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A NEW LANDSCAPE FOR SPACE APPLICATIONS

ILLUSTRATIONS FROM RUSSIA'S WAR OF AGGRESSION AGAINST UKRAINE

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A new landscape for space applications: Illustrations from Russia's war of aggression against Ukraine

By Marit Undseth and Claire Jolly (OECD Directorate for Science, Technology and Innovation)

For decades, governments have relied on space systems for intelligence gathering and satellite connectivity in remote areas, but today's situation marks a distinct break with the past. Extended coverage, advances in digital technologies and, importantly, free and/or commercial availability of space products allow many new uses by both government and non-government actors. This brings important benefits for users and citizens, but also leads to new challenges in terms of data management; infrastructure and supply chain resilience; and international co-operation.

This paper, expanding on an OECD Policy Note on the Impacts of the War in Ukraine, uses illustrations from the war to highlight recent developments in the sector, placing them in a broader context of digitalisation and government space investments. It discusses the implications of the growing importance of space technologies for society and suggests policy options and resources from other strains of OECD work.

Keywords: Critical infrastructure, data governance, digitalisation, space economy, space sustainability, global supply chains.

JEL codes: F53, H54, O25, O32, O38, Q01

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Executive summary

Boosted by public and private investments and advances in digitalisation, space capacities have taken on a new role in our economies. For decades governments have used space-enabled intelligence gathering and satellite connectivity solutions, but the current situation marks a distinct break with the past, featuring enhanced commercial availability of space products, allowing many new uses by governments and non-government actors.

This explosion in the availability of satellite data and signals is overall beneficial to society. It contributes for instance to improved quality and resilience of government systems – notably in crisis management and military operations – and to new civilian applications (e.g. open-source intelligence). Illustrations of this new state of affairs can be found in the responses to the Russian Federation's [hereafter 'Russia'] war of aggression against Ukraine, where satellite signals and imagery have made important contributions to Ukraine's war efforts and supported an unprecedented near-real-time media coverage of events.

However, society's increased reliance on space-based data and systems also comes with a series of risks. For example, unanticipated third-party uses of data may have consequences for national security and citizens' privacy. Open-source intelligence experts saw almost real-time the large-scale invasion of Ukraine, combining information from satellite imagery with live traffic monitoring on Google Maps, a service that was later shut down in the country.

Furthermore, recent crises highlight the inherent vulnerabilities of the space sector that policy makers need to take into consideration. Space infrastructure, as a growing critical infrastructure, is exposed to malicious acts and orbital threats (e.g. space debris, including from anti-satellite missile tests). The global space supply chain is small, specialised and concentrated and therefore particularly vulnerable to economic and geopolitical shocks. For instance, Ukraine and Russia are important international providers of space products and launch services, and the prolonged conflict and ensuing geopolitical consequences led to unforeseen delays and disruptions.

And finally, the current geopolitical situation raises questions about the future of international co-operation in space activities, most urgently in space exploration and space sciences, but also in meteorology and climate science, among others. Particularly worrying are the consequences of the war for the global management of orbital space debris. In a worst-case scenario, the uncontrolled accumulation of space debris in Earth's orbits could make certain valuable orbits unusable for human activity, with severe socio-economic consequences.

The OECD has done extensive work in several of these areas and can provide policy advice and instruments for governments to consider, on managing data access and sharing, securing critical infrastructures, and addressing the sustainability of space activities.

Key policy messages

This paper raises several issues concerning space infrastructure resilience, digital security, data management, commercialisation of space activities and space sustainability. The OECD has published extensively on several of these topics, and, building on this existing work, governments are encouraged to take note of the following areas for further attention.

- **Addressing the space sector's vulnerabilities:** Due to several factors, e.g. size of the sector, cost of entry and the nature of the space environment, space infrastructure and its related activities are particularly vulnerable to economic and geopolitical shocks, natural hazards and malicious acts. Policymakers are not necessarily aware of the scope and degree of these vulnerabilities that need to be mapped and addressed.
- **Managing access to and use of data and signals:** The recent dramatic growth in the availability of space-based data and signals has positively contributed to the management of the COVID-19 crisis, providing information on catastrophic droughts, floods and natural disasters, and helping monitor the war in Ukraine. Enhanced access and sharing to space-based data and signals is associated with notable social and economic benefits, but it also raises several questions, for example in terms of private ownership of public-good data and unanticipated consequences for security and privacy.
- **Fostering further space sector commercialisation:** The emergence of commercial space actors carries the potential for more innovative, affordable and resilient government and commercial services. Various forms of partnerships with the private sector are likely to grow in importance in the coming years, to keep costs of space activities as low as possible, diversify sources of supply and to foster the growth of innovative products. However, great care must be taken to reduce barriers of entry and remove excessive first-mover advantages, to favour equitable access and fuel competition.
- **Ensuring long-term sustainability of space activities through continued international co-operation with OECD support:** As space capacities become increasingly important for society, it is crucial to ensure the long-term sustainability of space activities, making space infrastructure more resilient to natural and human made threats and addressing negative externalities of space activities. One pressing challenge is the management of space debris and stabilising the orbital environment will require concerted action at both the national and international level. A long-term strategic view on the role and capabilities of both public and private actors is also needed.

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1. A new landscape for space applications

1.1. Introduction

This OECD policy paper explores the drivers that are shaping today's new landscape for space applications and discusses associated risks and challenges. It draws on a few illustrations from Russia's war against Ukraine, but it also describes more general trends that are likely to have a far-reaching impact on the sector in the coming years.

The landscape for space applications has indeed changed in only a few years – particularly in terms of the range and quality of product offerings, as well as of the types of actors providing them. This affects not only the scope of available space applications but also their overall impact on events, from wars to natural disasters management. In particular, the availability of commercial satellite services contributes to make civilian and military infrastructure more resilient and provide new services.

1.2. Increasing availability of space-based data and signals

Governments have relied on space assets for decades. Space technologies are particularly well suited to address different types of natural, technological and societal hazards and threats, both by allowing the acquisition of crucial data and providing early warning using earth observation applications, and by forming back-up hubs for telecommunications when needed.

Public and private investments and policy decisions over the last 10-15 years, accompanied by technological improvements and the lowering costs of access to space, are now leading to a more diversified and intensified use of space assets. The novelty in the current situation is the *level of coverage* by multiple complementary and overlapping satellite systems, and the *commercial and/or free availability* of data products and signals and hence their use by non-government actors.

The growing number of satellites as well as the increasing performance, complexity and resolution of instruments are leading to an explosion in the volume of data and signals generated by both public and private space systems. Many of these systems are, by definition, dual use systems, accessible to both military and civilian organisations. Advances in digital technologies furthermore facilitate data and signal processing, storage, sharing and analysis in combination with other types of data and information (OECD, 2019[1]). This is the culmination of decades of (mainly) government investments, increasingly complemented by private sector funding.

1.2.1. Government investments

Over the last two decades, governments have made considerable investments in satellite earth observation systems. This includes large institutional programmes (e.g. the Copernicus earth observation programme by the European Union and the European Space Agency) and the coming of age of new-generation satellites supporting decades-long missions (e.g. US Landsat programme, currently in its fourth iteration of sensors and Canada's successive Radarsat missions). As observed in 2015, the volume of data generated by from 15 US and European earth observation missions were projected to grow from an annual two petabytes in 2012 to more than 12.5 petabytes in 2018 (Schreier, 2015[2]).

The availability and precision of signals from satellite navigation systems has also significantly increased, and will be even more precise by 2030, as governments are making important investments in global navigation satellites systems (GNSS) and satellite-based augmenting systems (SBAS) (OECD, 2019[1]). There are currently three operational GNSS systems with global coverage; the US Global Positioning System (GPS) and the Chinese BeiDou and the Russian Glonass navigation systems. The European system Galileo will also soon reach full operational status. Furthermore, there are two regional systems with more limited geographic coverage (India, Japan) and a third Korean system under development. The accuracy and integrity of the open (civilian) signals emitted by these constellations can be further enhanced by both terrestrial and satellite-based augmentation systems, such as the US Wide Area Augmentation System (WAAS) or the European Geostationary Navigation Overlay Service (EGNOS). These augmentation systems play an important role in aviation, as well as in precision agriculture, marine and land transport and mapping/surveying.

This considerable deployment has been accompanied by dedicated programmes and initiatives to encourage the use of satellite data and signals, which include open data policies and the development of specific services and applications to make data more accessible to the public (OECD, 2021[3]), for example Digital Earth in Australia, satellittdata.no in Norway, or Satellite Data Portal in the Netherlands. In Canada, Radarsat data are accessible to the public through the Open Data and Information Portal and/or through the Earth Observation Data Management System. In Europe, data from the Copernicus programme are made available via Data and Information Access Services or the Open Access Hub. Governments have also supported technology testbeds tor satellite augmentation systems (e.g. Australia/New Zealand). Furthermore, data from government missions are available on popular commercial platforms, such as Earth on Amazon Web Services (AWS) or the Google Earth Engine. As another regional example, the Committee on Earth Observation Satellites (CEOS) and other partners supported the 2018 launch of the Africa Regional Data Cube. Finally, the global initiative Open Data Cube, supported by government organisations in Australia, the United Kingdom and the United States as well as commercial partners and CEOS, provides an open and freely accessible tool to access satellite data.

There are not always clear usage boundaries between public and private, or civil and military space systems and applications. Some military-owned systems may have a substantial number of civilian users. The most evident examples are global GNSS systems such as the US GPS or the Russian Glonass, both of which are operated by the military and provide degraded signals to civilian users (in contrast, the European Galileo system is a civilian-operated system with some military users). It also applies to the US Department of Defense's polar-orbiting meteorological satellites.

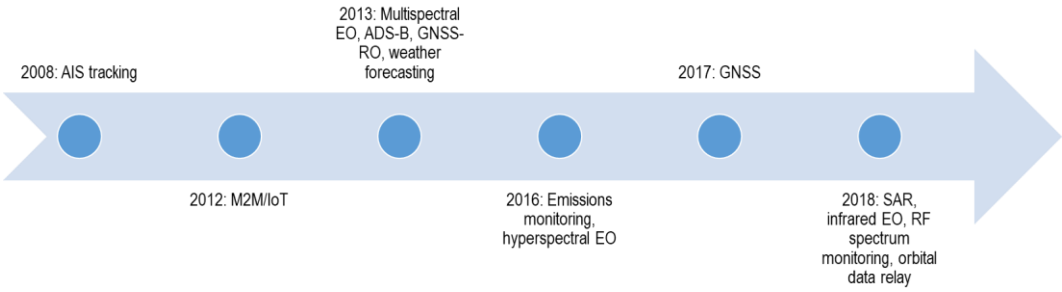
1.2.2. Increasing commercialisation of space infrastructure

The first wave of space system commercialisation took place in the 1980s and 1990s, with the privatisation of satellite operations and the emergence of geostationary telecommunications services. Further commercial telecommunication projects were launched as part of the dot.com bubble towards 2000, with reduced activity in the following decade, but which still saw the first commercial or public/private earth observation satellites. Commercial investments took off again in the early 2010s, boosted by miniaturised technology and increased usage of standardised and off-the-shelf products that considerably reduced satellite production and launch costs (OECD, 2014[4]).

This last development was enabled by the introduction of commercial small satellites and advances in nanosatellites[1] in low-earth orbits for earth observation applications. Figure 1.1 shows some of the technologies that have been introduced since 2012, flying on very small commercial satellites weighing 100 kg or less, the smallest of which are often referred to as "cubesats"[2].

Figure 1.1. Deployment timeline of selected miniaturised commercial space systems

Operational technologies on satellites < 100 kg



Notes: AIS: Automatic Information System, M2M: Machine-to-machine narrowband communication, IoT: Internet of Things, EO: Earth observation, GNSS: Global navigation satellite system, RO: Radio-occultation, SAR: Synthetic aperture radar, RF: Radio frequency, ADS-B: Automatic dependent surveillance-broadcast.
Source: Based on Kulu, E. (2022[5]), *NewSpace Index,* www.newspace.im/.

Cubesat missions are often deployed in multi-satellite constellations to improve geographic coverage and shorten revisit time, leading to a notable increase in the number of launched satellites or payloads. The most recent jump in launched payloads as shown in Figure 1.2 marks the deployment of Space X's Starlink constellation for satellite broadband. Indeed, satellite broadband is now the main driver of private investments and projects for mega-constellations[3] in the low-earth orbit are dwarfing all other launch activities. In early 2022, the satellites from only two commercial operators, SpaceX and OneWeb, accounted for almost half of *all* operational satellites in orbit (Union of Concerned Scientists, 2022[6]).

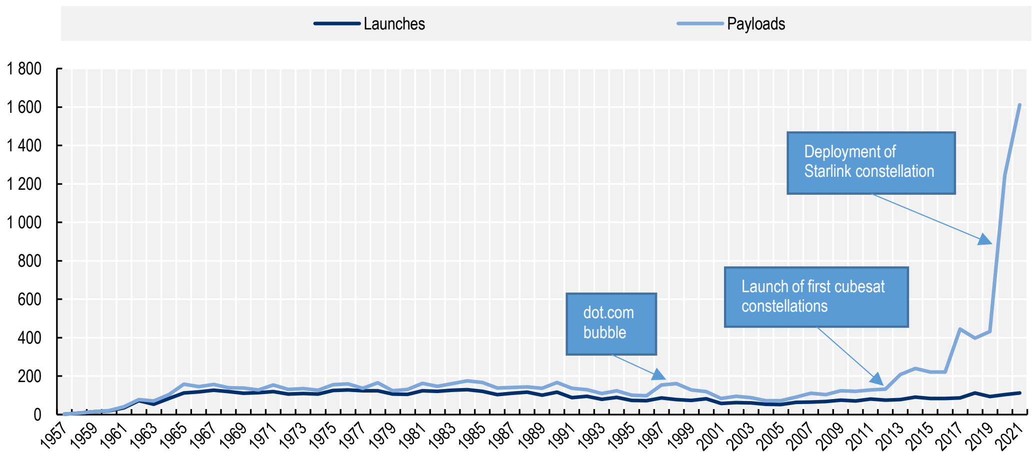
Following these technological developments as well as strategic government decisions – especially in the United States – to support space commercialisation with dedicated government procurement, a number of new applications are developing fast:

- **Satellite broadband in low-earth orbit:** More than ten broadband satellite constellations are in different stages of development, and three companies (SpaceX, OneWeb and Telesat) have already launched satellites. The Starlink constellation from SpaceX currently numbers more than 1 000 operational satellites and could soon achieve global coverage, pending regulatory approvals. Other commercial operators in North America and the People's Republic of China [hereafter 'China'], in particular, are following suit. While much bigger than nanosatellites (SpaceX's Starlink satellites weigh some 260 kg), these satellites greatly benefit from advances in miniaturisation, standardisation and economies of scale. They are orders of magnitude smaller than traditional telecommunications satellites by several metric tonnes.
- **Commercial earth observation (EO) and geospatial intelligence:** This sector mainly caters to defence and security markets, but multiple other smaller markets (e.g. agriculture, environmental protection and resource extraction) rely on these data as well. The first commercial EO satellites were launched around 2000, but

new entrants (e.g. US company Planet) disrupted the EO industry in the 2010s, providing lower-cost services with short revisit times and large geographic coverage, supported by greatly improved digital data processing, storage and imagery solutions. Still, service offerings are not entirely comparable. For instance, the US company Planet's smallest 3U cubesats (10 cm x 10 cm x 30 cm) operate in a constellation of some 130 satellites, provide a resolution of about 3 metres and a daily revisit time for the entire globe. In contrast, the satellites of incumbent operators Maxar (US) and Airbus Defence and Space (Europe) have a mass of 2.5 metric tonnes and 900 kg, respectively, both providing imagery with 30 cm resolution and with daily revisits over specific areas. Operators' imagery offerings are mainly multispectral but increasingly also hyperspectral[4] (useful for mineral exploration or detecting weeds and crop diseases, for example). Recently, commercial "low-cost" satellite synthetic aperture radar (SAR) data services have been introduced, used for cloudy conditions and night-time observations.

Figure 1.2. Orbital launch history

Number of launches and payloads. Activity as of 23 November 2021



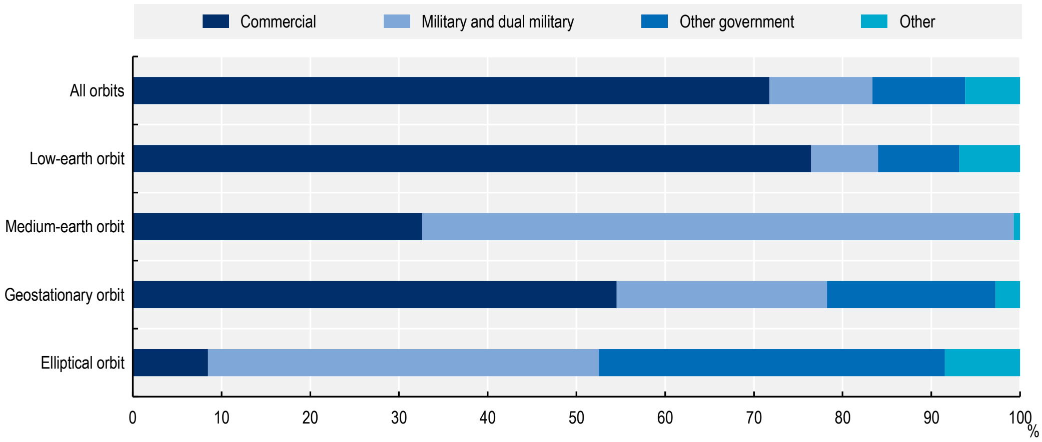
Note: Payloads refer to space objects (e.g. satellites, space probes) designed to perform a specific function in space, excluding launch functionality. It is worth to note that the number of launches remains stable over the period, with an increased number of satellites per launch starting around 2012.
Source: US Space Force (2021[7]), www.space-track.org.

- **Commercial signal intelligence:** In this paper, signal intelligence (SIGINT) refers to the interception of electronic signals from space, such as automatic identification signals (AIS) emitted from ships, as well as other radio frequencies. Applications are often military or security-related, e.g. monitoring of territorial waters (enforcement, search and rescue), control of fishing practices, detecting troops movements, etc., but can also be of a more civilian nature (shipping, resource extraction). Commercial providers have just recently entered the market (with miniaturised technologies, see Figure 1.1), following government decisions to encourage more direct service buys, e.g. as stipulated in different iterations of the United States National Space Policy (United States White House, 2010[8]).

Figure 1.3 shows the main types of operators responsible for different elements of space infrastructure as distributed between Earth's orbits, in terms of the number of operational satellites. Commercial operators and their infrastructure now dominate in the low-earth and geostationary orbits, while government missions have a stronger presence in medium-earth and elliptical orbits.

Figure 1.3. Main operators of space infrastructure

Operators as a share of operational satellites on orbit. Data as of 1 January 2022



Note: Military and dual military include fully military satellite missions, as well as military-civil, military-government, military-commercial, or a combination of the three.
Source: Union of Concerned Scientists (2022[6]), "UCS Satellite Database: January 2022 update", https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database, data accessed 17 March 2022.

Several commercial systems have been developed as public-private partnerships, where private sector actors commercialise signals or data for both civilian and military uses (e.g. the UK Skynet 5 satellite communications programme, the French Pleiades constellation for earth observation – more examples are provided in Undseth, Jolly and Olivari (2021[9])). Purely commercial systems may also rely heavily on government (notably military) customers. A major operational issue faced by different defence users in OECD countries is how to securely blend military and commercial space system capabilities.

1.3. Improved resilience of services and new applications

Access to satellite data and communications have never been more available (and affordable) around the world, as demonstrated by the response to Russia's war of aggression against Ukraine.

The use of commercial satellite services in Ukraine has rendered both civilian and military infrastructure more resilient and provided new services. To keep broadband access online, SpaceX has reportedly sent thousands of Starlink terminals to Ukraine, paid for by private sources and selected governments (e.g. Poland, France) (Sheetz, 2022[10]). This satellite broadband access has been intensively used by the Ukrainian military for tactical communications, for recreational purposes and conversations with family. Furthermore, government officials have been able to communicate with the wider world, thwarting attempts to isolate the country (Miller, Scott and Bender, 2022[11]). Commercial radio frequency spectrum monitoring, deployed on 15 kg satellites by the US company HawkEye 360, has also contributed to detecting troop movements and GPS jamming attempts (Werner, 2022[12]).

Commercial high-resolution and radar imagery maps almost real-time military activities and documents destruction on the ground almost at real time. The US National Geospatial-

Intelligence Agency (NGA) reports using data from more than 200 commercial satellites and some 100 different companies, leading to an "unprecedented" use of commercial geospatial intelligence (Erwin, 2022[13]). Other countries and private firms have also provided assistance. Canadian satellite operator MDA has provided Ukraine with near real-time satellite imagery to track troop movements and the European Union has also agreed to share classified satellite imagery.

In addition to supporting active warfare, satellite imagery is increasingly used to dispel disinformation. Notably, the US company Maxar's release of satellite imagery showing Russian troop build-ups along Ukraine's borders in February 2022 provided visual support for US government claims to that effect. The Centre for Disinformation Resilience has also launched the crowdsourced Russia-Ukraine monitor map, an online archive of verified videos, photos or satellite imagery that can be used by justice, accountability and advocacy groups (Centre for Information Resilience, 2022[14]). For example, open-source satellite imagery from several operators is being used to document potential Russian war crimes in the Ukrainian city of Bucha (Centre for Information Resilience, 2022[15]).

The ongoing aggression has also revealed an exponential use of commercial satellite imagery in international media coverage. The use of satellite imagery in the media is not new for war coverage and crisis management (e.g. mapping refugee camps, large fires and destructions), but it has never been seen at such a scale, with many news outlets around the world getting access to these technologies for the first time.

In the case of natural disasters and emergencies, private operators provide free access to their imagery via the International Charter for Space and Major Disasters. Commercial operators sometimes also provide imagery for non-commercial purposes on a case-by-case basis to support non-government organisations or news stories (Global Investigative Journalism Network, 2022[16]). For instance, the Maxar News Bureau is a partnership programme between the satellite operator and "trusted and respected media organisations". Today, news organisations and non-government organisations can easily acquire high-resolution data to use in their news stories, as data analysts and journalists actively use freely available satellite imagery as well as other data sources in "open-source intelligence" (OSINT), to track developments on the ground. Some commentators compare this "explosion" in near-real-time data to the televised live war coverage during the 1991 Gulf War (Datta, 2022[17]).

Finally, space assets are currently being used to monitor the global food supply – a critical area of international attention in the current geopolitical context. Data analytics based on satellite imagery precipitation and temperature forecasts gives the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) continued coverage of crop conditions within Russia and Ukraine for wheat and corn crops, as well as any updates that may affect exports.

More generally, the use of earth observation and GNSS technologies for "precision agriculture", i.e. for improved soil monitoring and guided equipment, is associated with notable efficiency gains and environmental benefits (reduced consumption of seeds, water, fuel, fertilizer and pesticides) and higher yields (Euroconsult, 2015[18]). Services based on satellite data also provide targeted information to food producers on crop management, pests, fertilizer and irrigation, etc. (Netherlands Space Office, 2022[19]).

2. Future challenges and revealed vulnerabilities of space systems

As shown in the previous section, a more widespread use of space technologies can bring multiple benefits to society. However, *unanticipated uses* of satellite data and signals, tracking the movements and behaviours of individuals or groups, may be harmful for countries and citizens by creating security risks and infringing on privacy. Furthermore, the growing socio-economic and tactical significance of space assets increase their exposure to threats. Both the COVID-19 pandemic and Russia's war of aggression against Ukraine have revealed considerable vulnerabilities, notably space infrastructure's vulnerability to natural hazards and malicious attacks and a fragile space manufacturing supply chain. Several of these issues are best addressed at the global level, requiring efforts to improve international co-operation.

2.1. Unanticipated uses of space data and signals

The broadening access to satellite data and communications to many different actors with different incentives is creating new and unexpected issues. The US company Alphabet had to disable live traffic services for Ukraine in its Google Maps application, because traffic jams could be used to detect military and civilian movements and put lives at risk.

Other examples of unintended and potentially dangerous uses of location data include the fitness service Strava's release of a global "heatmap" in 2017, comprised of several trillion GPS points from running and cycling routes of users wearing fitness trackers (Robb, 2017[20]). The map accidentally revealed the location of several US, French and Italian military bases (notably several CIA "black" sites) across the world and could reportedly be used to single out individuals. One researcher claimed to have been able to use Strava data to track the movements of a French soldier from his overseas deployment back home (Hsu, 2018[21]). Similarly, the image-sharing app Snapchat's geolocation features have been used to collect images and videos from the Iraq War (Flynn, 2016[22]). Snapchat has turned off its heatmap feature for Ukraine.

Unanticipated uses of space data and signals by third parties could become problematic in peacetime contexts as well. The use and release of satellite imagery is regulated from a spatial resolution standpoint in many countries (the higher the resolution, the more details can be seen on the ground). However, combined with other types of data, coarse low-resolution data may be enough to extract personal information, e.g. for marketing or for criminal purposes (access paths to houses and gardens).

2.2. Increasingly important, but also more exposed space infrastructure

The importance of space infrastructure is increasingly recognised by governments. The commercialisation and diversification of space assets have contributed to making services more distributed and resilient, but the remote location of space infrastructure components and the high costs of launch makes it difficult to protect them from human-made and natural threats, both of which are on the rise.

2.2.1. Space as a critical infrastructure

Various segments of the space infrastructure are increasingly embedded in national economic frameworks. With the digitalisation of the economy, the exploitation of satellite data and signals is playing an important role in the generation of societal value. Accordingly, satellite networks are considered integral parts of the economic infrastructure for information technologies (IT) and communications, while space launch facilities are becoming as critical as highways and airports, in terms of transportation infrastructure (Van de Ven, 2021[23]).

The space infrastructure is increasingly deemed a *critical* infrastructure itself, while supporting other critical infrastructures and activities (see Box 2.1 for definitions). Space systems notably ensure the secure operation of transportation, energy and finance infrastructures, and provide important inputs to public safety and food supply. Among the 16 sectors most frequently designated as critical infrastructure by OECD countries, space technologies support more than half (Table 2.1).

Box 2.1. Defining space infrastructure, critical infrastructures and critical activities

The term "space infrastructure" encompasses all space systems, whether public or private, that can be used to deliver space-based services (OECD, 2005[24]).

These include space segments as well as ground segments. The **space segment** mainly comprises orbital spacecraft (e.g. satellites) in addition to other spacecraft such as rovers, landers and probes. The **ground segment** includes launch facilities, ground stations, mission control centres and ground networks, which manage and communicate with spacecraft and distribute data and telemetry among operators and users. The user segment of space infrastructure consists of decentralised customer terminals, such as satellite dishes, modems or global navigation satellite systems receivers, which communicate either directly with the spacecraft or with the ground segment (the second edition of the *OECD Handbook on Measuring the Space Economy* (OECD, 2022[25]) provides more information on the composition of each segment.

Space-based services (space applications) typically include satellite communications; positioning, navigation and timing; earth observation; exploration; space safety/space situational awareness; and science, which support an increasing number of government services and industries, including security and defence, environmental protection, agriculture, transport, resources management and extraction, etc.

Space activities are increasingly included in designated OECD "critical infrastructures" and "critical activities". OECD defines critical infrastructures as those essential for national security, the economy, health and safety (OECD, 2019[26]). In its *Recommendation on Digital Security of Critical Activities*, OECD further defines critical activities as "economic and social activities the interruption or disruption of which would have serious consequences on:

- the health, safety, and security of citizens;
- the effective functioning of services essential to the economy and society, and of the government; or
- economic and social prosperity more broadly" (OECD, 2019[27]).

This has moved several OECD countries (Belgium, France, Spain, United Kingdom) to designate the space sector itself as "critical", and many more countries include space activities in other categories – satellite telecommunications are typically included in "ICT (Information and Communication Technology)" and space manufacturing in "critical manufacturing" and/or "defence industry" (OECD, 2019[26]).

Table 2.1. Sectors of designated critical infrastructure across OECD countries

Number of countries per designated sector

Sector	Number of OECD countries	Is supported by space technologies	Includes space activities	Is fully space-related
Transportation	32	√		
ICT	32		√	
Energy	32	√		
Finance	24	√		
Health	24			
Water	23			
Food supply	17	√		
Government	16			
Chemical industry	15			
Public safety	15	√		
Dams and flood defence	15			
Law enforcement	10			
Nuclear sector	10			
Critical manufacturing	7		√	
Defence industry	7		√	
Space sector	4			√
Other	19			

Source: Based on OECD (2019[26]) *Good Governance for Critical Infrastructure Resilience*, https://dx.doi.org/10.1787/02f0e5a0-en.

2.2.2. Natural and manmade threats on the rise

As space infrastructure becomes increasingly essential for the functioning of modern societies, its considerable vulnerability to natural and human-made hazards becomes more apparent. Space weather events and collisions with near-Earth objects (meteoroids) can impair or destroy spacecraft (OECD, forthcoming[28]). Furthermore, collisions with (human-made) orbital debris pose a serious and growing threat to space systems (Undseth, Jolly and Olivari, 2020[29]).

Space-based systems are designed to resist the multiple stresses of launch as well as the extreme temperature fluctuations and radiation of the space environment, and are, to a significantly lesser extent, shielded against minor collisions with debris. However, they are generally less protected against *malicious acts*. Civilian spacecraft follow predictable, publicly available, orbital paths and can be destroyed or blinded by physical anti-satellite weapons (Froehlich, 2021[30]). Several economies have demonstrated anti-satellite capabilities in recent years, including China, India, the United States, and most recently, Russia.

Furthermore, electronic attacks such as jamming and spoofing can interfere with the signals to and from a satellite, and in this way disrupt operations or send fake signals. Finally, ground systems, satellites or end-user equipment can all be the targets of cyberattacks (Harrison et al., 2021[31]). In the United States, the 2020 Space Policy Directive 5 (SPD-5) highlights this threat and outlines cybersecurity principles for space systems.

In the war in Ukraine, space infrastructure has been exposed to both electronic attacks and cyberattacks (Werner, 2022[12]; Foust and Berger, 2022[32]). Jamming attacks have targeted GPS signals as well as commercial SpaceX terminals for satellite broadband (which have mostly proven resilient). More significantly, a suspected cyberattack targeting Viasat's KA-SAT fixed broadband network led to widespread network outages in Central and Eastern Europe on the day of the invasion, as the attack knocked out thousands of modems communicating with the geostationary satellite. The incident is currently under investigation and is particularly sensitive because Viasat is a contractor for many defence actors (Pearson et al., 2022[33]).

Ensuring the resilience of space infrastructure has become strategically important in recent years for many countries. France and the United Kingdom have recently published military space strategies. The United States established the Space Force as a new branch of armed services in 2019. More regions and countries are building space tracking abilities (e.g., the European Space Surveillance and Tracking EUSST) network).

2.3. Fragile and strained global space supply chains

Recent crises are taking a particularly heavy toll on global supply chains for space manufacturing. Trade in space products and services has traditionally been limited because many nations prefer to keep some control over sovereign interests and defence-related sub-sectors. Still, international trade has been an integral part of space manufacturing for decades, as the industry segment is characterised by low production volumes, high barriers of entry and high levels of specialisation, with a limited number of suppliers (OECD, 2020[34]). Indeed, the most recent US space industrial base survey in 2010-13 (to be repeated in 2022-23) identified multiple high-level US government space programmes with international suppliers (US Department of Commerce, 2013[35]).For instance, the Japanese H-IIA and US Delta IV launchers share the same second-stage propellant tank configuration (OECD, 2014[4]).

2.3.1. A small and concentrated market for space manufacturing and launch

Russia's war of aggression against Ukraine affects global space supply chains in several ways. In this small and specialised market, Russia and Ukraine have long been notable international actors (building on the USSR space programme): first, as trade partners and manufacturers of components and full space systems; and second, as launch service providers. Two US launchers, the Atlas V heavy-lift launcher and the Antares launcher (which transports cargo to the International Space Station), rely on Russian engines, the Antares launchers also uses a Ukrainian-produced first-stage rocket (CNES, 2022[36]). The upper stage of the European Vega launcher (for smaller payloads) uses Ukrainian-built engines. The European Space Agency has also been using the Russian medium-class Soyuz launcher since 2011, e.g. for launching Copernicus and Galileo satellites.

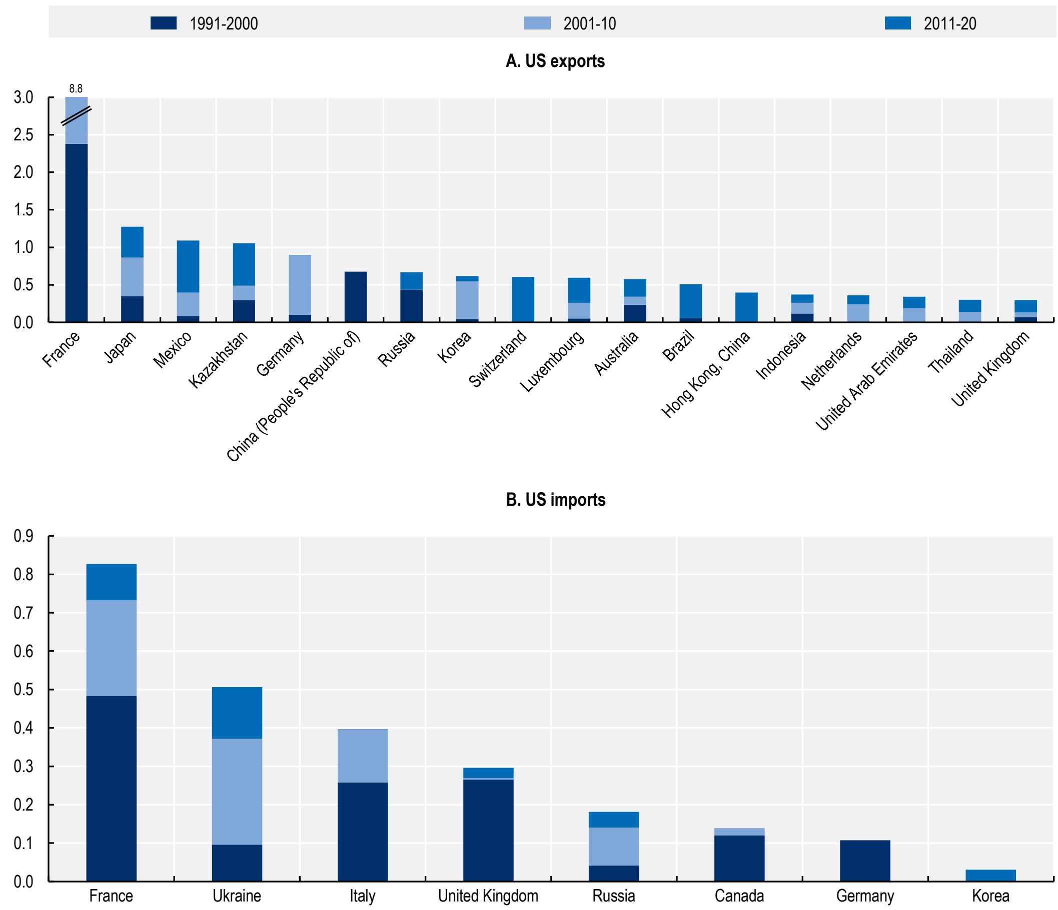
The Russian-operated Baikonur spaceport in Kazakhstan is frequently used for international commercial launches and was the only gateway to space for OECD partners of the International Space Station (Canada, European Space Agency, Japan and the United States) after the dismantling of the Space Shuttle programme in 2011 until the first crewed launch of the commercial Dragon spacecraft in 2020. In 2022, a batch of UK satellites for the OneWeb broadband constellations were temporarily grounded while looking for other launch opportunities (finally provided by their direct US competitor SpaceX).

Furthermore, several Ukrainian-built mega-freighter jets, used to transport oversize cargo such as geostationary satellites and other more conventional large objects, were stranded in Ukraine, creating additional problems for space operators who now needed to find other solutions for moving the biggest satellites from their manufacturing sites to launch facilities.

Figure 2.1illustrates how Ukraine and Russia (and Kazakhstan) have been important trade partners of the United States and other OECD countries for spacecraft, satellites and launch vehicles over the last three decades, as recorded in official trade statistics. It should be noted that these statistics show only a *fraction* of actual trade in space manufacturing and space launch, as they do not include components and subsystems, or selected transactions with different countries that have been excluded for statistical confidentiality reasons.

Figure 2.1. Recorded US exports and imports in spacecraft, satellites and launch vehicles for selected economies

In USD billion (current)



Note: These data reflect only **a fragment of actual trade** in space manufacturing, as they **do not** include components and subsystems, or transactions that have been excluded for statistical confidentiality reasons. Export and import countries are not the same.
Source: OECD (2022[37])), "Harmonised System 1988", *International Trade by Commodity Statistics* (database), https://doi.org/10.1787/data-00060-en (accessed on 15 April 2022).

There are some signs that trade patterns in the space sector are evolving. Structural changes in space manufacturing are leading to a stronger reliance on local, vertically integrated production of parts, use of commercial off-the-shelf components and additive manufacturing (OECD, 2019[38]). This links space manufacturing to bigger and more conventional supply chains, but which have their own set of issues. Indeed, the space sector is similarly affected by current shortages in microchips and rare materials as other high-technology sectors (United States White House, 2021[39]).

2.3.2. Small industry actors, vulnerable to economic shocks

All these elements add extra strain to a sector that has just been affected by the COVID-19 crisis. Industry segments such as space exploration and science, or even satellite manufacturing, tend to be populated by small and medium-sized enterprises (SMEs), which generally constitute the bulk of commercial actors in the space sector (e.g. 95% in Canada, 92% in Korea). Furthermore, they often rely on single, mainly government, sources of revenues (OECD, 2020[34]).

While many space sector firms seem to be able to cope, there are growing concerns about the medium and long-term effects of the crisis on government budgets and customer demand (i.e. due to inflation, human resources scarcity), and some industry actors anticipate possible funding cuts in future institutional programmes. Considering the high costs of entry to the sector, there is a risk that the current succession of economic crises could lead to the elimination smaller and younger firms that are key sources of innovation, employment and economic growth.

2.4. The future of international space co-operation is at risk

Civilian space activities are characterised by intense international scientific co-operation, motivated by the need to pool limited national financial resources, which then facilitates projects that are more ambitious, and which permits the joint tackling of unique shared challenges.

2.4.1. A sector reliant on international co-operation

A multitude of international organisations and committees co-ordinate activities in space exploration, space science, earth observation, space-based meteorological observations, space debris, radio frequencies, disaster management, space education, etc. There are also numerous international satellites with instruments/collaborations from several countries. This is also demonstrated at the level of individual researchers. In the bibliometric database Scopus, space-related scientific journal categories, notably “astronomy and astrophysics” and “planetary sciences” have the highest share of international co-authorships of all journal categories, both surpassing 50% of published articles in 2020.

So far, the biggest space science-related casualty of the war in Ukraine has been the suspension of the European-Russian ExoMars mission. The future of the first-ever European Mars rover Rosalind Franklin, originally scheduled for launch by a Russian rocket from Baikonur in September 2022, is uncertain. Member states of the European Space Agency (ESA) will need to agree on extra funding for the launch as well as for replacing the Russian landing platform – 2028 has been suggested as the next launch possibility. ESA has furthermore discontinued its co-operation on Russia’s planned robotic moon missions. Germany has also switched off the eROSITA telescope flying on the Russian Spektr-RG satellite, launched in 2019 to map black holes, as the country halted all science co-operation with Russia. The instrument had completed four out of eight intended all-sky survey passes before it went on safe mode (Max Planck Institute for Extraterrestrial Physics, 2022[40]).

Meanwhile, co-operation with Russian counterparts on the International Space Station (ISS) continues. A US astronaut was brought back to Earth as planned in a Soyuz spacecraft in March 2022, and in September 2022, the Russian cosmonaut Anna Kikina will fly to the ISS in a US spacecraft for the first time in 20 years. However, the war has rekindled discussions on the future of the joint space station, currently funded until 2030 by several members (e.g. Canada, United States). Russia signalled in July 2022 the intention to withdraw from the station in 2024, but this remains to be fully confirmed.

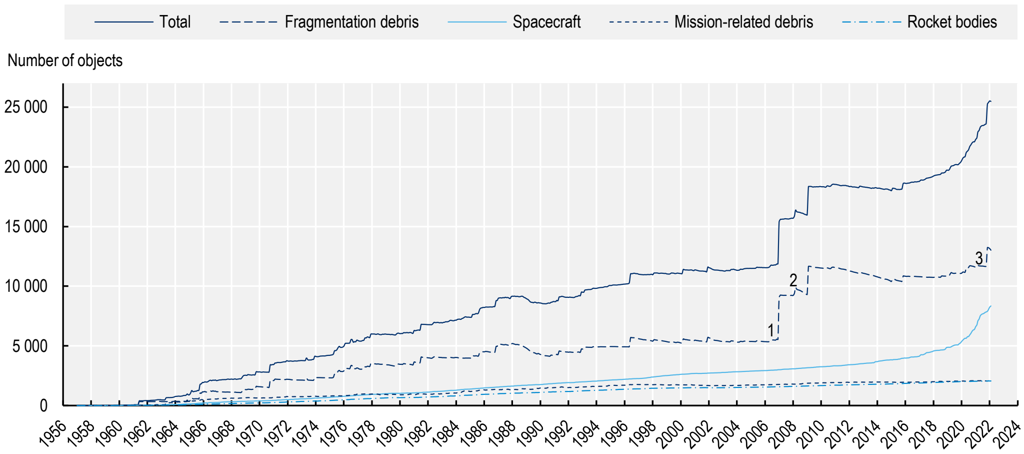
2.4.2. The looming threat of space debris

More broadly, Russia's war of aggression against Ukraine raises questions about the quality and nature of international co-operation, just as the space sector enters its perhaps most challenging phase in the history of spaceflight. In the last 15 years, levels of orbital debris have accelerated at a worrying pace, casting uncertainty about the long-term sustainability of current space activities, as shown in Figure 2.2.

Currently tracked debris objects are mainly fragmentations from satellites and rockets, followed by defunct spacecraft, rocket bodies and mission-related debris such as lens caps and solid rocket firings (ESA, 2019[42]). Recent increases in the orbital debris population are due to one collision between an operational and a defunct satellite and two anti-satellite tests (by China and Russia). The underlying fear is that the debris population reaches such levels that collisions become self-generating and uncontrollable, leading to the so-called Kessler Syndrome. This could disrupt human activities in several valuable orbits with severe socio-economic consequences (more information on space debris and potential impacts are provided in Undseth, Jolly and Olivari (2020[29])).

Figure 2.2. Monthly number of objects in the Earth's orbit by object type

Historical increase of the catalogued objects based on data available on 1 March 2022

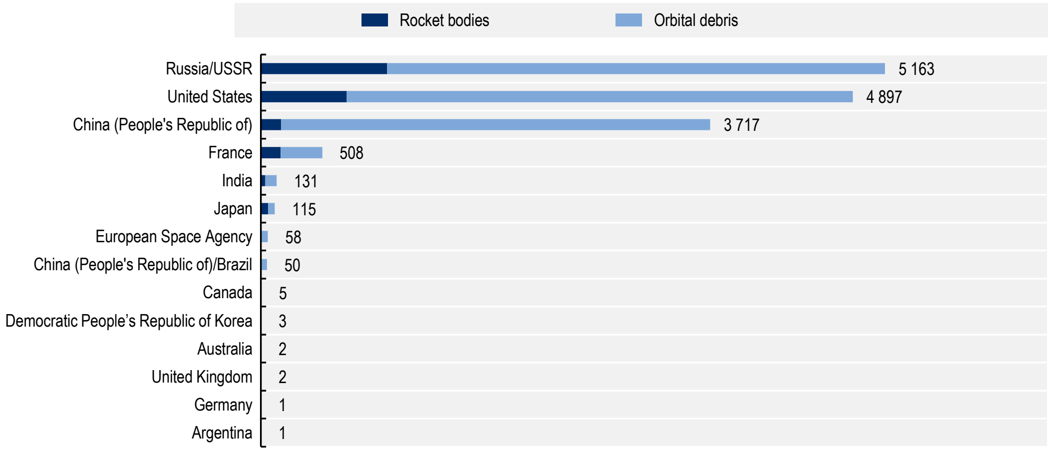


Notes: The three upward jumps in fragmentation debris correspond to: 1) the anti-satellite test conducted by the People's Republic of China in 2007; 2) the accidental collision between Iridium 33 and Cosmos 2251 in 2009; and 3) the anti-satellite test conducted by Russia in November 2021. More Cosmos 1408 fragments are expected to be added to the catalogue in the coming weeks and months of 2022.
Source: NASA (2022[41]), Orbital *Debris Quarterly News*, 26:1, https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/ODQNv26i1.pdf.

Although Russian space investments have waned compared with Cold War levels, the country remains a space superpower together with China and the United States in terms of crewed and military space capabilities (last demonstrated by the November 2021 anti-satellite test) and orbital presence. Russia still holds a notable share of operational satellites in orbit (behind the United States, China and United Kingdom) and, importantly, accounts for the lion's share of catalogued space debris (Figure 2.3) and of "concerning" orbital debris from a collision perspective (Figure 2.4) - due to their size, inclination and/or orbit (McKnight et al., 2021[43]).

Figure 2.3. Space debris objects by economy/institution

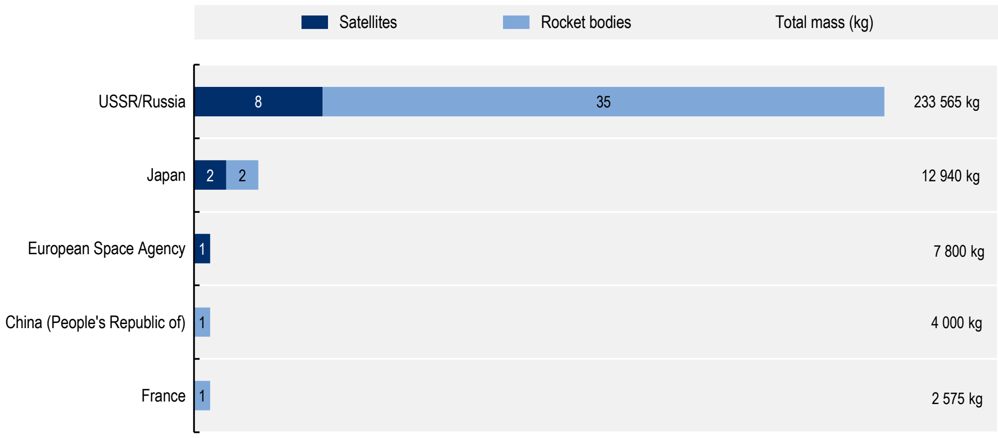
Number of debris and rocket bodies in orbit, January 2020



Note: US Space Force definition of debris and ownership.
Source: US Space Force (2020[44]), https://www.space-track.org/.

Figure 2.4. Top 50 most "concerning" orbital debris from a collision perspective

Number of satellites and rocket bodies by launch country/institution, with associated total mass



Source: Based on McKnight et al. (2021[43]), "Identifying the 50 statistically-most-concerning derelict objects in LEO", *Acta Astronautica*, http://doi.org/10.1016/j.actaastro.2021.01.021.

Co-operation and co-ordination between all major space actors will therefore be key to addressing the growing problem of space debris and the overall sustainability of space infrastructure and related activities. The United Nations' Committee on the Peaceful Uses of Outer Space (UN COPUOS) 2019 agreement on guidelines for the "long-term sustainability of outer space activities", which reflects an increased awareness about the negative externalities surrounding activities in space and particularly of the unrestricted use of certain orbits of value to activities on Earth, should guide such efforts.

3. Key policy considerations requiring further analysis

This paper has raised several issues concerning space infrastructure resilience and digital security, data management, commercialisation of space activities and space sustainability. The OECD has published extensively on these topics and, building on this existing work, governments are encouraged to take note of the following areas that could merit further attention and analysis, including through the OECD.

The following sections summarise the key points and give pointers to associated OECD resources and potential responses.

3.1. Addressing the space sector's vulnerabilities

Due to several factors, e.g. the small size of the sector, high costs of entry to the market and the hostile and remote nature of the space environment, space infrastructure and its related activities are particularly vulnerable to economic and geopolitical shocks, natural hazards and malicious acts. Policymakers are not necessarily aware of the scope and degree of these vulnerabilities that need to be mapped and addressed. To support work in that area, relevant existing resources include:

- The *Recommendation of the Council on Digital Security of Critical Activities* (OECD, 2019[27]) sets out a range of policy recommendations. These recommendations are focused on strengthening the digital security of operators of critical activities without imposing unnecessary burdens on other actors.
- The *OECD Policy Toolkit on Governance of Critical Infrastructure Resilience* (OECD, 2019[45]) helps governments design their national critical infrastructure resilience policies and implement them through effective partnerships with operators.
- The *OECD policy response brief on impacts of COVID-19 on the space industry* (OECD, 2020[34]) looks at the effect of global supply chain shocks on the space industry, in particular small- and medium-sized enterprises and start-ups and suggest targeted policy options.

3.2. Managing access to and use of data and signals

The recent explosion in the availability of space-based data and signals has positively contributed to the management of the COVID-19 crisis, providing information on catastrophic droughts, floods and natural disasters, and helping monitor the war in Ukraine. Enhanced access to and sharing of space-based data and signals are associated with notable social and economic benefits, but it also raises a number of questions, e.g. in terms of private ownership of public-good data and unanticipated consequences for security and privacy. To support work in that area, relevant policy tools include:

- The *Recommendation of the Council on Enhancing Access to and Sharing of Data* (OECD, 2022[46]) is the first internationally agreed upon set of principles and policy guidance on how governments can maximise the cross-sectoral benefits of all types of data – personal, non-personal, open, proprietary, public and private – while protecting the rights of individuals and organisations. It aims to reinforce trust across the data ecosystem, stimulate investment in data and incentivise data access and sharing, and foster effective and responsible data access, sharing and use across sectors and jurisdictions.

- The *Recommendation of the Council concerning Access to Research Data from Public Funding* (OECD, 2022[47]) cover not only research data from public funding, but also other research-relevant digital objects, such as metadata and bespoke algorithms, workflows, models, and software (including code) and provide updated policy guidance structured around seven key policy areas that have emerged as crucial to enhancing access to research data since the Recommendation's first adoption in 2006. These policy areas include data governance and trust; technical standards and practices; incentives and rewards; responsibility, ownership and stewardship; sustainable infrastructures; human capital; and international co-operation and access to research data.
- The *Recommendation of the Council concerning Guidelines Governing the Protection of Privacy and Transborder Flows of Personal Data* (OECD, 2022[48]) provides useful guidance for the collection, processing, and sharing of personal data to safeguard privacy and individual liberties, including in times of crisis.

3.3. Fostering further space sector commercialisation

The emergence of commercial space actors carries the potential for more innovative, affordable and resilient government and commercial services. Various forms of partnerships with the private sector are likely to grow in importance in the coming years, to keep costs of space activities as low as possible and to foster the growth of innovative products. However, great care must be taken to reduce barriers of entry and remove excessive first-mover advantages, to favour equitable access and fuel competition.

- Two recent OECD STI policy papers take a closer look at government commercialisation efforts in space activities, identifying good practices for public-private partnerships and other forms of collaboration ((Undseth, Jolly and Olivari, 2021[9]), and technological transfer (Olivari, Jolly and Undseth, 2021[49]).

3.4. Ensuring long-term sustainability of space activities

As space capacities become increasingly important for society, it is crucial to ensure the long-term sustainability of space activities, making space infrastructure more resilient to natural and human-made threats and addressing negative externalities of space activities.

One pressing challenge is the management of space debris. Stabilising the orbital environment will require concerted action at both the national and international level. A long-term strategic view on the role and capabilities of both public and private actors is also needed.

- A recent OECD policy paper on the economics of space debris identifies some of the shorter and longer-term costs associated with space debris and cluttered orbits and discusses possible policy actions (Undseth, Jolly and Olivari, 2020[29]).
- The OECD Space Forum and its eleven partnering space agencies have also launched an original project on the economics of space sustainability, collaborating with universities and research organisations to assess the costs of space debris and value of space applications. More information on the project and how to participate can be found on the dedicated project website.

Notes

[1] Nanosatellites belong to the larger category of "small" satellites, with a mass equal to or inferior of 500 kg and refer to satellites with a mass of 10 kg or less. (NASA, 2015[50]). This may include cubesats, pocketcubes, tubesats, suncubes, etc.

[2] Cubesats use a standard size and form factor: "one unit" or "1U", measuring 10x10x10 cm, and is extendable to larger sizes stacked lengthwise; 1.5, 2, 3, 6, etc. (NASA, 2015[50]).

[3] The term "mega-constellations" is used to describe projects under development for hundreds to several thousands of satellites in the low-earth orbit, mostly for the provision of satellite broadband services.

[4] Multi-spectral imagery measures light intensity on a limited number of separate bands of the electromagnetic spectrum (not limited to the visible spectrum). Hyperspectral imagery measures light intensity on dozens or hundreds of bands. This higher spectral resolution allows for detection, identification and quantification of surface materials, as well as inferring biological and chemical processes (ESA, 2020[51]).

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