacturing framework, an initiative that is intended to foster partnerships between industry, government agencies and academia and act as a *"knowledge centre"* to share information on satellite servicing. As part of this framework, and sharing its objectives, a consortium called COSMIC (Consortium for Space Mobility and ISAM Capabilities) was created in February 2023, funded by NASA but operated by the Aerospace Corporation. Its kick-off meeting is planned for Fall 2023. In 2021, **DARPA** launched the NOM4D (Novel Orbital and Moon Manufacturing, Materials and Mass-efficient Design) programme. Its objective is to develop relevant technologies for adaptive and large-scale structure manufacturing in space. The programme is made of three phases, lasting 18 months each. Each of these phases focuses on one specific concept: a 1-megawatt solar array for phase I, a 100m radio frequency reflector for phase II, and structures for a long-wave infrared telescope for phase III. The company **Nanoracks** plans to repurpose upper stages of rockets in orbit in order to create stations for space tourism and experiments. Nanoracks scheduled the Nanoracks Mission Extension Kit (MEK) mission to be launched in 2024 and expected to demonstrate the control of repurposed rocket upper stages in LEO. **Tethers Unlimited** has been developing the SpiderFab concept (see above), which will be able to manufacture and assemble structures in orbit.[411] The project is financially supported by NASA, which helped kickstart it with

[408] Olivarez-Giles, N. (2013) *NASA-backed SpiderFab robot aims to build 3D-printed spaceship parts in orbit*, *The Verge*. Available at: https://www.theverge.com/2013/8/31/4678046/nasa-funding-spiderfab-3d-printing-parts-in-space (Accessed: 17 April 2023).
[409] Stoor, B. (2018) *In-Space Manufacturing: A Roadmap to the Future*. Available at: https://apps.dtic.mil/sti/pdfs/AD1055025.pdf
[410] Arney, D. *et al.* (2022) *In-space Servicing, Assembly, and Manufacturing (ISAM) State of Play*. Available at: https://nexis.gsfc.nasa.gov/isam/docs/isam_state_of_play_final_2022_v2_S_2022_10_17.pdf (Accessed: 23 May 2023).
[411] Dunbar, B. (2016) *SpiderFab: Process for on-orbit construction of kilometer-scale apertures*, *NASA*. Available at: https://www.nasa.gov/directorates/spacetech/niac/2012_phase_I_fellows_hoyt_spiderfab.html (Accessed: 06 June 2023).

	$500,000 in 2013 after having provided $100,000 in 2012 for R&D.[412] The manufacturing activity of SpiderFab will benefit from the Trusselator technology, which will enable on-orbit fabrication of support structures for high-power solar arrays and large antennas.[413] Demonstrations of SpiderFab have been performed in laboratory on Earth.[414] **Redwire Corporation** is also active in this domain and several of its technologies are onboard the ISS, due to its acquisition of the company Made in Space. In March 2023, Redwire was awarded a $5.9 million contract by NASA to complete the design of FabLab, an in-space multi-material manufacturing 3D printer (which was part of the ISM projects). The system is expected to be tested onboard the ISS and will serve as a precursor for future missions to the Moon and Mars, including in the framework of the Artemis programme. The 3D printer will allow NASA crews in deep space to manufacture tools and components on demand using materials such as metal, plastic, ceramics, and electronics, and will thus enable a sustainable human presence.[415] Similarly, the Redwire Archinaut mission (also called OSAM-2) has been preceded by technologies flown to space or tested on Earth such as the Additive Manufacturing Facility and the Extended Structure Additive Manufacturing Machine. **Varda Space Industry** is a company founded in 2020 that plans to establish a space-based manufacturing facility, with the objective of producing new materials or products (fibre optic cables, semiconductors, pharmaceuticals) in microgravity before bringing them back to Earth. The company also signed a contract with Rocket Lab to produce three Photon spacecraft to put its platform in orbit but also to integrate them into this platform. The company planned to launch its first facility in 2023 but it has not happened yet.
	Concluded/Demonstrated
	In 2021, **Nanoracks** demonstrated the cutting of metal in orbit in LEO as part of its Outpost Mars Demo-1 mission.

Table 16: The United States' capabilities developments in OSAM

[412] Olivarez-Giles, N. (2013) *NASA-backed SpiderFab robot aims to build 3D-printed spaceship parts in orbit*, *The Verge*. Available at: https://www.theverge.com/2013/8/31/4678046/nasa-funding-spiderfab-3d-printing-parts-in-space (Accessed: 01 June 2023).
[413] *TRUSSELATOR - On-Orbit Fabrication of High Performance Support Structures for Solar Arrays, Phase II* (2014) *NASA TechPort*. Available at: https://techport.nasa.gov/view/17796 (Accessed: 25 May 2023).
[414] Stoor, B. (2018) *In-Space Manufacturing: A Roadmap to the Future.* Available at: https://apps.dtic.mil/sti/pdfs/AD1055025.pdf
[415] *Redwire wins NASA contract to advance new in-space manufacturing capability for journeys to Moon, Mars and beyond* (2023) *Redwire Space*. Available at: https://redwirespace.com/newsroom/redwire-wins-nasa-contract-to-advance-new-in-space-manufacturing-capability-for-journeys-to-moon-mars-and-beyond/ (Accessed: 16 June 2023).

On-Orbit Servicing Missions: A Legal Perspective

Existing international space laws, including the United Nations Outer Space Treaty, the Liability Convention, and the Registration Convention, serve as the foundation for understanding liabilities and responsibilities in OSAM missions. Some issues to be considered read as follow:

Liability Concerns. In absence of a clear determination of fault, each party typically bears its losses,[416] making insurance an indispensable part of OOS operations.[417] Moreover, as OOS can extend a satellite's operational life, insurance considerations become even more complex. Premiums are likely to rise as satellites age, complicating long-term financial planning for OOS.

Additionally, one unique issue arising from OOS is the classification of what constitutes a 'space object' during the servicing process. While individual satellites clearly fall under this definition, the status becomes unclear when two satellites dock for servicing.[418] Are they one composite 'space object,' or do they retain their individual identities for the purpose of liability? This has far-reaching implications, especially if an accident involving a third object occurs during servicing. Depending on this classification, both the state of the servicing company and the client could be held jointly liable unless specific agreements define liability differently.[419]

Finally, OOS missions that involve *"recycling"* add another layer of complexity.[420] The LIAB states that a space object includes its *"component parts."* Therefore, if an OOS mission involves integrating components from different objects, each original launching state could potentially be liable for damages caused by the new composite object.[421]

Registration and Jurisdiction. Servicing of a registered space object must occur with the permission from the state that holds jurisdiction over it.[422] This effectively means that OSAM activities must be preceded by a legal or diplomatic agreement between the concerned states. These agreements can set a framework under which OOS can operate without contravening international law, thereby serving as an example for broader multilateral agreements in the future.

In practice, there have been very few instances where jurisdiction over a space object has been transferred, and these were primarily due to changes in ownership.[423] As the field of OOS continues to evolve, we might see new frameworks where the State of Registry temporarily transfers limited jurisdiction to another state or a private entity for the duration of a servicing mission. This kind of arrangement could simplify the legal complexities, allowing greater flexibility in OSAM operations. The issue of registration has significant implications for OSAM activities. As technologies evolve, concerns arise about potential dilution of a State of Registry's responsibilities and the emergence of a market for 'jurisdictional rights' over space objects.

---

[416] Lesley Jane Smith & Armel Kerrest, 'LIAB' in Stephan Hobe et al (eds), *II Cologne Commentary on Space Law* (2009) 119, at pp. 135-136.

[417] Malinowska, K, 'Risk Management and Insurance of On-Orbit Servicing' in Froehlich A (ed), On-Orbit Servicing: Next Generation of Space Activities (Springer 2020) vol 26, at pp. 14-16.

[418] Piskorz, D., & Jones, K. L. (2018). On-orbit assembly of space assets: A path to affordable and adaptable space infrastructure. The Aerospace Corporation, 12-13.

[419] Moenter, R. (1998). The international space station: legal framework and current status. J. Air L. & Com., 64, 1033, at p. 1042.

[420] Thea Flem Dethlefsen, 'On-Orbit Servicing: Repairing, Refuelling and Recycling The Legal Framework' (70th International Astronautical Congress (IAC), Washington D.C., 21–25 October 2019) at pp. 1–2.

[421] Zhuang Tian & Yangyang Cui, 'Legal Aspects of Space Recycling in Removal' in Annette Froehlich (ed), *On-Orbit Servicing: Next Generation of Space Activities* (ESPI Springer 2020) at pp. 41-43.

[422] Michael Mineiro, 'Space Debris Remediation: The Public International Legal Status of Jurisdiction and Control of Space Objects' (Presented to the International Interdisciplinary Congress on Space Debris Remediation, Montreal, 11 November 2011), at p. 12.

[423] Kay-Uwe Hdrl & Kamlesh Gungaphul, 'Problems related to "change of ownership" with respect to registration - The Industry View' in Stephan Hobe, Bernhardt Schmidt-Tedd & Kai-Uwe Schrogl (eds), Proceedings of the Project 2001 Plus Workshop "Current Issues in the Registration of Space Objects" (20/21 January 2005, Berlin, Germany) at pp. 74-75.

4.3 Quantitative Analysis: Policy and Legal Perceptions of OSAM

Methodology note. The quantitative gap analysis assessed 86 space policy documents from all EU and ESA Member States as well as selected spacefaring nations in the rest of the world, namely the United States, China, Russia, Canada, Australia, India, the United Arab Emirates, Japan, and South Korea. The policy documents of the EU as a supranational body as well as ESA were included in the assessment.

The analysis exclusively focused on space policies. National defence policies, national research policies, and national science policies were not included in the quantitative analysis although they may include references to OSAM. These were assessed in the policy factsheets in the qualitative analysis above. The number of policy documents per country is heterogenous, ranging from one to 13 policies for a single country. Limits to the gap analysis pertain to the availability and language of policy documents.

The gap analysis gathered current and available space policy documents of the aforementioned States (including space strategies, doctrines, space defence policies, etc.) and assessed them against references to on-orbit servicing, assembly, and manufacturing.

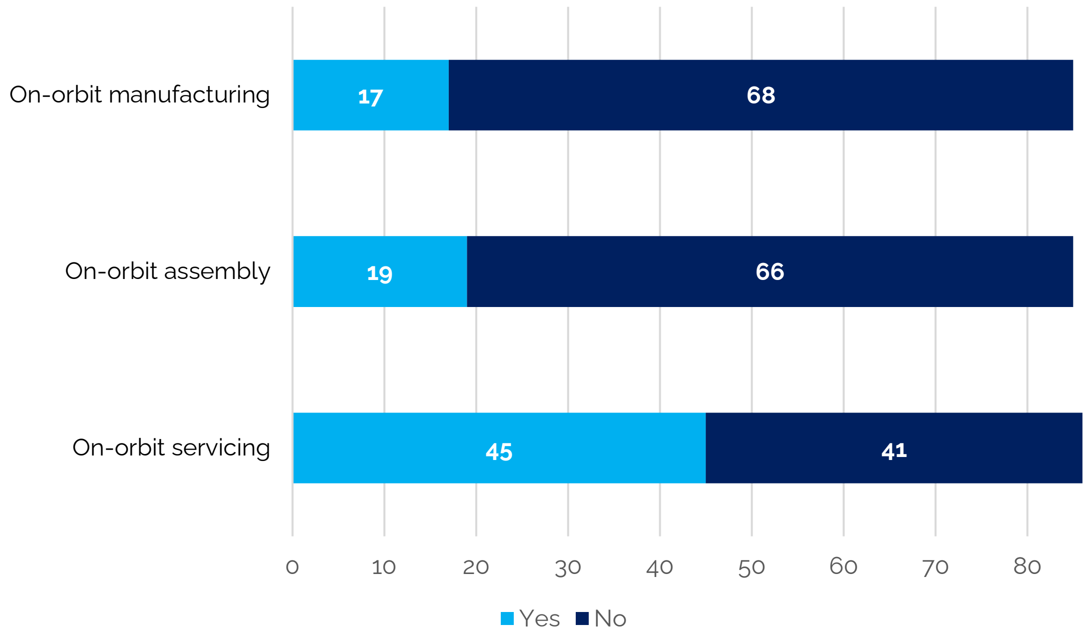

Figure 13: Mentions of OSAM in selected public policy documents

Out of **86 policy documents, 45 space policies referred to on-orbit servicing, 19 policy documents mentioned on-orbit assembly, and 17 policies mentioned on-orbit manufacturing, including ISRU.** This suggests a particular interest for on-orbit servicing among analysed countries, while not being their main priority. Assembly and manufacturing appear to be less referenced, likely due to the perceived distant timeframe by which these two technologies are expected to become mature.

Only 2 policy documents were exclusively dedicated to OSAM. These originated from the United States, namely the In-Space Servicing, Assembly, And Manufacturing National Strategy of 2022 and the National In-Space Servicing, Assembly, and Manufacturing Implementation Plan of 2022. Specific strategies on OSAM do not exist in Europe and nothing suggests that one is in the making.

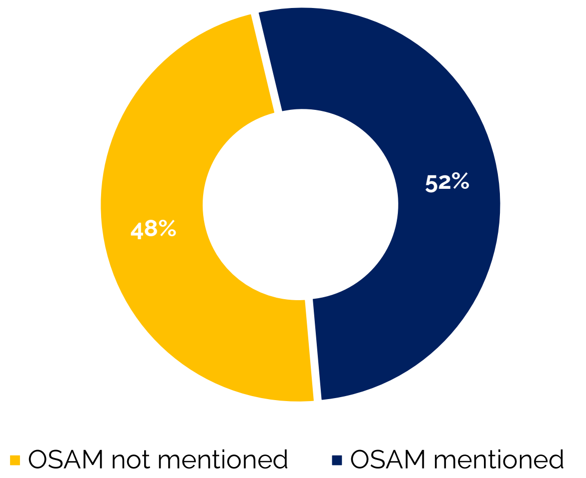

Figure 14: Mentions of on-orbit servicing in selected public policy documents

Focusing specifically on on-orbit servicing, **48% of policies included mentions of on-orbit servicing.**

Among these 45 policy documents that referred to on-orbit servicing, 29 policies originated from the EU, ESA, and European States. It translates the growing importance of on-orbit servicing in general as well as potential ambitions in this domain. Yet, references are mostly confined to a few major spacefaring nations, which regularly mention the technology throughout their policy framework. European States that have a policy mentioning on-orbit servicing at least once are depicted in the map below.

Figure 15: Map of countries with a space policy mentioning on-orbit servicing

Among the policy documents that mentioned on-orbit servicing, **40% of them illustrated a perception of the technology as an opportunity to improve sustainability in space, with a strong focus on Active Debris Removal**.

43% perceived OOS as an economic opportunity, mostly referring to OOS as an emerging market with potential for economic growth and industrial development, albeit emphasising uncertainty towards the market.

7% of them perceived OOS as a potential military threat. These originated from France and the United Kingdom, mostly underlining the potential malicious use or dual use of OOS, in particular robotic arms. 7% of policies considered it as a potential opportunity for military operations in space. These included the UK, the U.S., and the EU.

Only 3% of policies considered OOS as a potential threat to sustainability in space. These stemmed from Italy and Australia.[424]

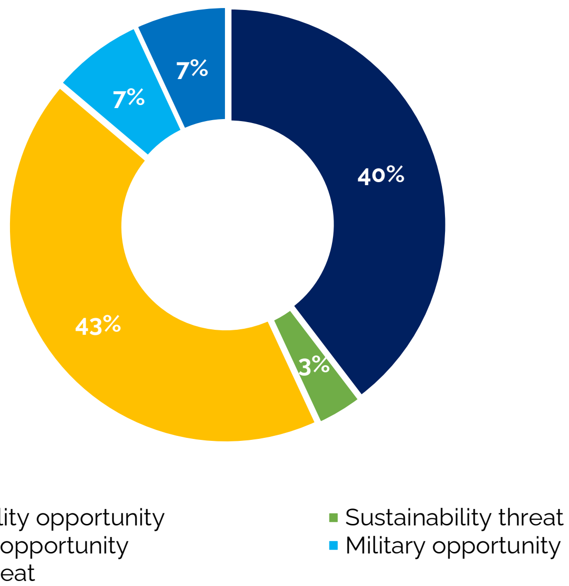

Figure 16: Perception of on-orbit servicing

Looking more closely at the references to on-orbit servicing in selected policy documents, **53% of policies documents mentioning on-orbit servicing were only describing the current situation in the space sector** with regard to the technology. Most policies were simply mentioning that the technology existed, was emerging, developing, or trending. Alternatively, policies provided an explanation of how they perceived the technology.

However, **only 47% of policies mentioning on-orbit servicing outlined concrete measures to** develop or address this technology. References included objectives to develop specific services, approaches to funding, goals to develop expertise or capabilities in specific areas. In this regard, **most documents defining concrete measures originated from outside Europe (e.g., United States, China, Canada, Korea), thereby suggesting a potential lack of true ambitions and structure to develop this domain in Europe.**

[424] Assessed perceptions are not mutually exclusive. A single policy may include all perceptions.

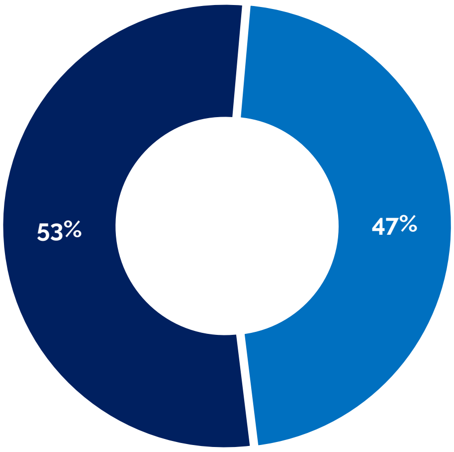

Figure 17: Concrete OSAM policy measures in policy documents

The following table provides an overview of references to OSAM is space policies, space laws, as well as diplomatic statements in COPUOS or the UN OEWG on Reducing Space Threats.[425]

Country	OSAM mentioned in space policy	OSAM mentioned in space law	OSAM mentioned in COPUOS	OSAM mentioned in UNOEWG
Europe				
Austria	✓	✗	✗	✗
Belgium	✗	✗	✗	✗
Bulgaria	✗	✗	✗	✗
Czech Republic	✓	✗	✗	✗
Cyprus	✓	✗	✗	✗
Denmark	✗	✗	✗	✗
Estonia	✗	✗	✗	✗
Finland	✗	✗	✗	✗
France	✓	✗	✓	✓
Germany	✓	✗	✓	✓

[425] Diplomatic statements from 2022 and 2023.

Greece	✗	✗	✗	✗
Hungary	✗	✗	✗	✗
Italy	✓	✗	✗	✗
Ireland	✗	✗	✗	✗
Latvia	✗	✗	✗	✗
Lithuania	✗	✗	✗	✗
Luxembourg	✓	✗	✓	✗
Netherlands	✓	✗	✓	✓
Malta	✓	✗	✗	✗
Norway	✗	✗	✗	✗
Poland	✓	✗	✗	✗
Portugal	✗	✗	✓	✗
Romania	✗	✗	✗	✗
Slovenia	✗	✗	✗	✗
Slovakia	✗	✗	✗	✗
Spain	✗	✗	✗	✗
Sweden	✗	✗	✓	✓
Switzerland	✓	✗	✓	✓
United Kingdom	✓	✗	✓	✓
Rest of the world				
Australia	✓	✗	✗	✗
Canada	✓	✗	✓	✗
China	✓	✗	✗	✗
India	✓	✗	✓	✗
Japan	✗	✓	✓	✗

South Korea	✓	✗	✗	✗
Russia	✗	✗	✓	✓
United Arab Emirates	✓	✗	✗	✓
United States	✓	✗	✓	✗

Table 17: References to OSAM in policy, legal, and diplomatic documents

5 Key Takeaways

The on-orbit servicing, assembly, and manufacturing (OSAM) market has undoubtedly evolved over the years, driven by advancements in technology and the growing demand for sustainable space solutions. At the political level, the most striking evolution is the **acknowledgment that it has become critical to develop the capacity to conduct on-orbit servicing missions** and develop capabilities such as active debris removal, feeding off from both sustainability and security drivers. However, it is essential to recognise that this evolution has not (yet) translated into mature and profitable markets, despite glimpses of potential as showcased by the MEV missions.

The OSAM market's limitations are exacerbated by regulatory and policy challenges that hinder the growth and scalability of OSAM services. The lack of legal obligations, in particular in ADR, does not seem conducive to the creation of a mature market as nothing compels operators to purchase such services. Overall, beyond OTVs, most services, in particular ADR, are only pushed by public contracts for demonstration missions, which does not translate a market-driven sector. In addition, more affordable methods exist such as passivation mechanisms, which may be seen as more affordable and easier methods by operators. Technological challenges related to interface equipment are also preventing the refuelling market to take off. As the EU and European Member States are currently considering updating their space strategies, priorities, and legislations, it is essential that OSAM is considered as a priority area to address.

In the past three years, OSAM has increasingly become acknowledged in space policy documents as an area of interest for economic growth, industrial development, defence operations, and space sustainability. **European States have broadly included OSAM in their space policy framework and diplomatic statements. However, looking into more details, the level of ambitions is lower than expected.** It appears that most of the policies mentioning OSAM are rather describing the context and evolutions of the space sector instead of providing specific policy measures and objectives in the domain, in particular regarding capability development and budgets.

In comparison to other space powers, **Europe's levels of investments and commitments in the domain are relatively limited and approaches to support the development of the market do not seem sufficient.** For example, the funding support to start-ups with fairly small amounts is unlikely to lead to the creation of industry leaders in this domain. These targeted investments will only be truly efficient if their volume is important and benefit from additional support at the regulatory level.

Europe has the technological capacity to ensure that its companies can become market leaders in some specific OOS. In the field of space logistics, **Europe is well positioned with several companies developing OTVs and one company providing consistent operational services.** Political objectives to position Europe as a responsible user of outer space and an actor taking part in space sustainability efforts would deserve higher means and ambitions in the field of OSAM. Pioneering missions such as but not limited to ClearSpace's or ASI's contract to Thales Alenia Space should be better leveraged to make sure that these initial missions become operational commercial services both for public clients acting as anchor customers and for private customers.

OSAM capabilities will be essential technological blocks of bigger missions and space ambitions within the in-space economy such as in the field of space exploration, space-based solar power, in-space data centres, etc., which are expected to generate significant revenue streams in the long term as well as to have deeper geopolitical, sovereignty, and strategic aspects related to the occupation of Earth's orbits and space exploration. **Europe should not miss this strategic turnaround and end up in a position of dependence or over its head once the in-space economy at large and OSAM will become mature and common place.**

6 Recommendations

This section aims to provide recommendations to foster the development of OSAM in Europe based on the findings of the report and the consultations with experts.

BETTER UNDERSTANDING OSAM

Further investigate potential use cases and applications

As markets are still only emerging, consulted stakeholders reported that policymakers and industries often perceived OSAM positively but did not necessarily see the importance of making it a priority in their space programmes or budgets notably for capabilities development. Beyond the absence of concrete business cases and demonstrations, decision makers also perceived the potential of uses and applications in this field as rather limited. Indeed, **if there is not a certain mass or volume of potential applications, it may not be seen as valuable to develop such technologies and develop dedicated programmes.**

As a result, **there is merit in further exploring the future use cases and applications that OSAM can generate**, in particular **further investigating areas and missions in which OSAM will be an essential technology block enabling new applications, access to new destinations or increasing revenues.**

Moreover, new business models that could involve OSAM should be better explored in light of the development of the in-space economy. For instance, developments in space tourism may create business opportunities for active debris removal. Affluent individuals, who are looking to go into space may want to reduce risks and purchase an ADR service that would clean the areas that they will reach prior to their launch, be it for safety concerns or to generate a positive image of their mission. This may be seen as an innovative way to fund space sustainability efforts and develop the ADR market.[426] In addition, the potential socio-economic benefits of OSAM technologies should be better assessed as market value and market forecast remain approximate.

Fully embrace the security dimension of OSAM

OSAM activities have clear security and defence applications for the protection of satellites in orbit. In the United States, this dimension is clearly recognised and Department of Defence's entities such as DARPA are conducting projects aiming at developing OSAM capabilities. Although growing, the **acknowledgement of this dimension is not yet fully present** in Europe, where most of the projects are established in order to pursue sustainability objectives.

While many European states emphasised in their statements at the Open-Ended Working Group on Reducing Space Threats that OSAM technologies have dual-use applications and may impact security and stability in space, limited programmatic action is designed with this in mind. Following this widely shared perception, the security dimension should be increasingly integrated by European and national stakeholders in future projects and programmes related to OSAM.

Better explore the links between climate change and space sustainability

As climate change also generates effects on the orbital environment through the phenomenon of **density decline in the upper atmosphere, which impacts on satellites in LEO and their altitude control/re-entry in the atmosphere, there would be merit in further exploring this topic by**

[426] Interview conducted by ESPI on September 13th, 2023.

conducting research on the extent of the impact on space operations and OSAM in the long term.

In the case that this phenomenon significantly impacts the required amounts of fuel and manoeuvring capabilities of satellites in LEO, models used by manufacturers to define system features as well as propellant levels would have to be adapted and updated accordingly. Moreover, additional interdisciplinary **research on the topic may unveil new applications and use cases for servicing in orbit. Overall, more scientific studies on space activities with regard to climate change is an effort to be pursued.**

CREATING THE MARKET WITH LEGAL AND POLICY PUSH

Taking advantage of the political interest in space sustainability to integrate legal obligations

The main obstacle in the creation of a true OSAM market is that there is not yet a business case for most services. Consulted stakeholders underlined that the only way to start a true ADR market was to oblige operators to remove their debris. Most consulted experts had **little confidence in the development of the market without any policy and legal push from governments**.

In the United States, the Federal Aviation Administration (FAA) recently proposed a new regulation to require commercial launch providers to dispose of their upper stages to deal with debris within 30 days of launch. The regulation proposes several approaches that operators can choose from, including ADR, which may prompt the creation of the U.S commercial market for ADR should this regulation be officially adopted.[427]

As the EU is considering proposing a text for its own space legislation, it would be essential to integrate provisions fostering the development of the OSAM market and providing support to European companies. The political willingness of Member States and implications for industry of such measures should be clearly assessed beforehand. Regardless, **any new legal obligations to ensure space sustainability should be coupled with initiatives and implementation support that enable space companies to remain competitive** in the market or else it will only be seen as a constraint (e.g., CNES Tech For Space Care's efforts to support national space law implementation, etc.). Three types of provisions can be envisaged:

Ensure that satellites are serviceable through dedicated interfaces	Enact measures to support a European ADR market	Impose measures after end-of-life
The EU Space Law may provide that all future satellites of the EU Space Programme (e.g., IRIS², Copernicus and Galileo) must be equipped with a European docking interface. Should the need arise, such missions will be serviceable, enlarging potential addressable markets. In addition, such	EU space legislation may integrate that in case the EU Space *Programme* or EU Member States space objects generate debris that will not eventually re-enter into the atmosphere in the short-to-mid-term, they will have to contract ADR services to European ADR companies	The EU space law may require operators to deorbit their satellites at the end of life after a certain period of time (e.g., 5 years) and should that not be the case, apply financial penalties for each additional month or year that the system remains in orbit

[427] Foust, J. (2023) FAA proposes rule to limit lifetime of upper stages in orbit, SpaceNews. Available at: https://spacenews.com/faa-proposes-rule-to-limit-lifetime-of-upper-stages-in-orbit/ (Accessed: 27 September 2023).

obligations will create demand for interfaces, which will support the entire OSAM segment and its supply chain.		

Table 18: Suggested OSAM-related provisions for the upcoming EU Space Law

Create incentives that foster the creation of the OSAM markets

Overall, whether it is in European or national laws or as part of contracts or insurance policies, there would be merit in creating a virtuous circle that rewards responsible behaviour and sanctions the absence of it through specific incentives.

For instance, instead of only awarding contracts to the industry to develop OSAM missions to contribute to the development of this market, space agencies or governments may provide financial incentives to operators that buy spacecraft equipped with interfaces. It does not bind operators to contract any OSAM missions but may incentivise them to integrate docking interfaces in the short term and may facilitate the purchase of OSAM missions in the long term (e.g., pay for the interface to be added to the satellite, pay a part of the spacecraft, etc.).

Promote OSAM as an opportunity to non-space sectors

The business models and business cases as well as the related challenges and opportunities for on-orbit servicing such as active debris removal or refuelling seem increasingly acknowledged by both industry and space policy makers. However, the potentiality of OSAM and its benefits for non-space sectors such as energy, materials, pharmaceutical, hospitality, food and beverages, etc. are rather overlooked and understudied in market analyses and market forecasts.

Yet, it is important to underline that there is a nascent interest from various sectors to take advantage of on-orbit manufacturing and on-orbit servicing. While this is best translated by an increasing number of eccentric or overambitious start-up projects, some may turn out to be profitable and address niche markets or contribute to major R&D discoveries. Moreover, significant investments from outside the space sector in OSAM projects may likely help foster the creation of the market. But to convince these non-space actors, the challenge for the space sector and decision makers will likely be to "pitch" the potential benefits that OSAM projects may bring to non-space industries as well as to ensure a high level of social acceptability for such services (e.g., avoiding the pitfalls in which the space tourism market fell into).

IMPROVING CAPABILITIES AND SERVICES

Explore new designs for space systems to foster servicing

Although the MEV missions demonstrated that satellites not designed to be serviced are still serviceable, As the lack of docking interfaces still creates difficulties to develop a market, it becomes therefore essential to work towards the development of interfaces and the required technology; similarly, advocating for more standardisation on this topic would be beneficial to the involved European industries.

Yet, **there would be merit in going beyond the servicing interface and look into new ways of designing and integrating satellite buses and satellites payloads as well as components on space systems**. At the moment, repairing or replacing payloads and satellite's components is almost impossible in orbit due to the way in which space systems are built. Finding a solution to locate components and payloads on the outside of the satellite or in a manner to ensure that they can be easily removed and replaced by a servicer while ensuring mission safety would help fostering the OSAM applications and market.

Furthermore, in order to make spacecraft more reliable and face potential risks, manufacturers have integrated redundancy and hardening of components in case of failure or malfunction, which generates higher costs and mass, and leads to increase the need for propellant. With increased options for servicing, redundancy and hardening might be potentially less relevant, which may lead to a decline of the spacecraft's average mass coupled with servicing missions. In other words, there would be merit in exploring the technical, security, and financial trade-off of building smaller lightweight satellites with minimum redundancy alongside system design that would ensure easy servicing to repair, refuel, repair, and recycle the satellite so that operators can purchase on-orbit services each time it is needed.[428]

Smart implementation of service-oriented and challenge-based procurement

Given the unique nature of the OSAM ecosystem, i.e. service-driven, procurement that is designed with challenge-based or service-oriented principles in mind is particularly fitting for further evolving and demonstrating technologies. Nevertheless, this has to be done with two considerations in mind. First, a single-mission approach should be complemented by mid-term commitments, either (i) directly by public actors, (ii) pooled from a variety of stakeholders, or (iii) incentivized through regulatory developments. This can provide companies with a (somewhat) more predictable and stable projection of revenues if successful and de-risk investments.

Nevertheless, while innovative procurement can catalyse innovation, it is also important to complement it with more traditional technology development schemes in areas where attained technological maturity is low or yet to be developed.

More generally, a service-oriented approach would enable more freedom in system designs, can inspire entrepreneurial ingenuity in the sector and incentivize new market entrants. It should, however, not be equated with a laissez-faire approach when the services (and underlying technologies) are of strategic nature.

Where SSA is essential, docking technology deserves more R&D efforts

Space Situational Awareness (SSA) is often referred to as the main key enabling technology for OSAM missions. Most European countries have acknowledged it and have outlined clear measures in their policies to develop better SSA capabilities and services. The lack of qualitative, timely, and available SSA data is often seen as a clear impediment in the development of OSAM missions in academic studies. Yet, while consulted stakeholders acknowledged the importance of such data, they also reported that improving SSA data, including with in-orbit SSA, was not a one-size-fits-all solution. They reported that the most challenging moment of servicing missions is often the docking process, in particular in case of a non-cooperative target, which mostly requires **Guidance, Navigation, and Control (GNC), computer vision, artificial intelligence, and inter-satellite links** with the servicer. If Europe wants to develop a true OSAM market and ensure strategic autonomy in its missions, it is essential that it also put a clear emphasis on developing these key enabling technologies.

Support active involvement of European universities in OSAM capability development

European Universities are lagging in terms of dedicated academic programmes and centres focusing on OSAM. When contrasted with the United States, which counts dedicated centres for

[428] Interview conducted by ESPI on September 13th, 2023.

OSAM, significant budgets, and partnerships with governmental agencies and space companies, Europe's deficit becomes evident.

Strengthening the connections among universities, space companies, and space agencies can enable to create an environment conducive to develop OSAM R&D efforts and contribute to market development. The creation of Centres of Excellence or dedicated OSAM programmes would be essential to foster R&D in Europe. In addition, Europe should **stimulate the inception of university spin-off companies, which can serve as a catalyst for innovation in OSAM capabilities (e.g., ClearSpace).** These emerging entities can bridge the divide between academic research and tangible, market-ready solutions.

The UK's approach to space research offers a compelling case for the benefits of investing in academia. With a focused effort on funding space-related academic pursuits, the UK has witnessed a significant rise in R&D activities associated with space technologies. This surge not only underscores the direct correlation between academic investment and innovation but also highlights the potential for such strategies to bolster economic growth and position Europe at the helm of OSAM advancements. However, the volume of programmes and funding should be diversified and increased to ensure that the means match the objectives.

STRIVING FOR EUROPEAN STRATEGIC AUTONOMY

Addressing OSAM with a more unified voice within diplomatic *fora*

European States are relatively active in diplomatic *fora* such as UNCOPUOS or the UN OEWG on Reducing Space Threats. However, mentions of on-orbit servicing in international frameworks remains rather limited considering that it has been under-addressed in the IADC or LTS Guidelines or other non-binding resolutions and norms. Aspects that should be addressed may include obligations to conduct active debris removal, safety zones for proximity operations, information sharing processes and mechanisms in advance of RPOs and inspection missions to avoid misunderstanding and ensure responsible space behaviour, preserved zones for inhabited space stations and potential obligations to remove debris in these areas.

States that often mention OSAM are usually major spacefaring nations (e.g., France, Germany, etc.). States as well as the EU should strive to speak with a more authoritative and unified voice on the aforementioned topics. These could be leveraged to **promote specific postures and solutions that would be advantageous for the European OSAM industry as well as space sustainability and may foster the creation of new applications and services in the OSAM market and related value chains (e.g., data sharing companies, data analysis, etc.).**

Europe should have a more coherent and harmonised position on standardisation

While there are notable efforts conducted by ESA to work towards standardisation regarding interfaces, in particular to ensure that they are ITAR-free and ensure strategic autonomy, there are currently no cohesive Europe-wide standardisation efforts to support a European position at global level in the field of OSAM.

At the EU level, the PERASPERA project and its successor PERASPERA-X have worked to promote *"European framework activity, collaborating with stakeholders to generate guidelines & principles, for operations in Space (e.g., OOS, OOA, OOM, etc.) in the context its commercialisation, that support further law & decision making activities by appropriate instances"*. However, PERASPERA-X ended in March 2023 and it is not yet clear if any project in this regard will follow. Therefore, **ensuring a follow-up initiative is essential to ensure standardisation efforts that benefit the European space sector. A follow-up should also ensure effective EU-ESA cooperation in this domain.**

There is momentum for such efforts as there is a growing sense of coopetition within Europe. European States and industries know that they are competing against each other on the market but remain aware that they have to work together on standardisation practices.

In parallel, the United States is much more advanced in promoting standardisation through initiatives such as CONFERS, which is an industry-driven initiative that promotes standards and international policies for satellite servicing. Several European companies including OHB, Thales and Clean Space have chosen to engage with CONFERS at varying levels of membership. As some companies and actors may approach standardisation efforts in Europe with scepticism, the need to take part in other *fora* to ensure that their products are interoperable and adapted to the global market may push them to look beyond Europe. However, while these standardisation efforts are positive for the development of OSAM, they are often adapted to U.S. interests.

Ensure better protection of intellectual property and efficient economic intelligence

Overall, European space start-ups (in the field of OSAM and beyond) have reported that they get offers to implement themselves in non-European countries or are subject to hostile takeovers or buyouts on a regular basis. Often, companies developing strategic technologies are acquired by foreign competitors and States are not always reactive to protect them. **European States should ensure effective cooperation with OSAM start-ups, monitor interactions with non-European entities, and strive to protect strategic companies even if they are not yet profitable and/or develop technologies for which the business case is not yet proven but are acknowledged as essential.** Economic intelligence capacities should be improved in the European space sector to identify critical technologies and companies in OSAM, ensure constant news monitoring, conduct awareness raising campaigns about risks and threats, and ensure dialogue between companies, political stakeholders in charge of space, and economic intelligence services.

Economic intelligence also implies to provide support to European companies that may face challenges due to the practices or regulatory changes that may take place outside Europe. Companies may need temporary support to adapt to changes in the market. In addition, in some market segments such as the OTV market, in which some European companies are taking significant market shares, States and agencies should ensure that these companies will be enabled to provide their services on future European launchers even in situations where they might have to face more restricted access on foreign launchers.

Several measures can therefore be taken to further develop the OSAM ecosystem in Europe. They can be grouped into four categories, which can be considered in a sequential manner. First, it appears crucial to better understand these activities at a technical level (feasibility, timeframe, risks, outcomes) and at a business level (potential commercial use cases and applications), but also in their interaction with other considerations (e.g., security and environmental challenges). Once the actual impact of these activities is known, several measures should be taken at the policy and legal level to incentivise the creation of a market and ensure its viability and predictability (e.g., by encouraging operators and manufacturers alike to integrate dedicated interfaces on their spacecrafts, which would later enable their serviceability). In parallel, for OSAM to be used and generate positive outcomes, it becomes necessary to improve the associated capabilities and services, for instance by developing new designs or investing more in related R&D. Finally, all these efforts should be underpinned by a true European will to become autonomous in this domain, in particular by establishing a European position which supports its political and economic interests. By doing so, Europe would have the opportunity to promote and further discuss such position internationally.

7 Annexes

7.1 Analysed policy documents

The quantitative policy analysis provided in Section 4.2 exploited the following policy documents:

Country	Name of Policy	Year of Publication
Australia	Australian Civil Space Strategy 2019-2028	2019
Australia	Australia in Space: A Decadal Plan for Australian Space Science 2021-2030	2021
Australia	Australia's Defence Space Strategy	2020
Austria	Austrian Space Strategy 2030+	2021
Belgium	Belgian Space Strategy	2022
Canada	A New Space Strategy for Canada	2019
Canada	Canada's Space Policy Framework	2014
China	China's Space Program: A 2021 Perspective	2022
Croatia	Spatial Development Strategy of the Republic of Croatia	2017
Cyprus	Cyprus Space Strategy 2022-2027	2022
Czech Republic	National Space Plan 2020-2025	2019
Denmark	Denmark's National Space Strategy	2021
Estonia	Estonian Space Policy and Program 2020-2027	2020
European Union	Action Plan on Synergies Between Civil, Defence and Space Industries	2021
European Union	European Union Space Strategy for Security and Defence	2023
European Union	An EU Approach for Space Traffic Management – An EU Contribution Addressing a Global Challenge	2022
European Union	Space Strategy for Europe	2016
European Union	A Strategic Research and Innovation Agenda for EU-funded Space Research Supporting Competitiveness	2020

European Space Agency	Agenda 2025	2021
European Space Agency	Technology Strategy	2022
Finland	Finland 2025	2018
France	Space Defence Strategy	2019
France	French National Space Strategy	2016
Germany	The Space Strategy of the German Federal Government	2010
Hungary	Hungary's Space Strategy	2021
India	Indian Space Policy 2023	2023
India	Commitment Towards a Reformed Space Sector	2020
Ireland	National Space Strategy for Enterprise 2019-2025	2019
Italy	Space Economy Strategic Plan	2016
Italy	National Security Strategy for Space	2019
Italy	Strategic Vision for Space 2020-2029	2020
Italy	Government Guidelines on Space and Aerospace	2019
Japan	Space Industry Vision 2030	2017
Japan	Outline of the Basic Plan on Space Policy	2020
Japan	Space Security Policy	2023
Korea	The Basic Plan for Promotion of Space Development 2018-2022	2018
Korea	Future Vision 2050	2019
Korea	Space Economy Roadmap	2022
Latvia	The Space Strategy of Latvia 2021-2027	2020
Lithuania	Lithuanian Space Sector Development Strategy	2022
Lithuania	On the Development of Science, Technology, and Innovation in the Field of Aerospace 2016-2020	2015

Luxembourg	Space Strategy 2023-2027	2022
Luxembourg	National Action Plan 2020-2024	2020
Luxembourg	Defence Space Strategy	2022
Malta	Malta National Space Strategy	2022
Netherlands	NSO Pre-Advice for its Space Policy from 2020	2020
Netherlands	Space Activities 2020	2020
Netherlands	Memorandum on Space Policy 2019	2019
Norway	Norwegian Space Policy for Business and Public Benefit	2012
Norway	A Strategy for Norwegian Space Activities	2019
Poland	Polish Space Strategy	2017
Poland	Draft National Space Programme	2021
Portugal	Portugal Space 2030	2018
Romania	National Research Development Strategy 2022-2027	2022
Russia	Federal Space Programme for 2016-2025	2016
Russia	Fundamentals of the Russian Federation's State Policy in the Field of Space Activities for the Period up to	2013
Slovakia	A Conceptual Framework of Space Activities in the Slovak Republic	2019
Slovenia	Draft Slovenian Space Strategy 2023-2030	2023
Spain	National Aerospace Security Strategy	2019
Spain	PERTE Aeroespacial	2022
Sweden	A Strategy for Swedish Space Activities	2017
Sweden	The Strategy of the Swedish National Space Agency	2019
Switzerland	Space Policy	2023
UAE	National Space Policy	2016
UAE	National Space Strategy 2030	2019

UAE	Mohammed Bin Rashid Space Centre Strategy 2021-2031	2020
United Kingdom	The National Space Strategy in Action	2023
United Kingdom	Joint Doctrine Publication - UK Space Power	2022
United Kingdom	Defence Space Strategy	2022
United Kingdom	National Space Strategy	2021
United Kingdom	UK Severe Space Weather Preparedness Strategy	2021
United Kingdom	Capability Management Plan	2022
United States	A Strategic Framework for Space Diplomacy	2023
United States	Defence Space Strategy Summary	2020
United States	National In-Space Servicing, Assembly, and Manufacturing Implementation Plan	2022
United States	In-Space Servicing, Assembly, And Manufacturing National Strategy	2022
United States	National Orbital Debris Research and Development Plan	2021
United States	National Space Policy	2020
United States	Space Priorities Framework	2021
United States	Tenets of Responsible Behaviour in Space	2021
United States	Space Power Doctrine for Space Forces	2020
United States	Combined Space Operations Vision 2031	2022
United States	DoD Directive 3100.10 Space Policy	2022
United States	National Low Earth Orbit Research and Development Strategy	2023
United States	National Orbital Debris Implementation Plan	2022

7.2 Doctoral research on OSAM from 2018-2023 in Europe

The table below provides a list of mapped PhD theses conducted between 2018 and 2023 on a topic related to in-orbit servicing, assembly, and manufacturing.

Country	University	Title of Thesis
United Kingdom	University of Warwick	Blake, James (2021): Optical imaging of space debris in low and high-altitude orbits
	University of Surrey	Bouhanna, Zakaria (2020): Intersatellite ranging with CDMA for space traffic management
	University Kent	Dignam, Aishling (2023): Development and calibration of a passive space dust collector for low earth orbit
	University of Southampton	Guthrie, Ben (2022): Enhancing autonomous vision-based navigation in space with deep learning technologies
	University of Surrey	Jackson, Lucy E. (2023): Using reinforcement learning to design and control free-flying space robots
	University of Strathclyde	Duering, Marcel (2020): Station-keeping and orbital transfers in the vicinity of the Moon exploiting quasi-periodic orbit dynamics
	University of Strathclyde	Polnik, Mateusz (2020): Routing and scheduling optimisation under uncertainty for engineering applications
	University of Glasgow	Robb, Bonar (2023): The dynamics and control of large space structures with distributed actuation
	University of Glasgow	Viale, Andrea (2021): Engineering near-Earth asteroid resources using the orbital siphon effect
	University of Glasgow	Viavattene, Giulia (2022): Artificial neural networks for multi-target low-thrust missions
	University of Strathclyde	Polnik, Mateusz (2020): Routing and scheduling optimisation under uncertainty for engineering applications
	University of Glasgow	Robb, Bonar (2023): The dynamics and control of large space structures with distributed actuation
	University of Glasgow	Viale, Andrea (2021): Engineering near-Earth asteroid resources using the orbital siphon effect

France	Cranfield University	Yilmaz, O. (2018) Infrared based monocular relative navigation for active debris removal
	Federal University in Toulouse	Kraiem, S. (2022): Development of steering law for On Orbit Servicing operation
	INP Toulouse	Raveneau, P. (2020): Satellites d'observation et réseaux de capteurs autonomes au service de l'environnement
	ISAE SUPAERO (Toulouse)	Claudet, T. (Ongoing): Guidance, Navigation and Control Enhanced Tools for RendezvousMissions for Low-Thrust Small Satellite
	University of Bordeaux	Zenteno Torres, Jazmin (2020): Sliding mode control with fault tolerance capacities : application to a rendezvous mission in a circular orbit
	ISAE SUPAERO (Toulouse)	E. Blazquez, (2021), Rendezvous optimization and GNC design for proximity operations on cis-lunar near rectilinear halo orbits
	Sorbonne University	de Gouyon Matignon, Louis (2020) Les contrats de services en orbite
	Université Paul Sabatier - Toulouse III	Arantes Gilz, Paulo Ricardo (2018) Embedded and validated control algorithms for the spacecraft rendezvous Algorithmes de commande embarqués et validés pour le rendez-vous spatial
	Federal University in Toulouse	Comellini, A. (2021), Vision-based navigation for autonomous rendezvous with non-cooperative targets
	ISAE SUPAERO (Toulouse)	Chelikh, Idriss (ongoing) Développement de contrôleurs de tâches robustes pour de la mise en service en orbite
Germany	Technical University of Berlin	Huwald, Markus (Ongoing): Guidance, navigation, and control for autonomous capture of debris objects
	Technical University of Berlin	Dornburg, Lars (2022): Entwurf und experimentelle Untersuchunngen einer Treibstofftransferschnittstelle für Raumfahrzeuge und ihre Anwendungsmöglichkeiten für das On-Orbit-Servicing

	University of the Federal Armed Forces Munich	Klionovska, Ksenia (2020): Analysis and optimization of PMD sensor data for rendezvous applications in space
	Munich University Munich University of Applied Sciences	Pietras, Markus: End-to-end simulation of teleoperated on-orbit robotics
	College of Aeronautics and Automotive Engineering (ESTACA)	Stoll, Enrico: Ground verification of telepresence for on-orbit servicing
	Technical University of Berlin	Tham, Dung (2021): A reconfigurable data communication system for on orbit serviceable, highly modularized satellites
	Technical University of Berlin	Ziemer,Lennart (Ongoing) AI-assisted dynamic capture of spacecraft using bio-inspired micro-patterned dry adhesives
Italy	University of Padova	Cao, Alex (2023) Development of a smart capture system for On--Orbit--Servicing with space robots
	Politecnico di Torino	Boggio, Mattia: Earth Gravity in-orbit sensing: MPC formation control based on a novel constellation model
	University of Padova	Duzzi, Matteo (2020) Spacecraft Rendezvous and Docking Using Electromagnetic Interactions.
	Politecnico di Torino	Pagone, Michele (2022): Nonlinear Model Predictive Control for Space Applications: optimal guidance and control systems for orbital transfer and rendezvous maneuvers.
	University of Padova	Antonello Andrea (2018): Design of a robotic arm for laboratory simulations of spacecraft proximity navigation and docking
	University of Padova	Mazzucato, Mattia (2018) Design and testing of a vision based navigation system for a spacecraft formation flying simulator
Luxembourg	University of Luxembourg	Mohatashem, Reyaz (2021): Strategies for Robotic Manipulators in Space Applications
	University of Luxembourg	Orsula, Andrej (Ongoing): Space Assembly through Learning of Transferable Skills
	University of Luxembourg	Xiao, Li (2022): Design and implementation of software in the loop architecture for active space debris removal high-fidelity scenarios

Netherlands	University of Luxembourg	Delisle, Maxime Hubert (Ongoing): Design of a Capturing, Absorbing, SEcuring system for active space Debris removal
	Delft University of Technology	Pasqualetto Cassinis (2022): Monocular Vision-Based Pose Estimation of Uncooperative Spacecraft
	Delft University of Technology	Ardaens, J.H. (2020): Angles-only relative navigation in low earth orbit
	Delft University of Technology	Shan, M. (2018): Net deployment and contact dynamics of capturing space debris objects
Slovakia	Comenius University in Bratislava	Hrobár, Tomáš (Ongoing): Analysis of torques affecting attitude state motion of space objects on geocentric orbits
	Comenius University in Bratislava	Kyselica, Daniel (Ongoing): Processing of light curves of satellites and space debris for the purpose of their identification
Spain	Sevilla University	Julio César Sánchez Merino (2021): Model Predictive Control Applications to Spacecraft Rendezvous and Small Bodies Exploration
	Carlos III de Madrid University	Chiabo, Luca (2022): Emissive Langmuir Probe Theory with Application to Low Work Function Electrodynamic Tethers
	Carlos III de Madrid University	Morante Gonzalez, D. (2020): Hybrid multi-objective trajectory optimization of low-thrust space mission design
	Carlos III de Madrid University	Shahsavani, Sadaf (2022): Modeling and mission analysis of Low Work Function tether
Switzerland	Ecole Polytechnique Fédérale de Lausanne (EPFL)	Juillard, Michael Y. (2022): Uncooperative Rendezvous in Space : Design of an Electronic Architecture for High Performance Avionic with Multi Sensor Input and Intensive Data Rate

ACKNOWLEDGEMENT

ESPI extend its appreciation to all the experts and consulted stakeholders, who provided their opinion, insights, review of the report. ESPI also thanks ExoLaunch for providing the cover of the report.

List of interviewees	
Abel Haddoud	Chief Executive Officer, Infinite Orbits
Agata Jozwicka Perlant	Space Transportation Beyond LEO Manager, European Space Agency
Bandini Flavio	Infrastructure and Transportation Product Lines Manager, Thales Alenia Space
Daniel Nöelke	Policy Officer, Seconded National Expert, European Commission
Diego Garcés de Marcilla	IOS Business Development Manager, D-Orbit
Durand Yves	Director of Technology, Thales Alenia Space
Hooghe Muriel	Senior Project Manager, Luxembourg Space Agency
Javier Rodriguez	Aerospace Programmes Department, Centro para el Desarollo Tecnológico Industrial (CDTI)
Jean-Marc Laurent	Gen. ® Executive Head of the Chair "Defence and Aerospace", Sciences Po Bordeaux
Joanna Ruiter	Advisor Satellite Applications, Space Safety Delegate at ESA, Netherlands Space Office
Joost Carpay	Deputy Director, Netherlands Space Office
Jörg Kreisel	Chief Executive Office, JK International Consultant
Lamboray Bob	Senior Project Manager, Luxembourg Space Agency
Manny Shar	Managing Director, Orbit Fab
Philippe Coué	Essayist, Lecturer, Project Manager, Dassault Aviation
Pierre Omaly	Expert, Spaceflight Security, CNES
Per Høyland	Adviser, Strategic Analysis, Norwegian Space Agency
Shin Sangwoo	Research Fellow, Korea Space Policy Research Centre

Stefano Antonetti	Vice President Business Development, D-Orbit
Stephan Meyer	Expert ESA Technology Programmes, Austrian Research Promotion Agency
Yngvild Linnea Andalsvik	Lead – Space Situational Awareness, Norwegian Space Agency

Authors

Clémence Poirier is a Research Fellow at the European Space Policy Institute (ESPI). Her expertise focuses on space security and space cybersecurity. She previously carried out policy research on the cybersecurity of the Australian infrastructure for Flinders University in Adelaide, Australia. She is SGAC's Space Generation Advocacy and Policy Platform Co-Lead on Responsible Space Behaviour. She holds a master's degree in International Relations, International Security, and Defence from University Jean Moulin Lyon 3, France.

Mathieu Bataille is a Research Fellow and Lead on Security and Defence at the European Space Policy Institute, whose research activities mostly focus on the use of space systems for the conduct of security and defence operations on Earth, as well as the protection of spacecraft in orbit. He worked previously at the Studies Department of the French Air Force. He holds a master's degree in Political Science and International Relations from Sciences Po Paris.

Alberto Rueda Carazo is a Research Fellow at the European Space Policy Institute with expertise in space and public international law. He previously worked at Sorbonne University and Paris-Saclay University. He served as Co-lead at SGAC Space Law and Policy Project Group and as an assistant to the head of the UNOOSA legal and policy section. He holds an LL.M in Public International Law from Leiden University and a master's in Space Law and Telecommunications from Paris-Saclay.

Lucas Bersegol is a Research Fellow at the European Space Policy Institute (ESPI) seconded by the French Space Agency (CNES) in Vienna, Austria. Prior to joining ESPI, he worked for several private companies. First as a Project Manager at Tesla, and most recently at Airbus Defence & Space as a Campaign Manager. He holds a master's degree in Business Management and International Affairs from Paris 1 Panthéon Sorbonne University, France.

Yui Nakama is a Global Fellow at the European Space Policy Institute. Previously, she worked as an Intern at Axelspace and ArkEdge. She has an economics background and is currently pursuing a master's degree at the University of Tokyo, researching Space Safety, Security and Sustainability.

Jules Varma was a Research Fellow and Lead for Industry and Finance at the European Space Policy Institute, now working at the European Space Agency. Prior to joining ESPI, he worked at the UNEP Economy division. He holds a MSc from the department of Space and Climate Physics at University College London (UCL). He also holds a ME in Climate Change Science from the University of Melbourne and B.A in Political Sciences from McGill University.

Editor

Matija Rencelj is the Research Manager of the European Space Policy Institute (ESPI). He previously worked at ESPI as a Research Fellow as well as at the European Space Agency, the European Commission, in the aviation and commodities sectors, and started his career at a corporate law firm. He holds an LL.M in Air & Space Law from McGill University and a Law Degree from the University of Ljubljana.

About ESPI

Policy & Strategy

Economy & Business

Security & Defence

International & Legal

ESPI is the European think-tank for space. The Institute is a not-for-profit organisation based in Vienna, World capital of space diplomacy, providing decision-makers with an informed view on mid to long-term issues relevant to Europe's space activities since 2003.

ESPI is governed by a General Assembly of member organisations and supported by an Advisory Council of independent high-level experts.

ESPI fulfils its objectives through various multi-disciplinary research activities leading to the publication of books, reports, papers, articles, executive briefs, proceedings and position papers, and to the organisation of conferences and events including the annual ESPI Autumn Conference.

Who we are	What we do
Independent think-tank specialised in space policy	Research and analysis on major space policy issues
Multinational team with interdisciplinary expertise	Monitoring of global space trends and policy developments
Part of a network of European and international partners	Organisation of thematic conferences and workshops

Download our reports, check out our events and subscribe to our newsletter online

www.espi.or.at

Schwarzenbergplatz 6 | A-1030 Vienna, Austria | (Entrance: Zaunergasse 1)
Phone +43 1 718 11 18 - 0 | E-Mail: office@espi.or.at

ABOUT WAY4SPACE

Way4Space is an initiative which was founded in Bordeaux, France by French public officials and world majors in the space industry (ArianeGroup, Dassault Aviation and Thales) and which joined forces with research players (Atomic Energy Commission, Defense & Aerospace Chair of Sciences Po Bordeaux, University of Bordeaux) and economic players (Nouvelle Aquitaine Development & Innovation Agency, Aerospace Valley international competitiveness cluster).

The Inspiration & Innovation Hub, Way4Space's ambition is to build and accelerate knowledge, new technologies and future space applications. Based in Nouvelle-Aquitaine, France, Way4Space aims to foster transversality between sectors, driving prominent thinkers to explore and develop new projects and ideas. Way4Space's goal is to gather group-wisdom and open up new avenues to Space.

Way4Space is a partner of ESPI.

THINK THANK

INSPIRATION & INNOVATION CENTRE

TECHNICAL & ECONOMIC FEASIBILITY

www.way4space.com

25 Avenue de Berlincan

33160 Saint-Médard-en-Jalles

FRANCE

ESPI

European Space Policy Institute

Schwarzenbergplatz 6, 1030 Vienna
(Entrance: Zaunergasse 1)

+43 1 718 11 18 - 0
office@espi.or.at

www.espi.or.at