The Space Economy in Figures

RESPONDING TO GLOBAL CHALLENGES

OECD

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OECD
BETTER POLICIES FOR BETTER LIVES

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Foreword

The space economy is operating in a much different context today than in 2019, when the last issue of the OECD's Space *Economy in Figures* was released. The world economy, society and geopolitical context are changing in ways that suggest a vastly different future compared to the previous 10-15 years and that have a major bearing on space activities. Those recent changes are altering the shape and intensity of the familiar list of global challenges and are adding new ones to it, such as COVID-19, the Russian Federation's war of aggression against Ukraine and the energy crisis.

Space technologies will play an integral part in tackling these global challenges, building not only on existing capabilities but also on more recent public and private investments. The transformation of the space sector has accelerated in the past five years, driven by the following key developments:

- Space is increasingly supporting and helping to expand and protect critical infrastructures (transport, water, power, communications) in the face of climate change and extreme environmental events.
- Significantly lower launch costs are facilitating access to space and contributing to the recent explosive growth in the number of satellites launched. Consequently, global capacity in and coverage of communications, navigation and observation has expanded, greatly enhancing the opportunities for responding to almost every single global challenge through a widening array of public and commercial applications. The population of operational satellites in orbit has grown from about 3 300 satellites at the end of 2020 to more than 6 700 in 2022, stimulated by the deployment of commercial satellite broadband constellations in low-earth orbit.
- Ever more actors involved in space activities – countries, governments, businesses and citizens – are helping to improve response capacity locally, regionally, and globally, triggering a huge expansion of satellite connections and end-users.

However, public and private action is required on multiple fronts to ensure a sustainable trajectory of the space economy. That includes ensuring the environmental sustainability of the space sector, maintaining adequate levels of public funding to support essential public systems, and spurring the innovations of tomorrow. It also includes building partnerships across countries to address mutual challenges, developing the right contractual arrangements to benefit both commercial endeavours and public missions and ensuring the effective and safe management of space resources and the space environment.

The chapters in this publication focus on specific aspects of the role of space activities in addressing global challenges and provide new indicators and analysis.

- Chapter 1 takes stock of overarching trends in space innovation and funding for space programmes and activities that are unfolding, just when their capacities are needed to deal with pressing global challenges, from climate change impacts to natural resources management. It also reviews how the space economy has fared in recent crises and identifies possible game changers.
- Chapter 2 discusses the fundamental importance of space as a provider of critical data and innovative applications in responding to global challenges.

- Chapter 3 explores some of the implications of growing competition for access to space and its resources for addressing global challenges.
- Chapter 4 highlights how the space sector's exposure to numerous existential vulnerabilities could undermine the effectiveness of its contributions to helping tackle global challenges, while itself becoming the source of new challenges.
- Finally, the country profiles provide more granular statistics on the state of the space economy in the countries that are members of the OECD Space Forum (Canada, France, Germany, Italy, Korea, the Netherlands, Norway, Switzerland, the United Kingdom and the United States).

In these challenging times that demand ever-more international co-operation, the OECD Space Forum will continue assisting governments, space-related agencies, and the private sector in better identifying the statistical contours of the space sector, while investigating the economic significance of space infrastructure and its role in the broader economy, as well as the contribution of the space sector and space technologies to address global challenges.

Acknowledgements

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The report was drafted by Marit Undseth and Claire Jolly from the OECD Space Forum in the Directorate for Science, Technology and Innovation (STI), with Kamila de Sousa Aben Athar Alencar, junior researcher, drafting sections in Chapter 4 and the country profiles, Christan Vambenepe, also junior researcher, cleaning official development assistance data, James Jolliffe, economist, and Barrie Stevens, senior advisor, kindly providing comments.

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Abbreviations and acronyms

ALMA	Atacama Large Millimetre/submillimetre Array
ASI	Italian Space Agency (Italy)
ASJC	All Science Journal Classifications
AWS	Amazon Web Services
BDI	Federation of German Industries
BERD	Business enterprise research and development expenditure
BRICS	Brazil, Russia, India, China, South Africa
BDI	*Bundesverband der Deutschen Industrie*
CAD	Canadian dollar (currency)
CASC	China Aerospace Science and Technology Corporation
CEOS	Committee on Earth Observation Satellites
CFC	Chlorofluorocarbons
CGMS	Coordination Group for Meteorological Satellites
CHF	Swiss franc (currency)
CNES	National Centre for Space Studies (France) *Centre National d'Études Spatiales*
CNY	Chinese yuan (currency)
COTS	Commercial Orbital Transportation Services
CSA	Canadian Space Agency
DIAS	Copernicus Data and Information Access Services
DLR	German Aerospace Center *Deutsches Zentrum für Luft- und Raumfahrt*
DSL	Digital subscriber line
EARSC	European Association for Remote Sensing Companies
EGNOS	European Geostationary Navigation Overlay Service
EO	Earth observation
ESA	European Space Agency
ESG	Environmental, social, and governance

EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUR	Euro (currency)
EUSST	EU Space Surveillance and Tracking
FAA	United States Federal Aviation Administration
FCC	United States Federal Communications Commission
GBP	British pound sterling (currency)
GDP	Gross domestic product
GEO	Geostationary orbit
GEOGLAM	GEO Global Agricultural Monitoring
GHG	Greenhouse gas
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite system
GPS	Global Positioning System
ICT	Information and Communications Technology
IDA	International Development Association
IMT	International Mobile Telecommunications
ISRO	Indian Space Research Organisation
ISS	International Space Station
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
KRW	Korean won (currency)
LAN	Local area network
LEO	Low-earth orbit
MEO	Medium-earth orbit
NASA	National Aeronautics and Space Administration (United States)
NICFI	Norway's International Climate and Forest Initiative
NMVOC	Non-methane volatile organic compound
NOAA	United States National Oceanic and Atmospheric Administration
NOK	Norwegian krone (currency)
NRO	United States National Reconnaissance Office
NSIL	NewSpace India Limited
ODA	Official development assistance
OECD	Organisation for Economic Co-operation and Development
OSINT	Open-source intelligence
PCT	Patent Cooperation Treaty

PNT	Positioning, navigation and timing
R&D	Research and development
SAR	Synthetic aperture radar
SKAO	Square Kilometre Array Observatory
SSLV	Small Satellite Launch Vehicle
STEM	Science, technology, engineering and mathematics
STI	Science, technology and innovation
UCS	Union of Concerned Scientists
UKSA	UK Space Agency
UN COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office for Outer Space Affairs
USAID	United States Agency for International Development
USD	US dollar (currency)
USGS	United States Geological Survey
USSR	Union of Soviet Socialist Republics
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization
WRC	World Radiocommunication Conference

ISO country codes

ISO codes for OECD member countries		ISO codes for other economies	
Australia	AUS	Afghanistan	AFG
Austria	AUT	Argentina	ARG
Belgium	BEL	Armenia	ARM
Canada	CAN	Azerbaijan	AZE
Chile	CHL	Bangladesh	BGD
Colombia	COL	Barbados	BRB
Costa Rica	CRI	Benin	BEN
Czechia	CZE	Brazil	BRA
Denmark	DNK	China (People's Republic of)	CHN
Estonia	EST	Colombia	COL
Finland	FIN	Democratic Republic of the Congo	COD
France	FRA	Egypt	EGY
Germany	DEU	Fiji	FJI
Greece	GRC	India	IND
Hungary	HUN	Indonesia	IDN
Iceland	ISL	Iran	IRN
Ireland	IRL	Iraq	IRQ
Israel	ISR	Kiribati	KIR
Italy	ITA	Lao People's Democratic Republic	LAO
Japan	JPN	Lebanon	LBN
Korea	KOR	Madagascar	MDG
Latvia	LVA	Malaysia	MYS
Lithuania	LTU	Micronesia	FSM
Luxembourg	LUX	Myanmar	MMR
Mexico	MEX	Namibia	NAM
Netherlands	NLD	Nigeria	NGA
New Zealand	NZL	Pakistan	PAK
Norway	NOR	Papua New Guinea	PNG
Poland	POL	Paraguay	PRY
Portugal	PRT	Peru	PER
Slovak Republic	SVK	Russian Federation	RUS
Slovenia	SVN	Samoa	WSM
Spain	ESP	Senegal	SEN
Sweden	SWE	Serbia	SRB
Switzerland	CHE	Solomon Islands	SLB
Türkiye	TUR	South Africa	ZAF
United Kingdom	GBR	Syrian Arab Republic	SYR
United States	USA	Chinese Taipei	TWN
		Tanzania	TZA
		Thailand	THA
		Tonga	TON
		Ukraine	UKR
		Vanuatu	VUT
		Viet Nam	VNM
		Zambia	ZMB

Executive summary

The space sector already contributes to tackling global challenges, but more needs to be done

The global challenges facing our planet are daunting. Climate change is well underway, bringing in its wake natural disasters of an unprecedented scale, The ocean is warming and its health deteriorating with impacts on sea level rise and the livelihoods of millions of people. Biodiversity is dramatically shrinking, while pollution has become ubiquitous. And still today, 32% of the world's population does not use the internet, as high-speed fixed broadband remains unavailable in remote and sparsely populated regions, including in some OECD countries.

Efforts to respond to these and other challenges have benefited from advances in space technologies:

- In OECD countries, **space-based systems already support more than half of the most frequently designated critical infrastructures** and services, such as transportation, energy, food supply and law enforcement.
- Space-based observations **provide more than half of the essential climate variables** that are used to monitor climate change, with atmospheric observations and ocean observations, such as sea surface temperatures, ocean colour, and land cover with terrestrial vegetation types and ice caps.
- In 2022, newly launched satellites detected more than 1 000 human-induced methane super-emitter events in landfills, **demonstrating how greenhouse gas emissions could be better monitored globally**.
- Space applications are also **increasingly used in developing countries** to monitor the environment, forests and food production, contribute to disaster prevention and emergency response; as well as to provide communication services via satellite TV and radio. Space-related official development assistance accounted for more than 700 million constant USD between 2000 and 2021, with commitments rising significantly recently thanks to targeted efforts by several OECD countries.

This has been achieved thanks to decades of mainly public investment. However, more needs to be done to secure the economic sustainability of critical missions, create the right policy and regulatory environment for innovative solutions and increase user uptake of satellite data for a broader distribution of benefits.

More applications are in the pipeline, thanks to government missions and new private sector investment

The last 20 years have seen the deployment of large institutional programmes and new-generation satellites supporting earth observation missions. These public investments have been accompanied by a recent surge in private sector activity.

- OECD government space budgets **reached an estimated USD 75 billion in 2022, accounting for 0.1% of OECD GDP.** This is a conservative estimate that includes both civilian and military activities where available.
- Almost **100 countries have been able to send a satellite with their flag in orbit since 1957**, **23 countries are pursuing national launcher projects**, and **11 countries are developing spaceports** to cater to national needs and attract commercial missions**.**
- There has been a significant increase in commercial space activities, as measured by the number of satellite launches and the amount of private investment. There were **some 6 700 operational satellites in orbit by the end of 2022, twice the number recorded in 2020, with over two-thirds of satellites from commercial operators**. This is linked to considerable reductions in the cost of access thanks to reusable launch technologies, smaller satellites, and increased competition.
- The key **driver behind the number of satellites is the deployment of several mega-constellations for satellite broadband in low-earth orbit,** each consisting of thousands of satellites. Satellite broadband is still much less used than other technologies, with only 0.2 fixed broadband subscriptions per 100 inhabitants in the OECD area. However, this could change with the rollout of new satellite consumer services.

Greater reliance on space assets and higher rates of activity create additional challenges

To support the sustainable growth of the space sector and its role in tackling societal challenges, governments must balance the efficient use of scarce resources (slots in orbit, spectrum) while supporting innovation and entrepreneurship, ensuring future recruitment to the sector and most importantly, keeping the orbital environment accessible to all and sustainably used. Targeted policy intervention is needed to better regulate access to space and its resources, to ensure a fair and broad distribution of the benefits of space technologies, while simultaneously fostering innovation and entrepreneurship.

- The most pressing problem facing the sustainability of the space sector is the accumulation of debris in Earth's orbits. **There are currently about 25 000 identifiable and tracked debris objects in orbit, but the total untracked population is in the hundreds of millions**. In a worst-case scenario, debris density could reach levels where it triggers an irreversible chain reaction of collisions, which may render certain orbits of great socio-economic value unusable. Restraining debris growth and removing debris objects will require more concerted public-private actions at national levels, considerable international co-operation, technological development, and innovative policy making supported by new economic instruments, as shown by OECD analysis.
- **Space-related administrations are encouraged to assess the social and economic returns of their missions and communicate the results widely**. Overall expenditure of government space programmes has remained stable or grown modestly over the last decade in most OECD countries, but rising inflation, fiscal austerity and geopolitical tensions put pressure on the further development of civilian programmes. Increasing efforts to monitor the uses of open satellite data and understand the barriers to uptake and conditions for success are also needed.
- **Space activities' ability to address key societal challenges will require human capital,** but the workforce in several space industry segments is ageing, unfilled vacancies are common. Women are under-represented in most activities. For example, in Canada, Korea and the United Kingdom, women represent only 29%,15% and 24% of the space industry workforce, respectively.
- **The OECD Space Forum will continue supporting these efforts** by providing guidelines on how to measure the space economy, compiling good practices and space-related policy instruments in the STIP Compass for Space Policies and producing new evidence on emerging policy issues, such as in the *OECD project on the Economics of Space Sustainability*.

1 Space technologies are coming of age

Many space systems are reaching maturity in terms of performance at a time when their capacities are needed to deal with pressing global challenges – from accelerating climate change impacts to natural resource depletion. This chapter explores overarching trends in space innovation and funding for space programmes and activities. It also reviews how the space economy has fared in recent crises and identifies possible game changers for the coming years.

This chapter explores overarching trends in space innovation and funding for space programmes and activities. It reviews how the space economy has fared in recent crises and identifies possible game changers for the coming years and provides multiple pointers for policy action.

A growing appreciation of space-based solutions by decision makers worldwide

The digitalisation of society and rising geopolitical tensions worldwide highlight the importance of space infrastructure, including space-based systems and their supporting ground segments (Undseth and Jolly, 2022[1]).

Satellite networks are increasingly recognised as integral parts of the economic infrastructure for information technologies and communications, while space launch facilities are becoming critical parts of overall transportation infrastructure (Van de Ven, 2021[2]). An important aspect of space infrastructure is how it has become essential in supporting other critical infrastructures and activities, such as the energy and finance infrastructures, public safety, transportation (e.g. air traffic management), and food supply. For example, energy grid systems rely on high-precision timing signals from navigation satellites to synchronise electrical waves and detect potential problems and faults in the transmission infrastructure. OECD (2019[3]) tracks the expansion of satellite navigation constellations and associated augmentation systems worldwide.

Table 1.1. Sectors of designated critical infrastructure across OECD countries

Number of countries per designated sector

Sector	Number of countries designating sector as critical	It 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[1]	4			√
Other	19			

1. Space sector infrastructures encompass all space systems, whether public or private, that can be used to deliver space-based services, both space-based (e.g. orbital spacecraft) and terrestrial (e.g. launch facilities, ground stations, mission control centres).
Source: Undseth and Jolly (2022[1]), "A new landscape for space applications", *OECD Science, Technology and Industry Policy Papers*, No. 137, https://doi.org/10.1787/866856be-en.

As shown in Table 1.1, space technologies support more than half of the 16 most frequently designated critical infrastructures in OECD countries. Several OECD countries (Belgium, France, Spain, United Kingdom) 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[4]). It is worth noting that the designation as a "critical" infrastructure can be accompanied by a higher administrative burden. The US Aerospace Industries Association is taking a stance against designating the "space sector" as critical infrastructure because several space activities are already implicitly designated as such – as part of communications, critical manufacturing, transportation, etc. – and such an indiscriminate approach may put undue regulatory and economic pressure on small businesses, for example (AIA, 2023[5]).

The growing supply and quality of space-based data and signals (much of which is open access), combined with improved capabilities of data processing and analysis, may finally be unleashing the full potential of space technologies. Recent illustrations include 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 (Undseth and Jolly, 2022[1]). Importantly, this also demonstrated the strategic importance of robust space-based broadband infrastructure, provided today by commercial operators such as SpaceX. There are several plans underway for many national and commercial broadband constellations, including the GuoWang project of the People's Republic of China [hereafter 'China'] and the European Union's IRIS^2 constellation.

Furthermore, during the COVID-19 crisis, space infrastructure provided high-speed connectivity to remote locations (e.g. establishing links to remote hospitals, residential and small business customers, and deployment of online solutions schooling) as well as earth observation imagery for industry intelligence and monitoring of remotely located installations (OECD, 2020[6]).

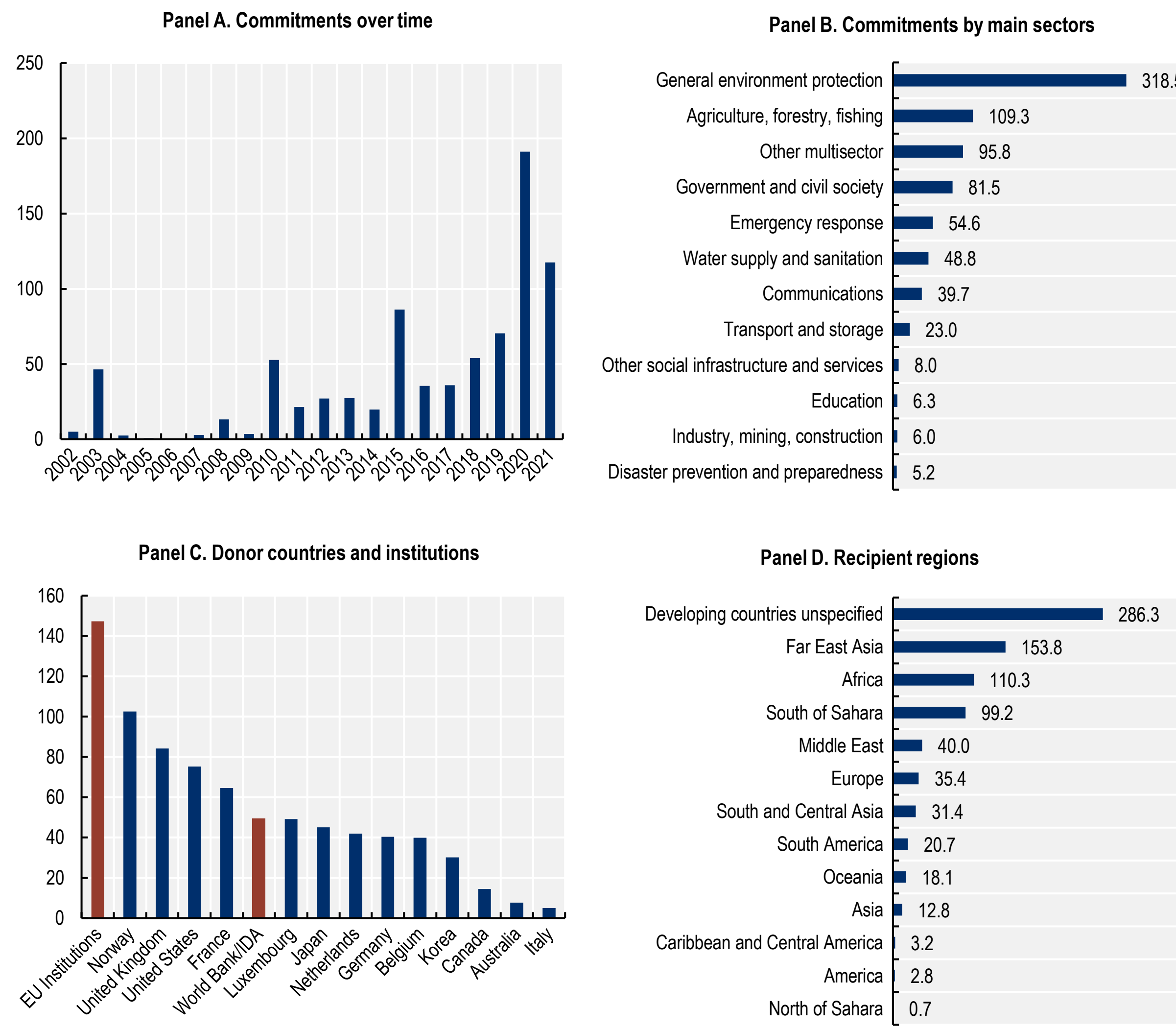
As for tackling the accelerating crisis linked to climate change and its policy responses, in 2022 newly launched satellites detected more than 1 000 human-induced methane super-emitter events landfills (Carrington, 2023[7]), demonstrating the global and continuous reach of space-based earth observation feeding data in assessing the sources of carbon emissions around the world (more on this in Chapter 2).

Space technologies are also increasingly used in official development assistance, as shown in Figure 1.1, with a notable growth in commitments over 2002-21, reaching more than 700 million inflation-adjusted USD in total over the period. Key applications include the monitoring of the environment and forests; information services to food producers; disaster prevention and emergency response; and different types of communication services via satellite TV and radio. This growth reflects targeted efforts and projects of several OECD countries, including the US SERVIR partnership programme between the US National Aeronautics and Space Administration (NASA) and the US Agency for International Development (USAID); the International Partnership Programme in the United Kingdom; the Geodata for Agriculture and Water (G4AW) project in the Netherlands; and the Satellite Data Programme of Norway's International Climate and Forest Initiative (NICFI). At the international level, the European Space Agency has teamed up with the International Development Association (IDA) and the Asian Development Bank to create the Space for International Development Assistance (ESA) programme, which aims to improve the uptake and understanding of earth observation data in development projects. Finally, the Global Monitoring for Environment and Security and Africa (GMES & Africa) initiative, co-funded by the European Commission and the African Union Commission, applies data and services from the European earth observation Copernicus programme to the African context.

More granular data on space-related official development assistance can be found in this publication's country profiles, featuring space programmes of OECD Space Forum members. Furthermore, a forthcoming OECD working paper will study space-related official development assistance in greater detail, looking at the type of projects and main channels of assistance.

Figure 1.1. The growing use of space technologies in official development assistance, 2002-21

Commitments in constant USD million (base year = 2021)



Notes: EU: European Union; IDA: International Development Association.
Source: Analysis based on OECD (2023[8]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

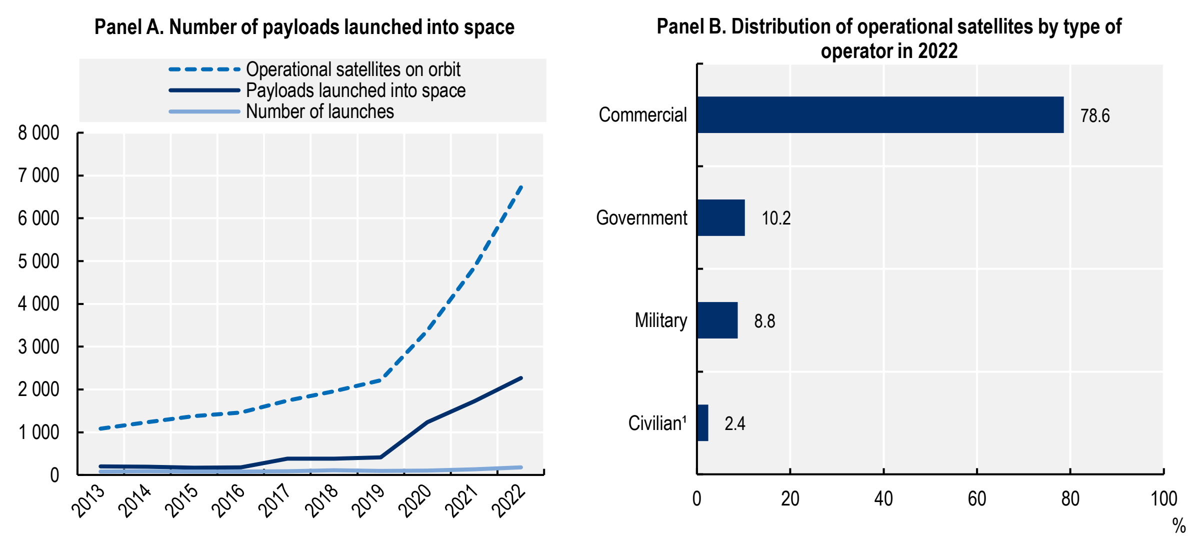
Explosive growth in the number of objects launched into space

There have never been so many active satellites in orbit. More satellites in orbit means in principle a growing availability of useful space services, but this comes also with its challenges. The number of satellites launched in the last 15 years has dramatically increased, as shown in Figure 1.2. After several active decades of space system deployment in the 1970s and 80s, launch activity had decelerated at the turn of the 21st century with some 80-110 objects (or payloads) launched yearly. This changed in 2013, which saw almost a doubling in launched objects. Since 2019, this number has been well above 1 000 per year and rising, with no end in sight.

As a result, orbits are getting more crowded. By the end of 2022, there were some 6 700 operational satellites in orbit (in addition to many more defunct satellites and other debris objects), twice the number recorded by the end of 2020 (Union of Concerned Scientists, 2023[9]). Active satellites are mainly operated by commercial actors (78.6%), followed by non-military government and military actors (10.2% and 8.8%, respectively), as shown in Figure 1.2. Chapter 3 looks more closely at these launch trends and at the ensuing "race" to occupy orbital space and resources such as the electromagnetic spectrum needed for operations and transmitting data and signals to Earth, as well as the effects of growing competition on the space sector itself.

It is worth noting that active satellites account for only 25% of (unclassified) space objects tracked by the US Space Force (2023[10]). Satellites in the orbits closest to Earth clear their orbits fairly quickly by natural processes, but satellites at higher altitudes may stay in orbit for decades or even centuries (or forever, as in the geostationary orbit) unless they are intentionally cleared from orbit. In addition, there are other types of debris, such as abandoned rocket stages or fragments from collisions or explosions. As a result, the orbital environment still carries traces of human activity dating back to the beginning of the space age in the late 1950s. The effects of this pollution on the orbital environment and society more broadly are treated in Chapter 4.

Figure 1.2. Increasingly crowded orbits



1. Civilian operators typically include universities and radio amateurs.
Note: Each category of actors also includes partnerships and dual-use missions (e.g. public-private, military-commercial).
Sources: US Space Force (2023[10]), *space-track.org website*, https://www.space-track.org, data extracted 16 December; and Union of Concerned Scientists (2023[9]), *UCS Satellite Database*, 1 January 2023 version, data extracted 27 July 2023, https://www.ucsusa.org/resources/satellite-database.

New opportunities for economic growth in certain applications but not everywhere

The overall short-term outlook for space activities is positive despite recent economic shocks, with sustained and (in some cases expected growing) government demand for space products and services, as well as increased commercial activity in certain domains. However, although many indicators of the space sector's expansion look positive – the growing number of countries, players, launches, satellites, a growing role in infrastructures etc., they do not necessarily translate into growth in revenues. The following sections look more closely at this apparent contradiction.

Uneven growth of the space economy

The optimism of numerous industry forecasts for the coming decade is not borne out by the historic record: only a limited number of activities have demonstratively grown between 2008 and 2021, as shown by data collected on behalf of the US Satellite Industry Association (BryceTech, 2022[11]). The manufacturing of positioning, navigation and timing (PNT)-related user ("ground") equipment, such as receivers and chipsets, is the *only* space industry segment that has experienced notable growth in real terms since 2008, with a compound average growth rate of 7% for the 2008-21 period. The other industry segments have, on average, performed more modestly: 0.8% compound average growth for space manufacturing, 1.3% and 1.5% for satellite services and launch, respectively.

These trends, based on data from industry surveys, are also reflected in the estimates by the Bureau of Economic Analysis (BEA) for the US space economy, which indicate that the average annual growth rate for the 2012-19 period of 1.6% was below the overall US growth rate (Highfill, Jouard and Franks, 2022[12]). The BEA's estimates come from the US Space Economy Satellite Account (SESA), and as such, they provide robust trends for more space industry segments integrated into US national statistical accounts.

Given such modest historical growth rates, it is hard to believe that the sector will become a "1 trillion economy" by 2040, as previously estimated by several investment banks (OECD, 2019[13]). Such projections lack in most cases the precision and granularity needed to adequately assess the health and growth potential of individual industry segments. Although this is an ongoing challenge, notable statistical efforts over the last years (e.g. the work to create statistical thematic (or "satellite") accounts in the United States and Europe) are strengthening the ability to identify and measure the space economy and its components and making them more comparable with other sectors in the global economy (OECD, 2022[14]).

Space industry segments are deeply heterogeneous

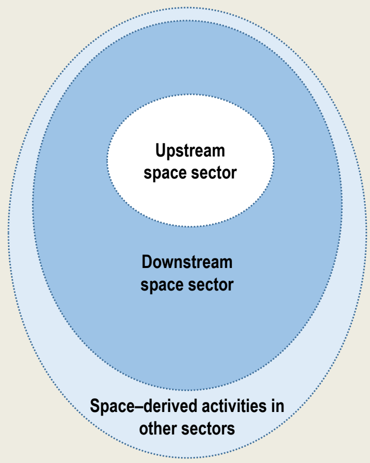
To better understand the industry dynamics, one needs to take a closer look at the distinct parts of the space economy. Indeed, the sector is deeply heterogeneous in terms of customer base, nature of activity and dependency on trade, and the different industry segments have fared very differently in the 2020-22 period The *OECD Handbook on Measuring the Space Economy* (2022[14]) defines three perimeters of activities: upstream, downstream and space-derived activities (Box 1.1).

Box 1.1. Defining the space economy

For measurement purposes; the *OECD Handbook on Measuring the Space Economy* (2022[14]) defines three perimeters of activities in the space economy (Figure 1.3): the upstream space segment, comprising fundamental space activities such as space manufacturing and launch; the downstream segment, including activities that depend on the exploitation of space data and signals (e.g. satellite television) as well as the manufacturing of associated equipment; and finally, "space-derived activities", which are derived from space technologies but not dependent on them to function.

Figure 1.3. Main perimeters of the space economy

Main perimeters



Scope	Activities
Upstream space sector = scientific and technological foundations of space programmes, manufacturing and production of space infrastructure	Fundamental and applied research; scientific and engineering support; dedicated ancillary services (e.g. insurance); supply of materials and components; design and manufacturing of space equipment and subsystems; integration and supply of full systems; space launch
Downstream space sector = daily operations of space infrastructure and "down-to-earth" activities that directly rely on the provision of a space capacity (satellite technology, signals or data) to exist and function	Operations of space and ground systems; supply of devices and products supporting consumer markets (e.g. GPS-enabled devices, set-top boxes, selected GIS); supply of services supporting consumer markets (e.g. satellite television broadcast)
Space-derived activities in other sectors = new activities in various economic sectors that derive from or have relied on space technology transfers	Activities/products/services derived from space technology, but not dependent on it to function (e.g. ad-hoc space technology transfers in the automotive or medical sectors).

Source: OECD (2022[14]), *Handbook on Measuring the Space Economy, 2nd Edition,* http://doi.org/10.1787/8bfef437-en.

Recent estimates of the size of the global space economy, when excluding government procurement, range from some USD 200 to 350 billion depending on the definition and measurement method, with the upper-range estimates also including revenues from location-based services (e.g. mobility apps on mobile phones) enabled by navigation satellite services (GNSS) (see for instance the Market Report of the European Space Agency (EuSPA, 2022[15])). Upstream segment revenues are dwarfed by those of downstream segments, typically satellite television and, increasingly, revenues generated by PNT services and equipment. Overall space economy revenues are strongly affected by developments in the satellite television market, which is declining faced with the rollout of fixed broadband and consumers' growing preference for streaming platforms over linear television.

Variable exposure to impacts of COVID-19 and other economic shocks

The space economy has been further affected by the impacts of COVID-19 and other economic shocks.

The degree of exposure of the space sector to the COVID-19 crisis has varied by industry segment, company size and company age. In general, upstream activities, comprising "core" industry segments such as manufacturing and space launch (see Figure 1.3), seem to have weathered the global pandemic relatively well, bolstered by government contracts, support measures and their ability to continue operations during lockdown, although also suffering considerable supply chain delays (OECD, 2020[6]).

But messages are mixed.

- In the United Kingdom, in a retrospective 2022 survey, less than half of respondents reported negative impacts of COVID-19 (on workforce and income, on demand, and from suppliers), with a notable share (15%) signalling positive effects on demand (know.space, 2023[16]).
- In Canada, a similar survey shows that the majority of respondents experienced negative effects on revenues, demand and supply chains (CSA, 2023[17]).
- Finally, a German survey conducted among space start-ups at a relatively early stage of the pandemic found that almost 40% of respondents reported "dramatic" negative impacts that

threatened the existence of their firm, with a large majority finding government measures insufficient (BDI, 2020[18]).

The strongest immediate impacts were probably in the downstream segment. Businesses catering to the transportation and extractive industries (e.g. inflight broadband) were the hardest hit, while broadband providers saw an increase in demand, enabling broadband connectivity from remote locations without appropriate terrestrial telecommunications infrastructure. Earth observation actors also observed increased demand for industry intelligence and remote monitoring applications.

Russia's war of aggression against Ukraine has dealt an additional blow to space industry supply chains (Undseth and Jolly, 2022[1]). In this niche market, Russia and Ukraine have long been notable international providers of specialised components, space systems and launch services. For instance, several US and European launchers have until recently relied on Russian- and Ukrainian-built engines (CNES, 2022[19]). In 2022, The European Space Agency stopped using the Russian Soyuz launcher, which since 2011 had launched satellites from the Kourou Space Centre in French Guiana, including European Union earth observation and satellite navigation satellites. The same year, the UK operator OneWeb suspended launch activities at the Russian-operated Baïkonur spaceport in Kazakhstan and left behind 36 broadband satellites, which have not been returned (OneWeb, 2022[20]).

More disruption on the horizon

It is worth noting that a too-narrow focus on commercial revenues may not fully capture the critical changes that are taking place in the sector, such as in the composition of investors and industrial actors, the volume of investments, and the maturing of disruptive technologies and services.

In the last 15 years, "new space" actors have provided disruptive new offerings in launch services, space manufacturing and operations, as well as in specific applications such as earth observation and satellite communications. This, combined with significant advances in data processing and computing, has lowered the cost of access to space and expanded the range of space applications, paving the way for new entrants into the sector and boosting further interest in space activities.

The term "new space" was coined in the early 2000s to distinguish a new type of commercial activities and actors from incumbents in the space sector. "Old space" actors were often affiliated with defence and aerospace industries, closely linked with government agencies on year-long projects and reliant on government procurement and R&D support.

In contrast, "new space" actors, big and small, brought with them funding and innovation strategies from other industries and typically still have one or several of the following characteristics:

- having a high dependence on private capital (third-party or otherwise), including equity finance in many cases, with some of the proponents of "new space" being digital economy billionaires
- making maximal use of lean production processes (standardisation, using off-the-shelf components, additive manufacturing) and digital business models ("space-as-a-service", etc.)
- putting on the market new products and services born from the convergence of digital and space technologies: miniaturised satellites, satellite constellations, data analytics combining location-based and satellite data.

"New space" activities have benefited from the favourable conjunction of technological developments, policy decisions and macro-economic events in the early 2000s. This includes a radical reduction in the size of space systems and instruments and innovative solutions for launching multiple satellites into orbit, as well as advances in storage, processing, and analysis of data (OECD, 2019[13]); new sources of funding from equity finance; and strategic policy decisions creating new markets and improving access to new types of actors, such as a shift to service buys in the United States and widespread promotion of commercial activities among both established and newer space actors (e.g. India, China, Korea) (OECD, 2023[21]). Some of the most important impacts of "new space" activities are listed below:

- disruption of the launch market with more affordable and reusable launch services
- disruptive and new applications from micro- and nanosatellite constellations (weighing less than 100kg and 10kg, respectively, see Box 1.2) in the low-earth orbit, for geospatial and signal intelligence (e.g. imagery, radio-frequency monitoring), weather and emissions monitoring, Internet-of-Things, etc.
- deployment of constellations with thousands of satellites for satellite broadband in the low-earth orbit (with satellites weighing some 150-200kg, which is still "small" compared to traditional satellite design).

Several developments in both the upstream and downstream segments could further shake up the status quo.

Box 1.2. What are smallsats and cubesats?

The use of space is closely related to the cost of access, and the popularisation of cubesats (cube-shaped miniature satellites originally developed for university projects) and other miniaturised satellites, has been a major enabler.

Satellites come in all shapes and sizes. The biggest telecommunications satellites in geostationary orbit weigh several metric tonnes, but it is increasingly possible to squeeze technology into smaller vessels, which may be interesting from a production and launch cost perspective, although it also may shorten mission life. For example, there have been several demonstration flights of prototype "chipsats", weighing less than 10 grammes.

Satellites with a mass equal to or below 500 kilograms are generally considered "small", and the US National Aeronautics and Space Administration (2015[22]) uses the following breakdown for even smaller satellites:

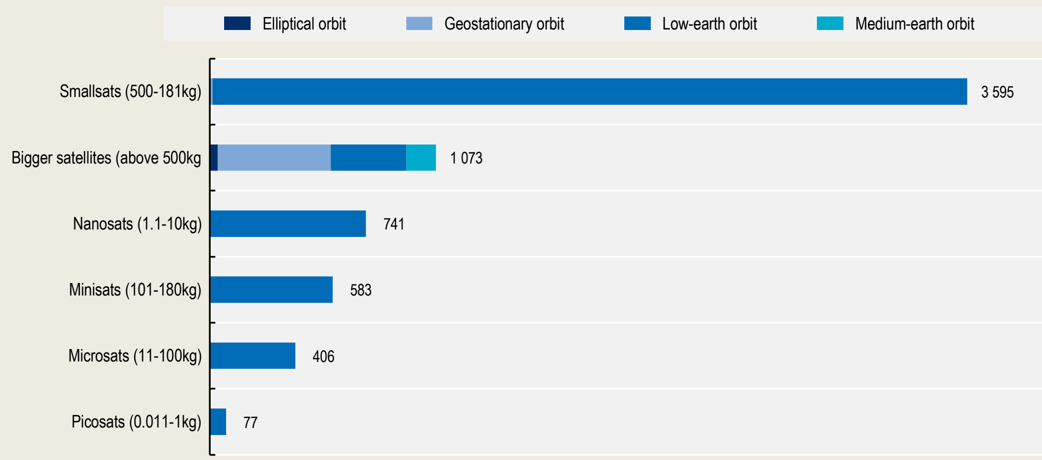
- Minisatellite, 100-180 kilograms
- Microsatellite, 10-100 kilograms
- Nanosatellite, 1-10 kilograms
- Picosatellite, 0.01-1 kilograms
- Femtosatellite, 0.001-0.01 kilograms

Cubesats belong to the class of nanosatellites and use a standard size and form factor. A standard cubesat measures 10x10x10 centimetres (1U), and is extendable to larger sizes, 1.5U, 2U etc. They provide an attractive platform for a range of applications either alone or in constellations, including commercial operations.

Among the population of operational satellites, bigger satellites are outnumbered by smaller ones, the most common of which are smallsats and nanosats (Figure 1.4).

Figure 1.4. Operational satellites by satellite class

Number of satellites, data as of 31.12.2022



Notes: The mass calculated is mass at launch. The sample excludes 243 blank entries.
Source: Adapted from Union of Concerned Scientists (2023[9]), *UCS Satellite Database*, 1 January 2023 version, data extracted 27 July 2023.

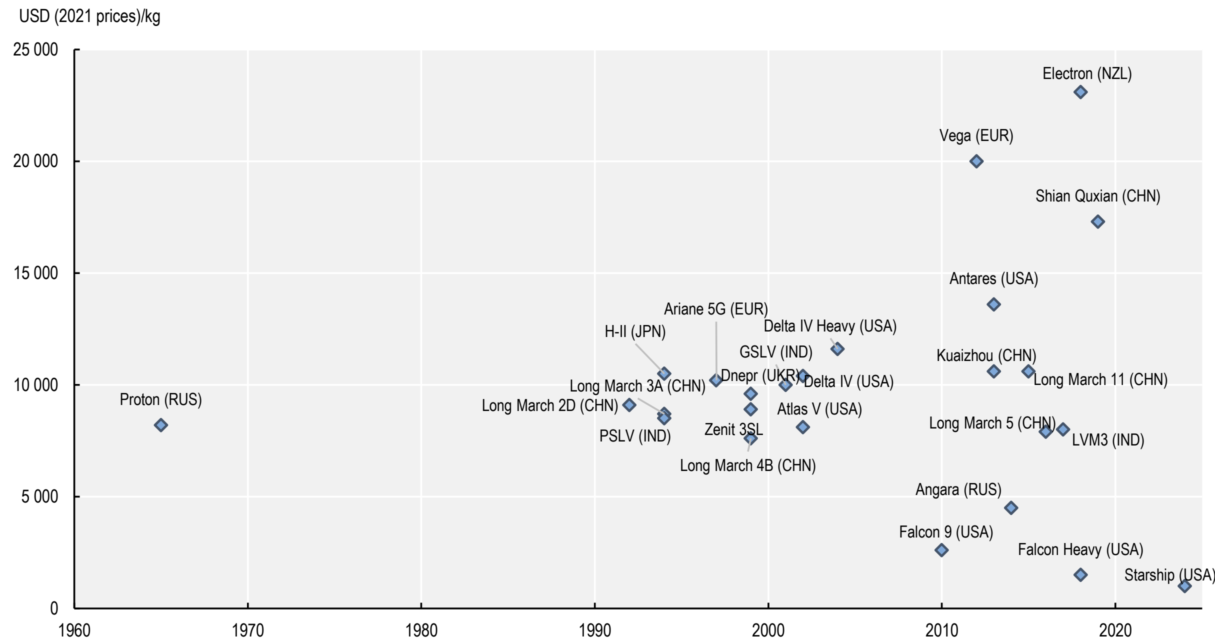
Considerable and sustained lowering of launch prices?

Launch options are becoming more numerous, diversified and cheap, with new opportunities closer to government, commercial and academic clients in Asia, North America and Europe (Figure 1.5), although Europe has for now no dedicated operational heavy launcher available. Lower prices, combined with more regular launches, could potentially create new commercial opportunities (e.g. for microgravity pharmaceutics, point-to-point space transportation), although launch represents just one of several cost drivers (Hollinger, 2023[23]). It could furthermore open new opportunities for government space programmes.

Furthermore, new commercial heavy-lift launchers (e.g. the US Falcon Heavy) are driving down prices to unprecedented levels. It is worth noting that launch prices are often not disclosed (e.g. for military launches) or not directly comparable due to heavy rocket customisation. The fully reusable super heavy-lift launcher Starship had a second failed orbital launch attempt in November 2023 but has several other prototypes in various stages of assembly. There is limited information about Starship's pricing. It is expected to go lower than existing offerings, but it would be competing against other launchers from the same company. There is also the question of availability, as SpaceX needs considerable launch capability to deploy its own missions, including the ultimate objective of colonising Mars. The development of new launchers is further described in Chapter 3.

Figure 1.5. Price estimates to low-earth-orbit for selected operational and experimental launchers

Estimated price per kilogramme, in USD (2021 prices)



Note: The figure includes small, medium and heavy-lift launchers that were operational in early 2023. Several of these launchers were set to retire by the end of 2023, e.g. Ariane 5 and Delta IV. Price per kilogramme is generally lower on heavy-lift vehicles. Deflators and currency exchange rates are the author's own.
Source: Adapted from Roberts (2022[24]), "Space Launch to Low Earth Orbit: How Much Does It Cost?"https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/.

Satellite connectivity reaching end users?

Despite considerable progress in the last decade, hundreds of millions of people in both high- and lower-income countries still have no access to a fast and reliable fixed Internet connection. In this context, satellite systems certainly have a role to play, despite technical limitations compared with terrestrial alternatives. The most performant low-earth orbit constellations under development/deployment (e.g. OneWeb, Starlink, Kuiper Systems), could offer a total capacity of around tens of terabytes per second, compared to terrestrial networks which move around thousands of terabytes per second (Pachler et al., 2021[25]). There are also other issues, such as sensitivity to weather conditions and the need for clear sight of the sky and horizon. Finally, there is the question of pricing of services, with operators providing limited information about how they intend to make their activities profitable. Satellite systems would therefore be most usefully deployed as a complement to terrestrial networks, by:

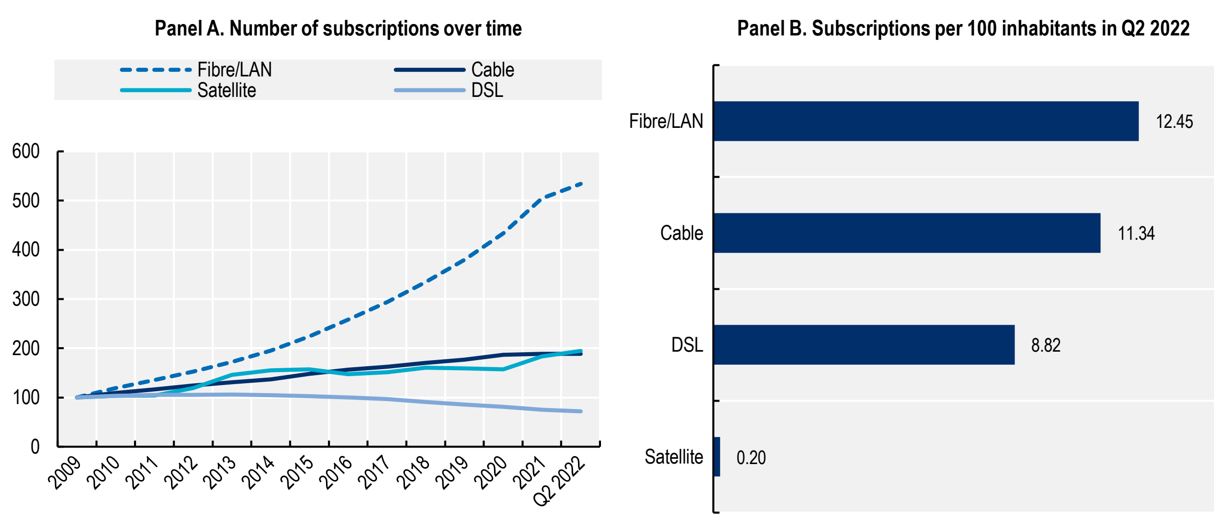
- filling the coverage gap to deliver fixed broadband services to residential and business users in remote and isolated geographic areas by offering ubiquitous and easy-to-deploy solutions
- providing backhaul or backbone network interconnection to the global Internet for terrestrial fixed or mobile telecommunication network service providers
- expanding the market for satellite broadband to deliver connectivity to lower-density areas, closely adjoining urban areas (OECD, 2017[26]; 2019[13]).

Satellite broadband is still much less used than other technologies (only 0.2 fixed broadband subscriptions per 100 inhabitants in the OECD area ((OECD, 2022[27])), as shown in Figure 1.6. However, this could change with the rollout of new consumer services. More than ten broadband satellite constellations are in different stages of development, with two companies (SpaceX and OneWeb) having already launched satellites. The US operator SpaceX is by far the most advanced, with new satellites launched every two weeks or so and comprising more than 3 000 operational satellites by the end of 2022. Indeed, Figure 1.6 shows a notable rise in the number of subscriptions from 2020 onwards.

The satellite mobile broadband market is also evolving rapidly. Existing services, typically catering to military, remotely located and maritime/offshore clients, require dedicated devices such as antennas and handheld equipment, but emerging projects are exploring different types of satellite connectivity on normal consumer mobile phones.

- In 2023, technology company Apple and satellite operator GlobalStar started offering emergency SOS text messaging via satellite on iPhone 14 models.
- Several satellite and mobile operators have announced partnerships to develop satellite-to-mobile services, including SpaceX and T-mobile Amazon Kuiper and Verizon, respectively.
- Start-ups are developing constellations for satellite-to-mobile connectivity, including US companies Lynk and AST SpaceMobile. The latter launched a test satellite in 2022 (which has raised concerns in the astronomy community because of its brightness, more on this in Chapter 4).

Figure 1.6. Fixed broadband in the OECD area by technology



Notes: DSL: Digital subscriber line; LAN: Local area network.
Source: OECD (2022[27]), "Broadband database (Edition 2022)", *OECD Telecommunications and Internet Statistics* (database), https://doi.org/10.1787/dc2d97f8-en (accessed on 25 May 2023).

An emerging in-orbit economy?

The lowering of launch costs and the growing number of orbital clients is making the emergence of a viable "in-orbit" economy more credible, comprising activities such as in-orbit servicing, connectivity relay and debris removal, or even resource generation and extraction, designed to serve terrestrial needs and/or support further space habitation and exploitation. Large parts of this in-orbit economy would certainly be fuelled first by heavy public R&D investments.

For instance, several connectivity relay constellations are under deployment, aiming to provide high-speed data transfer services via laser or radio-frequency links for satellites in low-earth orbit that are out of reach of terrestrial ground stations (Werner, 2022[28]). Other activities are at a much earlier technological stage.

In 2023, a solar power prototype from the US Caltech University demonstrated wireless energy transfer from space to Earth (Caltech, 2023[29]).

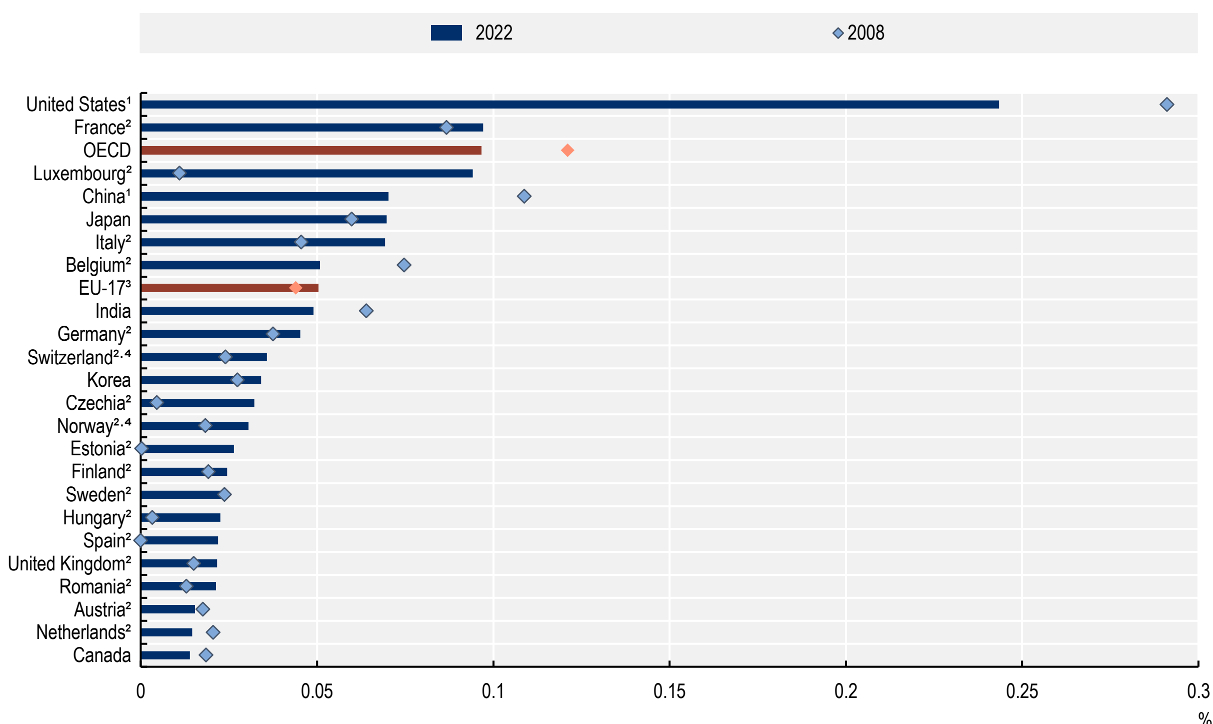
Still, accessing space is only one of several hurdles to clear, including a combination of technological, regulatory and economic challenges. For instance, in-orbit servicing and debris removal entail launching a dedicated spacecraft and agreements with operators to access proprietary technology. While service contracts typically envisage multiple servicing or multiple spacecraft, it remains costly for potential client operators. Asteroid mining companies attracted more than USD 50 million USD million in the 2010s until the bubble burst in 2019, because of investor scepticism about the technological feasibility and future customer base (Abrahamian, 2019[30]).

Optimistic but uncertain outlook for space investments

Governments play a pivotal role in industry segments such as space manufacturing and launch, as funders and procurers of R&D, products and services. In some OECD countries, sales to government customers account for a large share of revenues (e.g. close to 70% of upstream revenues in both Europe and Korea in 2021 (Eurospace, 2022[31]; Korean Ministry of Science and ICT, 2022[32])). However, private actors and venture capitalists have started to play a bigger role in recent years.

Figure 1.7. Selected government space budget estimates

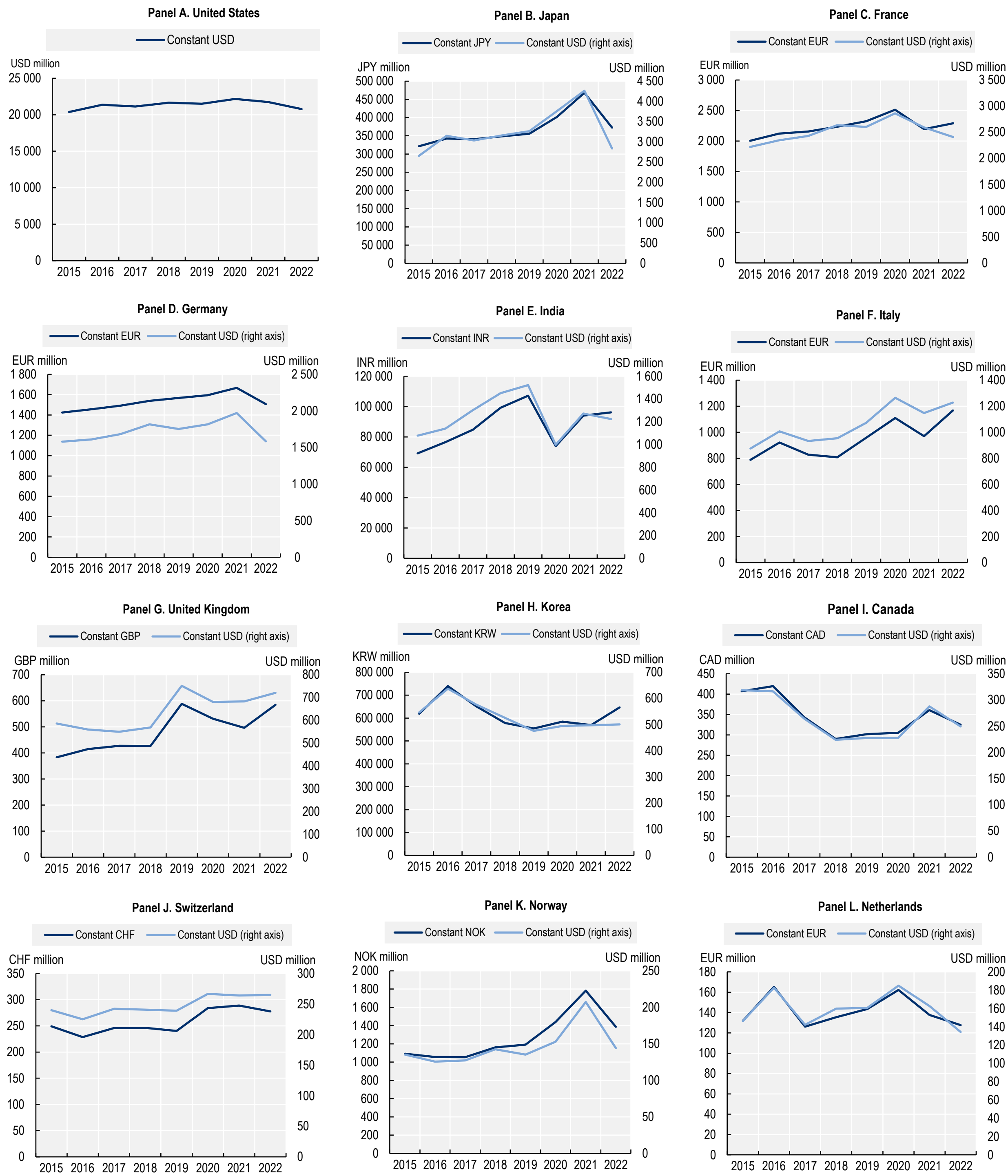
As a share of GDP (%)



1. Estimates, also including military activities, 2. Includes contributions to Eumetsat and the European Space Agency, 3. Includes AUT, BEL, EST, FIN, FRA, DEU, GRC, IRL, ITA, LUX, LVA, LTU, NLD, PRT, SVK, SVN and ESP, 4. Includes non-EU member contributions to selected EU programmes (e.g. Copernicus, Galileo).
Source: OECD calculations based on official government information.

Figure 1.8. Evolution in selected government space budgets

Constant local currencies and USD (base year 2015)



Notes: United States data include civilian budgets for the National Aeronautics and Space Administration and space programmes in the Departments of Commerce, Transportation and the Interior. Data for France, Germany, Italy, Netherlands, Norway, Switzerland and the United Kingdom include contributions to the European Organisation for the Exploitation of Meteorological Satellites and the European Space Agency. Data for Norway, Switzerland and the United Kingdom also include subscriptions to selected European Union programmes (e.g. EGNOS/Galileo, Copernicus).

Source: OECD calculations based on official government information.

Sustained government space budgets most of the time…

Public space budgets support a range of activities, including government services and operations (e.g. defence, disaster management, environmental protection); space science and exploration; and research and development (R&D), performed either in-house by government agencies or outsourced to external academic and commercial actors through grants and procurement. Over the last decades, the focus on economic growth, innovation and entrepreneurship has increased.

In 2022, government space budgets accounted for an estimated 0.10% of total OECD gross domestic product (GDP), compared to 0.12% in 2008 (Figure 1.7). Changes in the OECD average are dominated by developments in big and established space nations (e.g. United States, European Union countries, Japan) such as the retirement of the US space shuttle in 2011 or the introduction of European programmes Galileo (satellite navigation) in the early 2000s, and Copernicus (earth observation) in 2014.

Another part of the picture is the evolving role of smaller and emerging actors. Luxembourg, for instance, has significantly increased spending since 2018, its national programme includes support to new national facilities and an ambitious R&D support programme attracting start-ups. Korea started developing its space programme in the early 1990s and launched its first fully autonomously-built rocket in 2022. New Zealand has been proposing commercial launch services since 2017 and other small OECD countries are building spaceports (e.g. Canada, Norway, Sweden). Several countries in Eastern Europe have significantly increased their space budgets as they get more closely associated with European space programmes, both in the European Space Agency (ESA) and the European Union.

Figure 1.8 shows budgetary changes in greater detail over the 2015-22 period for selected OECD countries and other economies, generally revealing constant or increased levels of spending, but with inflation affecting purchasing power in 2022. COVID-19 has had limited short-term effects on space programmes. In several cases, it has led to an *increase* in spending through specific government plans and recovery packages (e.g. France, Italy). However, the future of civilian government space activities is uncertain.

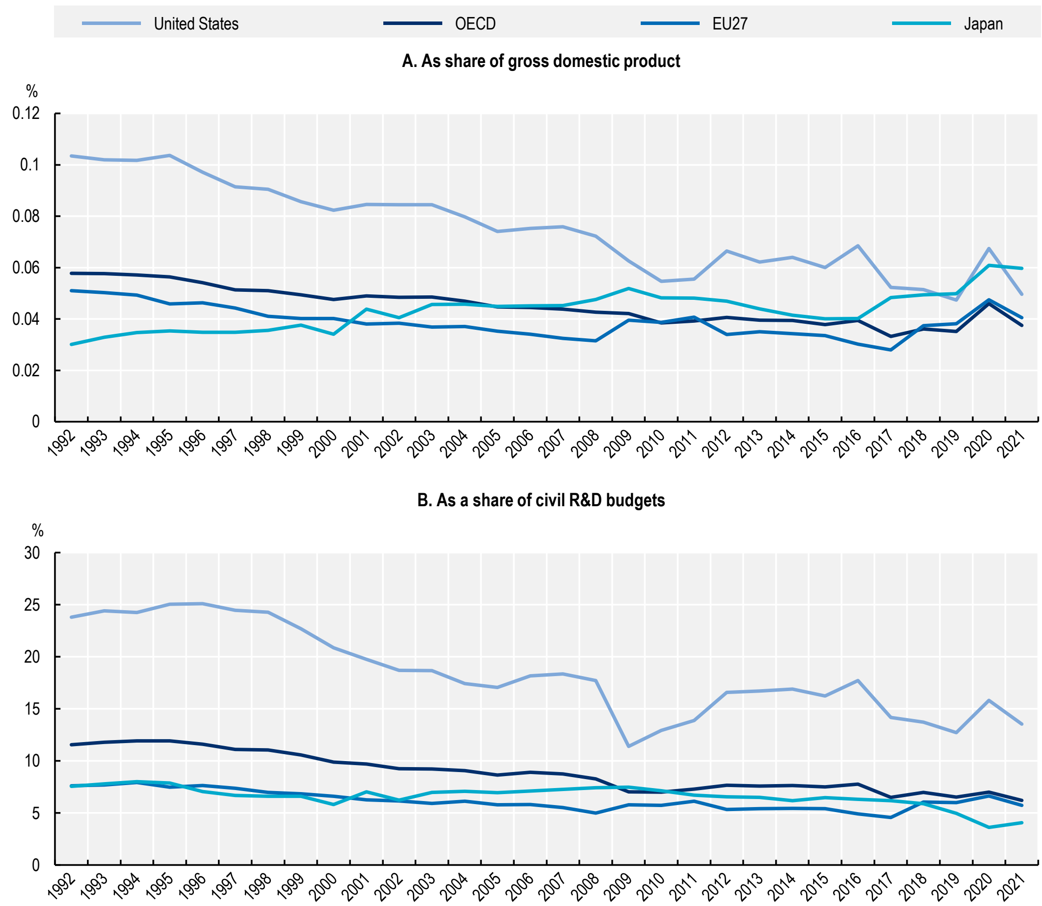
…but uncertain future for selected civilian activities

There is growing interest in several OECD countries and beyond for military space activities, illustrated by a multiplication of military strategies and investments (e.g. the creation of the US Space Force, military strategies in France and, the United Kingdom). It is uncertain how this will affect civilian space activities. For the fiscal year 2023, the US Congress allocated more funding to the US Space Force (USD26.3 billion), three years after its creation in 2019, than to NASA (USD 25.4 billion). The ESA science programme's share of the total multi-annual budget has gradually decreased over the years (in an overall increasing budget) accounting for 24% of the 2002-06 budget compared to 19% of the allocations for 2023-27.

Strong inflation is also affecting purchasing power, effectively limiting options for launching new activities. For example, both ESA’s and NASA’s budgets saw a decrease in funding after the 2008-09 financial crisis, followed by a rebound (delayed in Europe due to the prolonged crisis) and then another inflation-induced dip in 2022, which brings current 2023 purchasing power of NASA close to or below 2008 levels in real terms.

Figure 1.9 traces longer-term trends since the 1990s for Japan, EU27, the United States and the OECD area. The data show an overall decline in public R&D allocations since the 1990s, both as a share of GDP and of total civilian R&D budgets, coinciding with the end of the Cold War, the deregulation of certain downstream applications and the finalisation of the International Space Station (1998). It is worth noting that the negative trend is slowing down or even reversed towards the end of the period.

Figure 1.9. Long-term OECD trends for government civilian space R&D budgets



Note: Panel A illustrates how public civil space R&D allocations compare to the size of the overall economy (as a share of GDP) while panel B displays their order of priority in the overall public civil R&D portfolio (as a share of civilian R&D budget).
Source: OECD (2023[33]), "Main Science and Technology Indicators", *OECD Science, Technology and R&D Statistics* (database), https://doi.org/10.1787/data-00182-en (accessed on 15 May 2023).

Improved access to private investments

In the meantime, access to private funding, including private third-party sources of equity, debt and acquisition finance, has significantly improved since 2008 and reached an all-time high in 2021 with some USD 15.4 billion in global investments, according to one industry observer ((BryceTech, 2023[34]), before significantly dropping in 2022. The data indicate a strong increase in equity finance (seed, venture, private equity, initial public offerings) from 2016 onwards. Although initially benefiting a limited number of companies (e.g. SpaceX and OneWeb), the distribution of funding is becoming more diversified, also geographically.

However, rising levels of inflation and interest rates are also negatively affecting the overall supply of venture capital, for all domains and activities. As observed by the US Venture Capital Association, in early 2022 available venture funding supply exceeded demand by a ratio of 1.5-to-1, while by the end of the year demand for funding surpassed supply 2-to-1 (NVCA, 2023[35]).

This will most likely lead to reduced investment in the space sector in the coming years from equity finance; but the sector may still be more attractive to venture capitalists than in previous decades, because of the evolving composition of its actors with more fast-moving and digital start-ups; the lowering costs of access to space and stronger public reliance on space technologies.

Policy actions for sustained and sustainable growth of the space economy

Overall, the outlook for the space sector and the space economy is good, but there are also reasons for concern, such as the environmental sustainability of space activities, the continuity of important public missions, or the vitality of the space innovation ecosystem, that will require a targeted and long-term response from decision makers.

Ensuring the environmental sustainability of space activities

Stabilising the orbital environment and mitigating debris will require concerted action at both national and international levels as well as innovative policymaking. Furthermore, more evidence is needed on the externalities of space activities as well as the socio-economic effects, e.g. of space debris or orbital congestion.

The OECD has published several reports on the economics of space sustainability, identifying some of the shorter and longer-term costs associated with space debris (Undseth, Jolly and Olivari, 2020[36]; OECD, 2022[37]). The OECD Space Forum and its partnering space administrations 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 the value of space applications.

Ensuring adequate levels of public funding

Public funding will continue to play a key role in the space sector to maintain critical programmes and infrastructure, and to support commercial activities through R&D subsidies and partnerships; procurement programmes; and debt finance. However, there is room for improvement in where and how to deploy these instruments for the best effect and value for money.

- Governments need to align strategic objectives that do not necessarily pull in the same direction. For instance, the consolidation/verticalisation of the commercial manufacturing segment in many countries may make it more cost-efficient but a more concentrated supply chain may be more vulnerable to shocks.
- Also, supporting innovation and entrepreneurship may eventually lead to more innovation, but relying on incumbents and tested technology could reduce economic and technological risks.
- Public authorities therefore need to identify the industry segments with the highest risk profiles – least likely to attract third-party capital – and provide adequate demand-side/supply-side support following national objectives and procurement guidelines.
- The size and stability of public markets for space products and services affect business firms' incentives to invest. Some 18% of respondents to the 2013 US industrial base "deep dive" survey reported that the *variability* in US government space-related demand had somewhat or significant adverse effects on their willingness to stay in the sector, their solvency, their ability to retain skilled personnel, etc. (US Department of Commerce, 2013[38]). Evidence from other STI (Science, Technology and Innovation) domains indicates that it could positively affect their ability to raise third-party funds. OECD research on "clean-tech" industries has found a positive correlation between government deployment policies and higher levels of equity financing (OECD, 2014[39]).

The OECD Space Forum will contribute further to these efforts by providing definitions and guidelines on how to measure the space economy to encourage evidence-based policies and international comparability of results (see OECD (2022[14])), and by compiling space-related policy instruments in the STIP Compass for Space Policies to support analyst and policy makers.

Building partnerships to address mutual challenges

Faced with mounting fiscal pressures and global challenges, governments are invited to build partnerships at both the national and international levels. Government agencies have a broad range of procurement mechanisms and instruments at their disposal to make use of private sector capabilities (Undseth, Jolly and Olivari, 2021[40]). With revamped public procurement practices and more service buys, new partnerships are being set up with the space industry throughout OECD countries and beyond. Space agencies and other procurement agencies will need to have adequate and sustained skills and resources to negotiate contracts and carry out oversight.

At the international level, space is already characterised by high levels of collaboration, as 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. Still, more efforts will be needed to muster the necessary economic, technological, and human resources to sustain and expand existing and new missions in earth and space exploration, or other challenging domains. In this regard, a useful addition is the European Centre for Space Economy and Commerce (ECSECO), founded in 2022, which serves as a platform for cross-border and interdisciplinary discussions and research on these matters. Several important lessons from managing the COVID-19 crisis for science, technology, and innovation communities (OECD, 2023[41]) are also applicable to future space developments and their sustainability challenges:

- Decision makers need to recognise the role of research infrastructures as unique resources for training and capacity-building; as intermediaries and brokers vis-à-vis other disciplines and sectors; and in international collaboration, by sharing data and analysis. For space, they include physical and virtual space infrastructures, such as the internationally co-ordinated meteorological satellites and future joint space stations for example.
- The pandemic further showed how only globally inclusive responses can provide the necessary level of protection. The same applies to efforts to address space debris, which is a truly global challenge. Establishing or better employing existing international funding mechanisms, trusted relationships and scientific networks could contribute to making society more resilient.

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2 Space as a provider of critical data and innovative applications

Over the last two decades, there have been considerable public and private investments in space-based earth observation systems, providing additional capacity and technological capabilities. This chapter demonstrates how space systems have become reliable data providers for addressing selected global challenges, but it also identifies some of their limitations as well as possible solutions to further benefit from these systems.

Introduction

Over the last two decades, there have been considerable public and private investments in space-based earth observation systems. This includes large institutional programmes (e.g. the Copernicus earth observation programme managed by the European Union and the European Space Agency) and new-generation satellites supporting decade-long missions (e.g. US Landsat programme, currently in its fourth iteration of sensors, and Canada's successive Radarsat missions).

Earth observation satellites gather information about our planet's physical, chemical, and biological systems and make important contributions to civilian government services such as environmental and climate monitoring, natural resource management, disaster planning and response, etc. The number of applications addressing global challenges is increasing, but uptake in some communities dealing with these challenges remains slow in some cases. This can be linked to demand-side challenges, such as a lack of adequate connectivity or equipment, skilled personnel, or biases in the user community; but it may also be associated with the quality and nature of the observations themselves, lack of *in situ* validations, etc.

It is also important to note that space-based and surface-based observations are highly complementary. First, depending on variables and user needs, some requirements are best met from space (e.g. global coverage, high spatial resolution over large areas), while other variables may be more feasible to measure using surface-based or aerial sensors (e.g. surface pressure, fine-scale vertical resolution observations) (WMO, 2020[1]). For instance, in the envisaged operational carbon monitoring system backed by the World Meteorological Organization, the space-based component will provide global clear sky observations of greenhouse gas concentrations at high spatial resolution in cloud-free regions, while the surface-based component will provide data in persistently cloudy regions and at night, as well provide solid evidence to attribute anthropogenic emissions (WMO, 2020[1]). Second, surface-based observations are crucial for satellite data calibration and validation, and vice versa.

This chapter highlights recent trends demonstrating how space systems have become reliable data providers for addressing selected global challenges, but it will also mention some of their limitations and possible solutions to benefit further from these systems.

A dramatic increase in satellite observations and data analysis

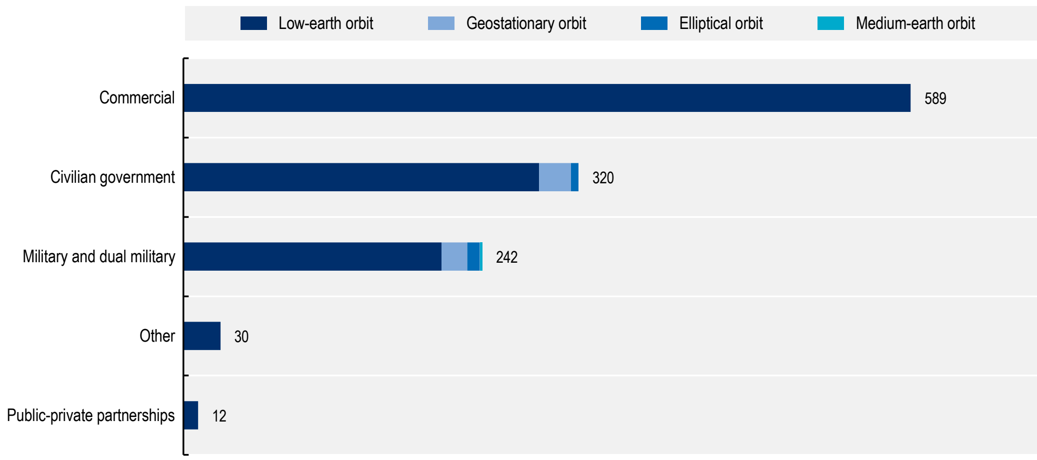
A new era has started with more actors and higher-performance satellites

In numbers and particularly in mass, around half the earth observation satellites are publicly owned (as shown in Figure 2.1), but there is a growing number of commercial missions that first started emerging around 2000. The sector was boosted in the early 2010s by miniaturised technology and increased usage of standardised and off-the-shelf products (e.g. so-called microsatellites and nanosatellites, with a mass inferior to 100kg and 10kg, respectively, as described in Box 1.2. in Chapter 1) that considerably reduced satellite production and launch costs (OECD, 2014[2]).

As of late 2022, there were more than 1 000 operational earth observation and earth science satellites, mainly located in the low-earth (LEO) orbit (100km-2 000km altitude), but with some civilian and military government satellites in the geostationary (GEO) orbit at 35 786km altitude, in the medium-earth orbit (between the low-earth and geostationary orbits) and elliptical orbits. Satellites in elliptical orbits have a low perigee (the point of the orbit nearest to Earth) and a higher than geostationary apogee (the point farthest from Earth), giving them longer dwell time at specific points when approaching and descending from the apogee, which can be used for covering polar areas, for instance.

Figure 2.1. More than 1 000 operational earth observation satellites in orbit in 2022

Number of operational satellites as of 31 December 2022



Notes: The category "Other" refers mainly to academic satellites. Public-private partnerships refer to different combinations of military and civilian government actors co-operating with commercial ones.
Source: Union of Concerned Scientists (2023[3]), "UCS Satellite Database: 1 January 2023 update", https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database, data accessed 07 August 2023.

The latest 15-year period has been characterised by the introduction and continuation of government legacy programmes. But over the same period, there have been several interesting changes in the geographic and public/private composition of earth observation satellites in orbit.

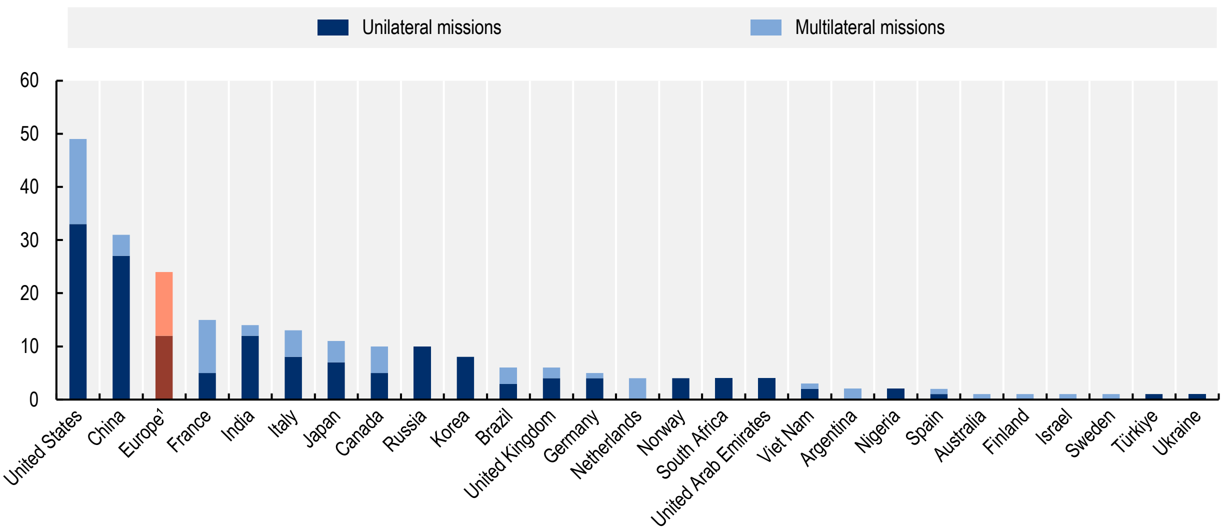
- The longest-running government earth observation programme is the US Landsat programme, which launched its first satellite, Landsat-1, in 1972, and 2023 has Landsat-8 and -9 in orbit. The European Union, in close co-operation with the European Space Agency, started the deployment of the Copernicus programme in 2014, with the launch of Sentinel-1. Other long-running legacy programmes include the Canadian Radarsat Constellation and the French Spot satellites.
- More than half of all earth observation satellites are now commercially operated. Among these 574 satellites listed as commercial, two-thirds, or 67%, of commercial earth observation satellites are US-operated, and the great majority are nanosatellites. The biggest operators (in terms of numbers) are US firms Planet and Spire. It is important to note that nanosatellites do not have the same lifetime or instrument performance as higher-mass satellites, although great progress has been made.
- In terms of leading countries and regions, according to the data from the Union of Concerned Scientists, satellites from the People's Republic of China [hereafter China] account for some 36% of all civilian government-led missions (although some of these may also be dual-use with the military) in 2022, followed by the United States, Japan, the European Space Agency and the Russian Federation [hereafter 'Russia'] (Union of Concerned Scientists, 2023[3]). In the last decade, China has vastly improved its earth observation capabilities, including for instance its Gaofen high-resolution satellites (first launched in 2013), Fengyun meteorological satellites, Haiyang ocean observing satellites, etc. Other countries are also expanding their activities.

Growing number of government actors, adding new capabilities

There are currently some 180 operational civilian unilateral and multilateral missions to monitor the environment and climate, with another 158 in various stages of planning, as recorded by the Committee on Earth Observation Satellites (CEOS) (2023[4]). Figure 2.2 shows the number of civilian earth observation missions by economy (or region, when counting the numerous European missions).

Figure 2.2. Number of civilian earth observation satellites by economy/region

This includes operational, extended and commissioning satellites as of 10 January 2023



Note: Multilateral missions include more than one economy, which contributes to the satellite and/or an instrument on the mission. Unilateral missions may comprise several agencies within the same economy.
Source: CEOS (2023[4]), *The CEOS database: Updated for 2023*, data accessed 10 January 2023, http://database.eohandbook.com/.

The United States participates in the highest number of multilateral missions, followed by China and programmes funded by the European Space Agency, the European Commission and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). These missions collect data on the atmosphere (97% of current observations); land (76%); ocean (26%); snow and ice (26%); and gravity and magnetic fields (12%) (CEOS, 2023[4]). Box 2.1 gives more insights on the international co-ordination of space-based weather observations.

As for national and regional developments, NASA is working on its Earth System Observatory, a USD 2.5 billion programme covering five missions over the next decade. In Europe, the European Commission renewed its commitment to the Copernicus programme with EUR 5.6 billion in funding. Six Copernicus “expansion” missions (Sentinels 7 to 12) are being studied. China is driving the development of a virtual BRICS remote-sensing satellite constellation, consisting of satellites from Brazil, Russia, India and China (ISRO, 2023[5]).

Box 2.1. The coordination of weather satellites as an illustration of international co-operation

Weather forecasting is an excellent example of the value of international co-operation. Since the 1960s, space-based observations have been a key part of the global weather observation system, In early 2023 the World Meteorological Organisation Integrated Global Observing System (WIGOS) included space observations from 19 operational satellites in geostationary orbit and 15 satellites in low-earth (polar) orbits, operated by space and meteorological agencies in China, Europe, India, Japan, Korea, Russia and the United States (WMO, 2023[6]) and which are co-ordinated by the Co-ordination Group for Meteorological Satellites (CGMS). Since the launch of the Chinese Fengyun-3E satellite in 2021, polar-orbiting weather satellites have made observations in three orbital planes (early morning, morning and afternoon orbits), providing more data to numeric weather prediction models around the world.

More than 15 gigabytes of satellite data are received daily at operational weather centres, a number that is growing (Saunders, 2021[7]). In its *2040 vision*, the World Meteorological Organisation (WMO) foresees several improvements, notably multi-spectral visible/infra-red imagery with rapid repeat cycles in GEO; a better permanent coverage of the polar regions through observations in high-elliptical orbits (polar regions are poorly served by GEO satellites); and lower-flying observation platforms and LEO satellites with low or high inclination for a more comprehensive atmosphere sampling (WMO, 2020[1]).

The observation of solar weather is also co-ordinated at the international level. Space-based observatories currently count five missions – four US missions and one joint mission between NASA and the European Space Agency (WMO, 2023[6]). These efforts are complemented by terrestrial observatories and other space research missions. For instance, China launched its first space-based solar observatory, ASO-S, in 2022 and the Parker Solar Probe by NASA became the first spacecraft to enter the Sun's outer atmosphere in a flyby in 2021.

These missions monitor solar activity, notably increases in the radiation of extreme ultraviolet, X-ray and radio wavelengths (solar flares), as well as the emission of ionised energy particles and plasma (e.g. coronal mass ejections – CMEs). (RAE, 2013[8]) Such events can cause radiation or geomagnetic storms, with potentially severe impacts on both space-based and terrestrial activities. As the Sun progresses in its 25th solar cycle, more intense solar activity is expected in the 2023-26 period, with yet hard-to-fathom impacts as climate change is accelerating in parallel.

Sources: WMO (2023[6]), "*WMO OSCAR database*, https://space.oscar.wmo.int/ and OECD (2022[9]), *Earth's Orbit at Risk: The Economics of Space Sustainability*, https://doi.org/10.1787/16543990-en.

More numerous, more precise and more diverse observations and measurements

Earth observation instruments include for instance active and passive sensors for imagery, atmospheric chemistry and data collection, as further described in Table 2.1. Passive sensors collect radiation emitted or reflected by the Earth, while active sensors send signals and detect their echo. Several of these instruments are frequently referred to as "sounders", derived from the use of sound waves to measure temperature and salinity in the ocean.

Thanks to increased earth observation launch activity, the different user communities benefit from improvements in temporal (revisits) and spatial resolutions, improved spectrum coverage and more sensitive data products (Ustin and Middleton, 2021[10]). For example. a recent trend is the growth in hyperspectral sensors, which measure light intensity through several dozens of spectral bands and are more sensitive to subtle variations in reflected energy than multi-spectral sensors. Between 2016 and 2022, at least ten hyperspectral satellites have been launched into low-earth orbit (Qian, 2021[11]).

Table 2.1. Selected earth observation instruments

Type of measurement		Description	Selected instruments and missions
Passive	Panchromatic imagery	Measures intensity of solar radiation, combining typically 1-2 bands in the electromagnetic spectrum into one band. Sacrifices colour for brightness and creates high-resolution grayscale imagery.	**WV110/WorldView 3 (Maxar Technologies)**
	Multi-spectral imagery	Measures light intensity on a limited number (5-36) of spectral bands, e.g. infrared, visible, ultraviolet, etc.).	MSI/Sentinel-2 (European Commission/European Space Agency), Landsat-8 (US Geological Survey)

Type of measurement		Description	Selected instruments and missions
	Hyperspectral imagery	Measures light intensity from 37+ spectral bands). Produces more data per pixel than multi-spectral imagery and is more sensitive to subtle variations in reflected energy, e.g. for classifying geologic surface composition or vegetation types.	Hyperion/EO-1 (US Geological Survey); HYC/PRISMA (Italian Space Agency)
	Infrared radiometry	Measures atmospheric temperature and humidity, ozone profile and total-column greenhouse gases.	AIRS/Aqua (US National Aeronautics and Space Administration); IASI/Metop-C (Eumetsat)
	Microwave radiometry	Measures intensity of thermal radiation, e.g. to determine the integrated atmospheric water vapour column and cloud liquid water content. Also useful for determining surface emissivity and soil moisture over land, for surface energy budget investigations to support atmospheric studies, and for ice characterisation.	Advanced Microwave Sounding Unit (AMSU-A)/Metop-C (Eumetsat)
	GNSS radio occultation (GNSS-RO) or atmospheric limb sounding	Measures the time variation of the excess path length of GNSS signals as they are refracted by the atmosphere. Provides high-resolution temperature and water vapour profiles.	Sentinel-6 (European Commission/European Space Agency; **SENSE/LEMUR satellites (Spire)**
Active	Synthetic aperture radar (SAR)	Transmits electromagnetic pulses towards the Earth's surface. The intensity and latency of return pulses are used to generate SAR imagery. Sees through cloud cover.	Radarsat Constellation Mission (Canadian Space Agency); **IceEye constellation (IceEye**)
	Light detection and ranging (Lidar)	Same principle as SAR, but works in the infrared, visible or ultraviolet wavelengths to measure topographic features, monitor glaciers, profile clouds, quantify atmospheric components, etc.	ALADIN/Aelous (European Space Agency)
	Radar altimetry	Uses the ranging capability of radar to measure the surface topography profile along the satellite track (e.g. for ocean surface topography)	Poseidon 3B/JASON-3 (US National Aeronautics and Space Administration and others)
	Radar scatterometry	Measures the backscatter of radio or microwaves at the sea surface, at skew incidence angles, which provides a measure of wind speed and direction near the sea surface. Important for numerical weather prediction models. Also used to study vegetation, soil moisture, polar ice, etc.	ASCAT/Metop-B and -C (Eumetsat); DDMI)/CYGNSS (US National Aeronautics and Space Administration)
Gravity sensing system		Observe Earth's gravity field along the orbit.	SuperSTAR/GRACE and GRACE-FO (National Aeronautics and Space Administration)
Data collection systems		Geostationary or low-earth orbit transponders pick up signals from stationary and mobile transmitters for data collection (e.g. Argos, AIS) or search and rescue.	Argos-4 satellite/US National Oceanic and Atmospheric Administration GEOS&R/MTG-I1 (Eumetsat) AISSat-2 (Norwegian Space Agency)

Note: Entries in bold are commercial missions.

As observed above, many instruments are flown on increasingly small satellite platforms. The most recent generation of nanosatellites in the 130-satellite PlanetScope constellation from US commercial operator Planet, have the shape of a 10cm x 10cm x 30cm shoe box and weigh about 5 kilogrammes, carrying a multispectral camera. US company Spire's LEMUR satellites for GNSS radio occultation have a similar shape and mass and carry three instruments for weather measurements, maritime vessel tracking and airplane tracking. These satellites have a mission life of about two years.

Still, the small satellite platform size puts constraints on performance and mission life compared to satellites several magnitudes bigger. The European LEO weather satellite Metop-C weighed almost 4 000kg at launch in 2018, including 300kg of fuel to keep it in orbit for at least 10 years, and it carries 10 instruments (WMO, 2023[6]).

Sharing satellite data as never before

Opening access to government data (of different types, beyond satellite data) is associated with new scientific insights; economic growth, innovation and productivity; and enhanced social welfare (OECD, 2018[12]; OECD, 2020[13]). The OECD estimates that the aggregate economic impact of "public sector information" was equivalent to some 1.1% of cumulated GDP in 2008 (OECD, 2015[14]). For instance, a Canadian study found that open geospatial data had led to new business models, additional economic actors and a change in the demand (greater focus on value-added products and services), overall adding CAD 695 million to Canadian gross domestic product (GeoConnections, 2015[15]). Box 2.2 gives more details on what it entails to "open" access to data.

When focusing specifically on the effects of free and open satellite earth observation data, an Italian survey of firms using a mix of open and restricted data sources found that earth observation data improved the quality of products and services, improved R&D capability and contributed to developing new products and services, which again translated into increased revenues and employment (Lupi and Morretta, 2022[16]).

Consequently, space agencies and related organisations have multiplied their efforts to enhance access to satellite data (OECD, 2020[17]).

- In 2008, it was decided to make US Landsat data available for download free of charge (all Level-1 data and Level-2 and Level-3 science products). Similarly, most European Copernicus data are available on a free, full and open basis.
- Several countries have taken steps to make data available by creating national data portals, for example, Digital Earth in Australia, satellittdata.no in Norway, or Satellite Data Portal in the Netherlands. In Europe, data from the Copernicus programme are made available via Data and Information Access Services (DIAS) or the Open Access Hub. Open data is the stated objective in the 2022 Canadian strategy for earth observation (CSA, 2022[18]). Data from government missions (e.g. from NASA, Canadian Space Agency, Japanese Space Exploration Agency (JAXA), and European Space Agency) are also available on commercial platforms, such as Earth on AWS or Google Earth Engine.
- During COVID-19, ESA, NASA and JAXA created a free and open "earth observation dashboard" for climate observations, that combines the agencies' resources, technical knowledge and expertise to provide a low-threshold resource for both specialist and non-specialist users to study human activity and the changing environment (ESA, 2023[19]).
- Special efforts are made to make data available to lower-income countries. The Committee on Earth Observation Satellites (CEOS) and other partners supported the 2018 launch of the Africa Regional Data Cube. Furthermore, 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 exploitation tool of satellite data (OECD, 2020[17]). In 2020, Norway launched the Satellite Data Programme as part of its International Climate and Forest Initiative (NICFI), purchasing commercial high-resolution satellite imagery of tropical forest regions for universal access and use.
- There is furthermore growing focus on opening access to other types of resources, such as training data needed for machine learning. NASA is for instance supporting initiatives such as the Radiant Foundation's ML Hub, an open library of training data, models and standards for applications of machine learning on earth observation.mo.

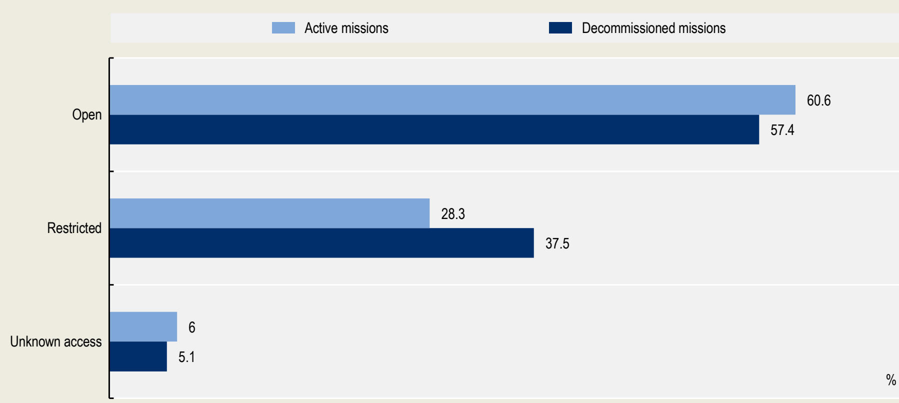
Box 2.2. Enhancing access to data

Free and open access to government data needs to be balanced against costs, privacy, security, intellectual property rights and preventing malevolent uses. The *OECD Recommendation concerning Access to Research Data from Public Funding* (2022[20]) encourages governments to *"promote access to research data […] resulting from public-private partnerships in ways that help ensure data collected with public funds is as open as possible while recognising and protecting legal rights and legitimate interests of stakeholders, including private-sector partners".*

Different degrees of openness may include: i) open access with an open licence; ii) public access with a specific licence that limits use; iii) group-based access through authentication; and iv) named access explicitly assigned by contract (OECD, 2019[21]). More restricted access to data can be organised within the framework of safe environments (e.g. the Five Safes framework), which rely on safe software platforms, where only approved researchers can access the data within a specific environment, analyse them without extracting the actual sensitive data and then submit the results of their research for approval.

Figure 2.3. Accessibility of earth observation data from CEOS missions

Share of instruments, and data as of 10 January 2023



Source: CEOS (2023[22]), *CEOS Virtualization Environment (COVE)*, http://www.ceos-cove.org/en/.

Open data are not necessarily free of cost, Different models include institutional subscription to research databases; "author pays" variants; open-access archives and repositories (supported by organisations); and several hybrid solutions, such as delayed open access and open choice (OECD, 2017[23]; Houghton and Sheehan, 2009[24]).

Concerning access to satellite earth observation data, the Committee on Earth Observation Satellites reports that some 61% of data from active missions (and 57% from decommissioned missions) are open access (Figure 2.3). Restrictions include user fees (common for dual use public/commercial missions), multiple-day latencies, requirements to register or submit research proposals, geographic prohibitions on use outside national borders, etc. Flagship US and European missions, such as the Landsat and Copernicus programmes, both provide free and open access to their datasets.

Sources: OECD (2020[13]), *Enhanced Access to Publicly Funded Data for Science, Technology and Innovation*, https://doi.org/10.1787/947717bc-en, and CEOS (2023[22]), *CEOS Virtualization Environment (COVE)*, http://www.ceos-cove.org/en/.

A growing number of applications with tangible societal benefits

In addition to tried and tested applications such as remote sensing for weather and climate monitoring, disaster management and food production (see for instance (OECD, 2014[2]; 2019[25]; 2020[17]; UNOOSA, 2023[26]), more affordable systems and sensors, combined with increasingly powerful data processing and open data policies, have paved the way for innovative uses of space technologies, including the monitoring of emissions from greenhouse gases and the use of satellite data as open-source intelligence by news media and non-government organisations.

Table 2.2 gives an overview of selected mature applications of earth observation data, while selected important developments are highlighted in the following sections, with a focus on emerging uses of new capabilities. Box 2.3 later in the chapter presents efforts to identify and quantify benefits.

Table 2.2. Selected mature earth observation applications

Sector	Application	Description
Climate and weather monitoring	Climate monitoring	Space-based observations account for at least half of the essential climate variables that are used to monitor climate change, mainly atmospheric observations but also ocean and land cover characteristics, such as sea surface temperatures, ocean colour, terrestrial vegetation types and ice caps
	Weather forecasting	The inclusion of space-based observations in numerical weather prediction models allows for more precise and timely forecasts. Satellite observations are particularly important in the southern hemisphere, where *in-situ* observations are sparser than in northern regions. Data denial simulations indicate that withholding satellite observations degrades forecasting skill at day 5 by about two days in the southern hemisphere, compared to 0.5 days in the northern hemisphere (McNally, 2015[27]) Improvements in forecasting skill are associated with considerable cost avoidance and lives saved, see for instance Eumetsat (2014[28]).
Environmental protection	Biodiversity and ecosystem monitoring	Satellite data are essential for detecting and monitoring land cover change (e.g. human conversions of land from a more natural state to a more artificial state that has potentially large implications for ecosystems and biodiversity). While land cover change is a proxy and does not directly measure biodiversity; changes in the spatial structure of natural habitats are considered the best measure currently available to broadly monitor pressures on terrestrial ecosystems and biodiversity (see Hašcic and Mackie (2018[29]).
Disaster management		Satellite imagery contributes to improved disaster prevention planning (land use) and emergency response, by detecting and mapping affected areas and functions. The International Charter for Space and Major Disasters provides satellite imagery and maps free of charge to disaster-affected countries around the world. Initiated in 2000 by the European, Canadian and French space agencies, it was supported by more than 20 organisations in 2023, involving 270 satellites. Since its introduction, the Charter has been activated more than 750 times, by 130 countries (International Charter Space and Major Disasters, 2023[30]).
Food production and security	Crop monitoring	In addition to the benefits of more accurate weather forecasts that are essential for adequately timing planting and harvesting, multi- and hyperspectral imagery can monitor crop vitality and water stress, thus ensuring a more targeted and efficient use of water, pesticides and fertilizer and allowing for higher yields (see for instance the Copernicus Sentinel data benefit studies carried out on farm management in Denmark and Poland (EARSC, 2023[31]).
	Land use management	Compared with other types of data and observations, e.g. land use censuses and aerial surveys, space-based observations offer regularly updated, wide-angle imagery with a growing range of applications following the evolutions in instruments (e.g. hyperspectral imagery) and spatial and temporal resolution. It can be particularly useful in areas where access to field information is limited and smallholder subsistence agriculture dominates (Becker-Reshef et al., 2020[32]).

Recording the accumulation of greenhouse gases from space

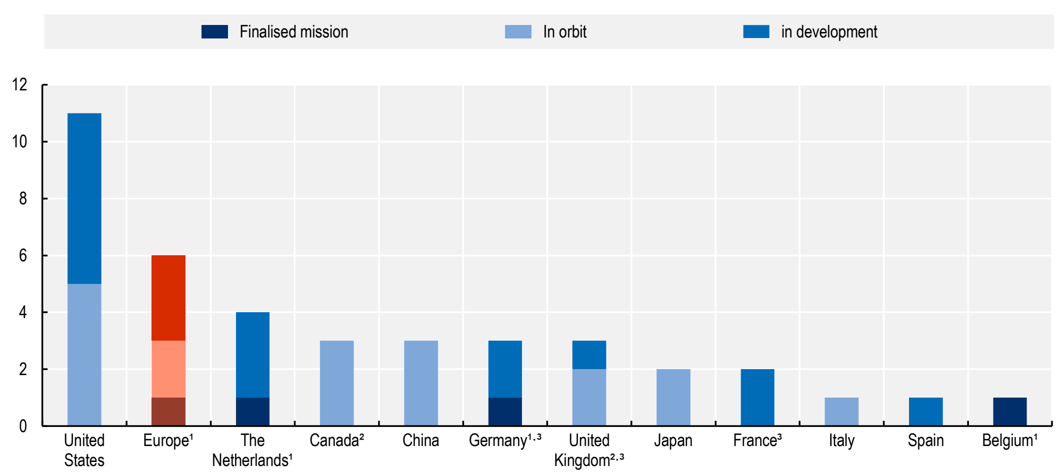
The warming of our planet coincides with record-high emissions of greenhouse gases induced by human activity, the most important of which being carbon dioxide (CO2), methane (CH4) and nitrous oxide (NO2). Carbon dioxide emissions in 2022 were (then) the highest ever recorded (Friedlingstein et al., 2022[33]).

Official measurements of greenhouse gases are mainly from ground-based sensors, but as noted in the introduction to this Chapter, the WMO Global Atmosphere Watch (GAW) plans to increase the role of satellites in the observing system to support air quality forecasting and inverse modelling to improve emission estimates (WMO, 2017[34]). This includes efforts to validate satellite data, foster synergies between different scientific communities to tailor measurements to user needs, facilitate combined use of different observations (ground-, satellite- and aircraft-based), and aid the evaluation of specific low-precision satellite measurements (e.g. retrievals greenhouse gas distributions from radiance measurements, which currently are short-term, low-precision and subject to bias) (WMO, 2017[34]). Data from two satellite missions are currently available in the World Data Centre for Greenhouse Gases, the Japanese GOSAT and the US OCO-2 mission, both tracking carbon dioxide emissions (WDCGG, 2023[35]).

In 2022, there were all in all 16 missions in orbit specifically tracking greenhouse gas emissions (several with multiple participating countries, also including commercial and non-profit actors) and another 16 missions under development, as shown in Figure 2.4. Satellite missions monitor carbon dioxide and methane much more frequently than nitrous oxide, at global, national and point-source levels (GEO, ClimateTRACE, WGIC, 2021[36]). And until recent developments in satellite technology, some methane emissions had been hard to detect. Sensors can now detect not only flaring, used to burn unwanted gas and put CO2 into the atmosphere, but also deliberate and accidental venting which simply releases invisible and unburned methane into the air. Leaks of fossil fuel sites from around the world can now be identified and could help prompt reactions to control large methane emissions. In 2022, more than 1 000 human-caused methane super-emitter events were detected by satellites, more than half from oil and gas fields, 105 from coal mines, and 340 from waste sites, such as landfills (Carrington, 2023[37]).

Figure 2.4. Economies and regions with greenhouse gas tracking missions

Number of missions, whole counts for multilateral missions, as of 1 April 2023



1. Including finalised multilateral missions; 2. including multilateral missions in orbit; 3. including multilateral missions in development.
Note: This figure includes whole counts for multilateral missions so that the total number of counted missions exceeds 100%.
Source: Based on GEO, ClimateTRACE, WGIC (2021[36]), "GHG Monitoring from Space: A mapping of capabilities across public, private, and hybrid satellite missions", https://earthobservations.org/documents/articles_ext/GHG%20Monitoring%20from%20Space_report%20final_Nov2021.pdf.

There are currently two commercial missions in orbit, the Canadian GHGSat constellation and the US Orbital Sidekick's Aurora satellite. Another four commercial projects are under development in the Netherlands and the United States, each aiming for national or point-source coverage (GEO, ClimateTRACE, WGIC, 2021[36]). On a similar note, UK operator Satellite Vu is planning a constellation to monitor the temperature of buildings through high-resolution infrared imagery. Several of these satellites are microsatellites and/or nanosatellites, e.g. GHGSat satellites have a mass of 15kg (UTIAS-SFL, 2023[38]).

In addition to dedicated GHG gas tracking missions, other earth observation satellite data can also be used, such as the Tropospheric Monitoring Instrument (TROPOMI) flying on Copernicus Sentinel-5P, which feeds into the French company Kayrros' global methane watch platform.

In early 2023, observations from Landsat-8 and NASA's EMIT imaging spectrometer on the International Space Station helped to detect methane emissions from two US oil and gas operators (Targa and Exxon Mobil) that the operators had failed to report to regulators (Wethe, Mider and Clark, 2023[39]; Clark and Mider, 2023[40]). In the United States, the Environmental Protection Agency is seeking to empower "approved and qualified" third parties to detect and report super-emitting events of 100 kilogrammes of methane per hour, or more (EPA, 2022[41]).

Satellite data and "green finance"

Commercial satellite missions aim to support government decision making but are also targeting a growing market for Environmental, Social and Governance (ESG) reporting to monitor compliance with requirements for corporate social responsibility and "green finance" investments. Several international bodies frame non-financial reporting, such as national and international issuer information disclosure bodies; exchanges, self-regulating bodies and industry associations; oversight authorities such as markets regulators and bank and pensions supervisors; and standard-setting international organisations regarding responsible investing and sustainability goals (Boffo and Patalano, 2020[42]).

Table 2.3. Environmental ESG criteria – major index providers

Pillar	Thomson Reuters	MSCI	Bloomberg
Environmental	Resource use	Climate change	Carbon emissions
	Emissions	Natural resources	Climate change effects
	Innovation	Pollution and waste	Pollution
		Environmental opportunities	Waste disposal
			Renewable energy
			Resource depletion

Source: Based on Boffo and Patalano (2020[42]) "ESG investing: Practices, progress and challenges", www.oecd.org/finance/ESG-Investing-Practices-Progress-and-Challenges.pdf

Data providers such as Bloomberg and Thomson Reuters produce ESG metrics and disclosure scores along the three main pillars. When it comes to environmental criteria in particular, the most common of which are listed in Table 2.3, space-based observations could contribute to filling data reporting gaps and providing globally uniform and consistent data, which are not subject to variations between reporting units and instruments.

Satellite data as open-source intelligence

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 statements 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[43]). For example, open-source satellite imagery from several operators is used to document potential Russian war crimes in the Ukrainian city of Bucha (Centre for Information Resilience, 2022[44]).

The ongoing war 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[45]). 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[46]).

Policy implications

The availability of earth observation data has grown rapidly in the last two decades, following considerable government investments, open data initiatives and new commercial missions. However, multiple questions remain concerning the economic sustainability of government earth observation activities, the management of partnerships with the private sector and internationally; and returns on investment (user uptake, etc.).

Mounting budgetary pressure on government missions

It is not a given that crucial satellite observations of our planet will continue smoothly. The future and sustainability of selected government missions are uncertain, as many government agencies and science departments face growing budget constraints after COVID-19 and other global crises and struggle with increased costs induced by supply-chain issues and growing inflation (OECD, 2023[47]).

As documented in this chapter, an important share of the growth in space-based observations and data in the last 15 years can be traced back to OECD civilian government missions with free and open data policies. In addition to supporting government services, they form the backbone of innovative data products, either on their own or combined with other types of data and signals. For example, Landsat data provide geometric and radiometric standards (allowing to adequately detect change over time) that are then applied to commercial data with higher spatial and temporal resolution, such as Planet's Planetscope constellation (NGAC, 2020[48]). Business intelligence companies such as Kayrros apply their algorithms to freely available Copernicus data to track GHG emissions, among other things.

An independent review board of NASA;'s Earth System Observatory, which is the Agency's new suite of earth observation missions for the upcoming decade, identifies a high risk of cost overruns for the planned Earth Science Observatory, which may eventually lead to compromises on mission risk or the number and nature of scientific measurements (NASA, 2022[49]).

This is part of a longer trend of reduced public funding in earth observation in many countries. In short, earth science divisions in government agencies will increasingly need to make more with less. Modifying the composition of bigger and smaller missions is one possibility. Smaller missions have the benefit of being more agile (requiring five years or less for development), responsive to new scientific discoveries, and more tolerant of risk. On the other hand, large missions tend to nurture big scientific communities, contribute to building large data archives and are scientifically highly productive (Committee on Large Strategic NASA Science Missions: Science Value and Role in a Balanced Portfolio et al., 2017[50]).

Partnerships with other agencies, including international ones, is another commonly used option, as documented by the many bilateral and multilateral missions co-ordinated by the Committee on Earth Observation Satellites. In its Earth System Observatory programme, NASA has been encouraged to seek more international partnerships and well as to explore new types of partnerships, covering for instance ground and/or space operations (NASA, 2022[49]). As noted above, new types of partnerships are emerging in other parts of the world, e.g. between BRICS economies.

As a result of these developments, many agencies have started to build evidence of social and economic returns of earth observation missions, beyond the most typical scientific benefits (see Box 2.3).

Box 2.3. Measuring socio-economic benefits from government earth observation missions

The benefits of earth observation to society and the economy are increasingly documented and, to the extent possible, quantified. Several initiatives, such as the GEOValue community, the NASA-funded VALUABLES Consortium and the Sentinel Benefits studies funded by the European Space Agency and the European Union, have contributed to producing more evidence in this area (GeoValue, 2021[51]; Valuables Consortium, 2021[52]; EARSC, 2023[31]). All these groups collect and provide accessible case studies, community-accepted methodologies and peer-reviewed publications. Benefits are often calculated using a value-chain approach, information economics ("value of information") or contingent valuation (OECD, 2022[53]).

The value-chain approach identifies the types of beneficiaries (e.g. business firms, the general public) and the value generated (e.g. productivity gains, cost avoidances) at different stages of the value chain. For example, the European Association of Remote Sensing Companies, in co-operation with the European Space Agency and other stakeholders, have produced over 20 use cases outlining value chains of applications built upon data flowing from the European Union's Copernicus-Sentinel satellites. Examples of activities relying upon applications built upon satellite data include the management of farms, forests, floods and maritime navigation. (EARSC et al., 2016[54]).

Information economics is often used to quantify the non-market effects of the use of satellite data applications (Macauley, 2005[55]; Pearlman et al., 2016[56]; Straub, Koontz and Loomis, 2019[57]), i.e. of goods and services that are not traded in markets, and which often have public good characteristics in the sense that their use cannot be restricted to a single individual or group and whose use by one person does not reduce their use by others (Rothman, 2002[58]). The theory proposes that data only realises its full value once it is used as information – the value of information is therefore calculated as the difference between some measure of the outcomes associated with a decision based on the information under scrutiny and an estimate of the outcome that would have occurred had a decision been made without the information.

- In North America, A 2018 Resources for the Future study suggests that the information provided by satellite-derived air pollution monitoring systems in the United States saves roughly 2 700 lives annually over and above an alternative scenario where monitoring does not occur (Sullivan and Krupnick, 2018[59]).
- In Europe, it has been estimated that satellite data used to produce poor air quality warnings could generate some EUR 8.3 million to EUR 21 million worth of avoided hospitalisations by 2035 (PwC, 2017[60]). More generally, the same Copernicus ex ante study foresees annual benefits of some EUR 4.3 billion in 2025 for all of Europe, gradually rising to EUR 8.3 billion in 2035 (low estimate, values not discounted). Furthermore, a 2022 study assessing the value generated by the European demonstration mission Aeolus-1 and its follow-on operational mission Aeolus-2 found major improvements in specific weather data availability at the poles and the equator, also filling the gap

left by reduced air traffic observations during COVID-19, with total combined lifetime benefits of the two missions estimated to surpass EUR 10 billion (ESA, 2023[61])

- A study exploring the value of earth observation applications to the UK government, found that meteorological applications accounted for about 90% of the current derived value, estimated at GBP 966 million annually in 2020 (London Economics, 2018[62]).
- At the European level, the cumulative 20-year socio-economic benefits derived from satellite-based meteorological information, combining the effects of better protection of property and infrastructure, added value to the economy and private use by citizens, have been valued at somewhere between EUR 16 billion (low estimate) and EUR 61 billion (likely estimate) (Eumetsat, 2014[28])

Finally, willingness-to-pay (contingent valuation) is sometimes used to quantify the value of satellite data. In the United States, this method has been used several times to assess the economic benefits of the Landsat programme, which was most recently valuated at USD 3.45 billion by US and international users (Straub, Koontz and Loomis, 2019[57]). In China, willingness-to-pay was used to value the (high) benefits of the Public Weather Service to CNY 46.5 billion (0.22% of gross domestic product) in 2006 (Yuan, Sun and Wang, 2016[63]).

Thanks to these efforts, the evidence base for decision makers has grown considerably. However, results still need to be used with care, as findings rely on the methodologies used and should not be directly compared with different approaches or interpreted out of context, and/or are not always reproducible. Furthermore, information remains scarce about the non-market effects of space activities (OECD, 2022[53]).

Source: Adapted from OECD (2022[53]),” Strengthening assessment of the impacts of the space economy”, in *OECD Handbook on Measuring the Space Economy, 2nd Edition,* https://doi.org/10.1787/1db200df-en.

Managing government purchases of commercial data

Partnerships with commercial partners are another option for government agencies seeking to save costs and nurture private sector capacity-building and innovation, something which is also a stated government objective in several OECD countries (CSA, 2022[18]; United States White House, 2010[64]; German Federal Ministry of Economics and Technology (BMWI), 2010[65]; USGEO, 2019[66]). Beyond potential cost-effectiveness, commercial data may have other benefits. The science community, for instance, sometimes chooses to pay for commercial data because of their high spatial resolution that can be used to improve maps and/or validate interpretations; their high temporal resolution that serves to build time series maps; and their innovative development of new types of data (Ustin and Middleton, 2021[10]).

However, there are several issues to consider. First, how would government procurement of commercial data affect non-commercial third-party users (e.g. other government agencies, research communities and international organisations) and their activities; second, how would it affect *commercial* third-party users, in particular small and young firms?

US government agencies are the most experienced when it comes to commercial data purchases. The National Oceanic and Atmospheric Administration (NOAA) has been purchasing commercial radio occultation data since 2016 for integration into the agency’s numerical weather prediction models (NOAA, 2023[67]). NASA has been using the Commercial Smallsat Data Acquisition programme since 2017 to augment or complement its own data or that of other partners (NASA, 2023[68]). In 2022, the National Reconnaissance Office made its largest commercial contracts yet to three data providers, worth several USD billions until 2032, as part of its Electro-Optical Commercial Layer (EOCL) programme (NRO, 2022[69]). Other countries and organisations are following suit. Eumetsat launched a commercial radio occultation third-party pilot data service in 2022 (Eumetsat, 2022[70]).

A review of US government earth observation data purchases provides valuable insights from these stakeholder groups (US Office of Science and Technology Policy, 2022[71]).

- The extent of data sharing rights remains a contentious issue between commercial data providers and government users. Providers consider licenses proving full and open sharing as incompatible with their ability to have multiple clients and create markets, as well as an obstacle to raising third-party funding (due to investors' negative views of open licenses). Their preferred option is limiting use to the purchasing agency and scientific and non-commercial third parties. Government users, on the other hand, argue that data purchased with taxpayers' money, irrespective of the data source, should be made publicly available for scientific purposes and for spurring commercial entrepreneurship and innovation.
- Academic users are concerned about how the increased share of commercial data purchases in government agencies could affect their access to all relevant data sets (as well as raw data and metadata) and consequently their research activities. Notably, it may lead to potentially disrupted time series (particularly important for climate research); reduced ability to test, verify and validate research; hampered ability to publish (many journals require access to datasets); and finally, reduced ability to train future researchers on the full lifecycle of data analysis without access to raw data. Finally, paywalls could widen the gap between "rich" institutions and those with fewer resources. Government users highlighted the important function of academic users to check and verify earth observation data and associated algorithms. Furthermore, government grants to academia typically require data sharing, without which the datasets are not viewed as reproducible.
- Finally, the US government has several international obligations for earth observation data-sharing, most notably with the WMO and the Group on Earth Observations, which promote free, open and timely (non-commercial) access. Government agencies noted that their continued sharing has an important signal effect vis-à-vis international actors' willingness to share data. The licensing agreement of NOAA's purchase of radio occultation data takes international sharing into account, and so does Eumetsat's pilot scheme.

In any case, this issue is likely to become increasingly important. US government agencies expect the share of government data with commercial to grow in the coming years (US Office of Science and Technology Policy, 2022[71]). The balancing act between the benefits of open access and respecting data producers' business models/intellectual property has therefore just started.

Tracking and increasing user uptake

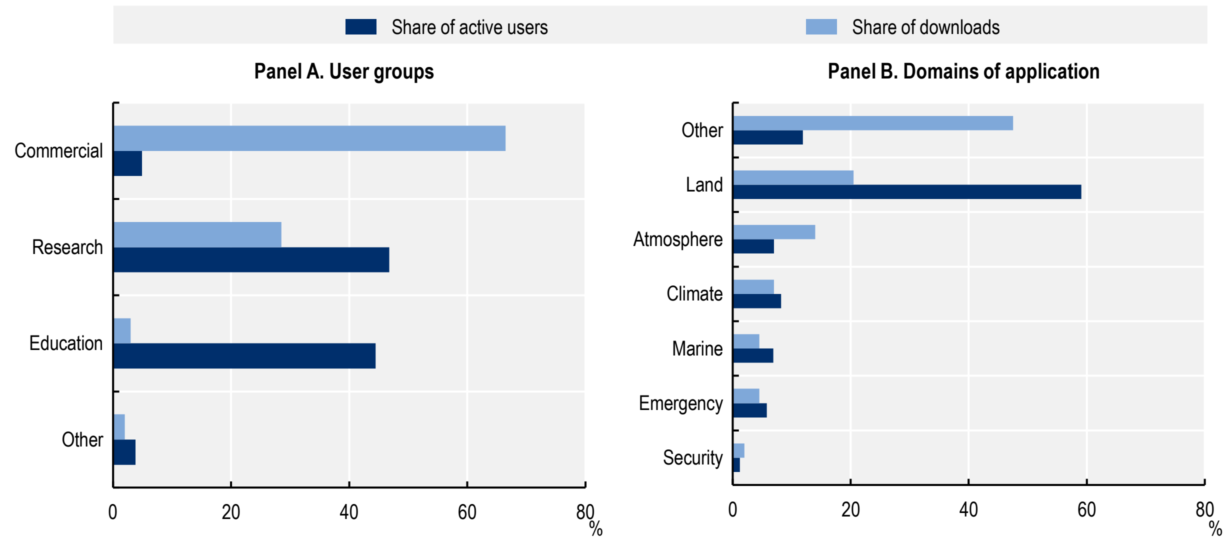
Public space organisations have promoted the use of space technologies for addressing environmental challenges for years, and although detailed download statistics are an important first step, we need to learn more about the actual uptake in the different user communities, as well as the most important barriers to further technology adoption. The following paragraphs look at the types of statistics that track the usage of earth observation data, before highlighting important policy implications.

User statistics from the Copernicus and Landsat programmes show that education and research communities account for the highest number of registered users Figure 2.5). However, they do not necessarily account for the highest number of downloads. In Europe, commercial users account for 67% of the number of Copernicus downloads (out of a total of 185.7 million user downloads and 80 pebibytes (PiB) of data), probably to make the data available on their data platforms for other users further along the value chain (Serco, 2022[72]).

In the United States, the USGS keeps track of Landsat downloads from its EarthExplorer platform, with science and education users accounting for the highest number of user profiles and downloads (in file size), as shown in Figure 2.6 (USGS, 2023[73]). It is worth noting that Landsat data are also available on other platforms, such as Amazon Web Services' Registry of Open Data, which may attract other (more commercial) user groups.

Figure 2.5. Usage of Copernicus satellite data: User groups and thematic domains

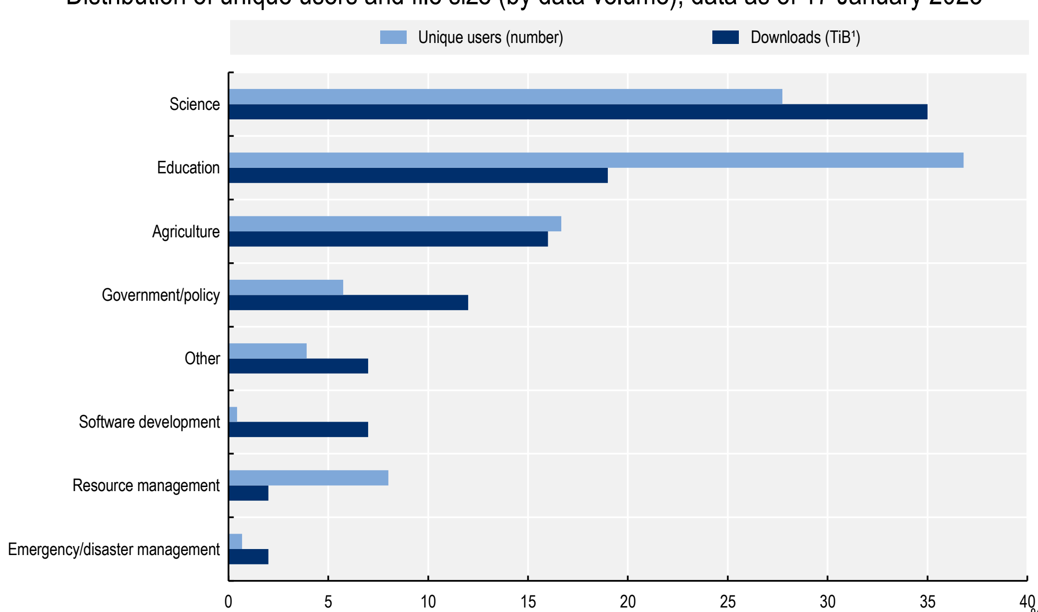
Percentages of active users and downloads (by number). Data for 2021



Note: The "Other" thematic domain probably includes commercial mass downloaders, replicating the data collection on their infrastructure.
Source: Serco (2022[72]), "Copernicus Sentinel Data Access Annual Report Y2021", https://scihub.copernicus.eu/twiki/pub/SciHubWebPortal/AnnualReport2021/COPE-SERCO-RP-22-1312_-_Sentinel_Data_Access_Annual_Report_Y2021_merged_v1.0.pdf.

Figure 2.6. Users of Landsat data

Distribution of unique users and file size (by data volume), data as of 17 January 2023

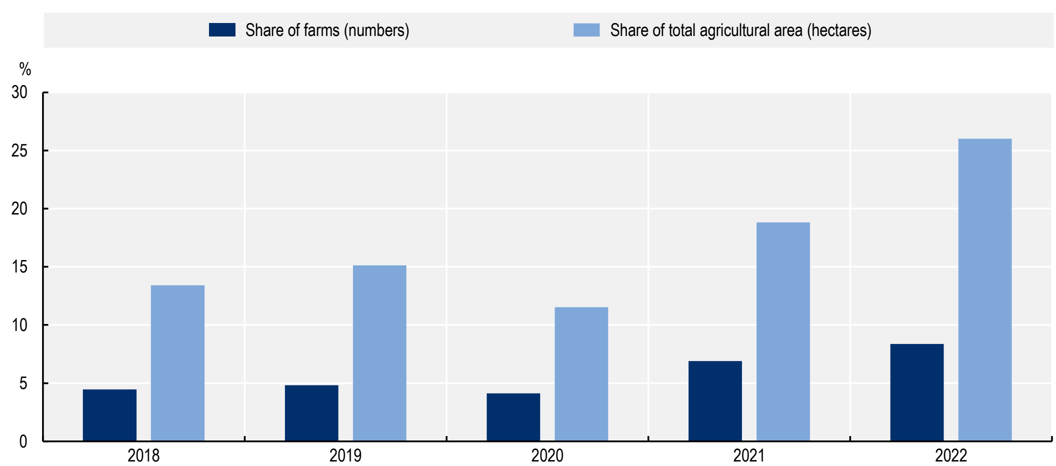


Source: USGS (2023[73]), "Landsat project statistics", https://www.usgs.gov/landsat-missions/landsat-project-statistics.

What about data on sectoral uptake? This type of information is available for agriculture in Denmark (Figure 2.7). Agriculture is sometimes identified as one of the most promising areas of application for earth observation data, because of the opportunities it offers to better assess and monitor crop health and calibrate the use of inputs (water, fertilizer, pesticides) (see EARSC (2023[31]) and Euroconsult (2018[74])), and having high-quality statistics on uptake is therefore very valuable. Statistics Denmark has included questions on the combined usage of satellite/drone imagery and precision technology in their annual Agricultural and Horticultural Survey addressed to individual farms (2022[75]). While the use of precision technology is relatively common (used by 37% of farms, covering 77% of the total agricultural area), the reported use of satellite and drone/imagery is much rarer, with 8% of farms reporting this practice, covering 26% of total agricultural area. There has still been a notable increase since 2018.

The reliance on satellite/drone imagery for agriculture may be higher than the data indicate given that the use of space technologies may be more widespread among agricultural co-operatives and consultancies than among individual farms.

Figure 2.7. Use of photos from satellites/drones on Danish farms



Source: Statistics Denmark (2022[75]), *Agricultural and Horticultural Survey 2022*, https://www.dst.dk/en/Statistik/dokumentation/documentationofstatistics/agricultural-and-horticultural-survey.

Figures 2.5, 2.6 and 2.7 provide important evidence on uptake but also reveal important knowledge gaps about commercial users and usages at the *mid-stream level* of earth observation value chains. It would be useful to better pinpoint how commercial users exploit earth observation data and how they generate value for commercial users (e.g. beyond basic data provision, such as providing de facto standards for calibration). This would better inform government efforts to promote the use of space-based remote technologies data to third-party user groups and domains and identify potential benefits. For instance, the US National Strategy to Develop Statistics for Environmental Economic Decisions (2023[76]) expects a growing future role of space-based data when it comes to measuring natural assets (e.g. thanks to improved spatial resolution).

Beyond monitoring uptake, more needs to be learned about challenges to uptake, to understand whether they are technical, cultural, financial, etc., and at which level of decision making these challenges could be addressed.

Melo et al (2023[77]) have looked at the use of satellite-based global-scale maps in national greenhouse gas inventories submitted to the United Nations Framework Convention on Climate Change (UNFCC). The authors found that such maps are only rarely used, despite considerable efforts by both national and international actors to launch dedicated satellite missions, improve the accuracy and relevance of data products and facilitate their dissemination and processing (as described earlier in this chapter). Possible explanations include inadequate spatial and temporal resolution (land cover maps with spatial resolutions coarser than typical national level area definitions of 5 000-10 000 m^2 were never used in country submissions); furthermore, satellite data products only rarely met the requirements of consistent annual measurements over 10-15 year reference periods (Melo et al., 2023[77]). On a more positive note, the uptake of satellite products was higher in countries with lower forest monitoring capacity.

The United Nations Economic Commission for Europe carried out an in-depth review of satellite imagery/earth observation technology in official statistics in 2019 (UNECE, 2019[78]). The review found that earth observation inputs are commonly used to support agricultural statistics and environmental accounts, with an increasing level of activity in the area of sustainable development indicators such as land use, climate change, water stress and water quality. Macro-level collection and reporting were listed as the key strength of this type of data, well suited to agriculture and environment statistics, as well as reporting on the target indicators of several Sustainable Development Goals. However, several statistical agencies warned about overestimating the potential of earth observation data (ignoring the need for calibrating them against other datasets) and underestimating the needed investments in infrastructure to fully support data processing, interpretation and analysis.

Gaps in spatial and temporal coverage in existing data products for agricultural monitoring, to better cover key areas and at critical periods in the growing season, are also highlighted by the requirements of the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) for agricultural information products, in addition to better access to synthetic aperture radar products (CEOS, 2019[79]). In 2022 the first version of a set of 'Essential agriculture variables' was released, aiming to provide actionable information on the state, change, and forecast of agricultural land use and productivity (GEOGLAM, 2023[80]).

The development of product requirements (or essential variables) in close collaboration with user communities seems like a useful step to increase technology adoption. However, in several cases, other factors, which are outside the reach of space agencies and mission planning, may play a more important role, e.g. the financial resources of organisations to make the necessary infrastructure investments, access to reliable internet broadband to access cloud-based services and process data, the availability of adequately trained staff, access to *in-situ* data etc. (Cerbaro et al., 2020[81]; Burke et al., 2021[82]; CEOS, 2019[79]).

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3 Managing a growing space economy

To maximise the potential of space-based services in tackling global challenges, the orbital environment needs to remain accessible for multiple users and future generations. This chapter tracks recent and significant changes in the use and distribution of resources such as orbital slots and the electromagnetic spectrum and discusses how this could affect the vitality of the space innovation ecosystem and future growth.

Introduction

As described in the previous chapters, space technologies and space-based infrastructure have today unprecedented potential to contribute to managing global challenges. However, for this to happen, existing barriers to entry to space must be further lowered, and a healthy level of competition between actors needs to be maintained, to ensure that the benefits of space activities are distributed as widely as possible.

Space is unlike any other natural environments accessible to humankind. Parallels are sometimes drawn with airspace or the high seas, but space is in most aspects unique, in terms of difficulty of access, remoteness, size, and strategic and geopolitical significance. As a result, doing business in space is generally expensive, technologically challenging, risky and associated with a significant amount of government regulations and red tape.

These elements have shaped the space industry in OECD countries, traditionally characterised by a limited number of private firms working alongside government agencies, with strategic technologies and knowhow controlled by national interests (Undseth, Jolly and Olivari, 2021[1]). After decades of government-controlled activities, the first wave of 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 appeared (and crashed) as part of the dot.com bubble towards 2000, followed by the first commercial or public/private earth observation missions (Undseth and Jolly, 2022[2]).

The current phase of commercial investments took off in the early 2010s, closely linked to the growth of the "new space" ecosystem described in Chapter 1 and boosted by product innovations reducing the costs of access to space, government policies favouring commercialisation and improved access to equity finance (OECD, 2023[3]). At the same time, a growing number of economies are mastering sophisticated space technologies. All this has led to unprecedented levels of launch frequency and orbit occupancy.

Although space is vast, there are definitive first mover advantages in occupying specific orbital slots or electromagnetic frequencies, which can then be renewed indefinitely. There can also be other economic or military advantages (McClintock, Langeland and Spirtas, 2023[4]). All this is leading to several ongoing "space races" – between countries and between conflicting commercial interests – not only for orbital space and the electromagnetic spectrum but also for space "real estate" on celestial bodies, all of which have knock-on effects on launch activity and capacity.

As a result, policymakers have several issues to consider:

- How to balance the efficient use of resources with equitable access, not only from a socio-economic and geographic standpoint but also for future generations?
- How to optimise innovation performance, entrepreneurship, and intensity of competition in the space sector?
- How to address resource extraction and property rights in space?

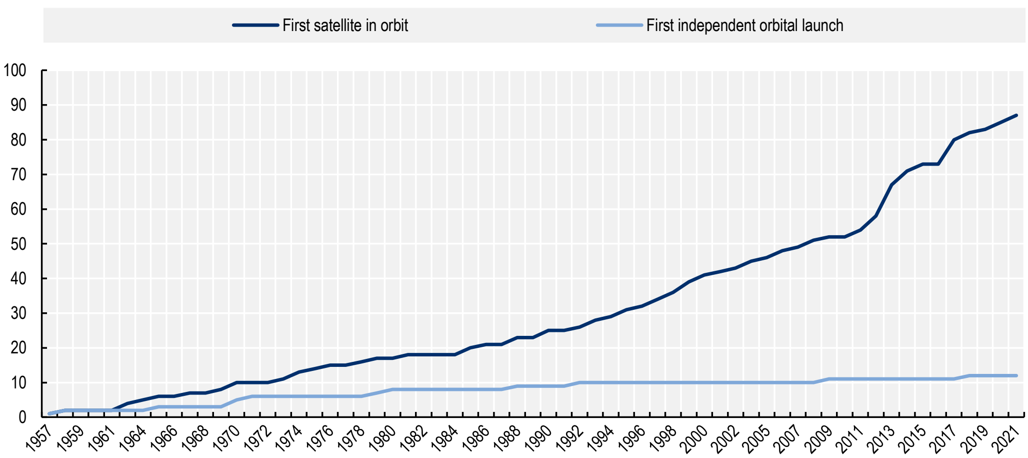
This chapter looks at recent trends in accessing and using the space environment and discusses these questions in greater detail.

An increasingly diverse population of space actors with growing capabilities

One of the key legacies of "new space" is the democratisation of space technologies and resource exploitation, both in the geographic sense and from a user perspective, thus maximising the potential gains of space exploitation. There are more opportunities for small, innovative actors, such as universities and start-ups, and commercial operators now dominate in both the geostationary and low-earth orbits (UCS, 2023[5]).

Figure 3.1. Almost 100 countries having had a satellite in orbit

Number of countries with a first satellite in orbit (launched via a third party or independently between 1957 and November. 2023)



Source: Updated from OECD (2022[6]), *OECD Handbook on Measuring the Space Economy, 2nd Edition*, http://doi.org/10.1787/8bfef437-en.

Furthermore, geographic diversity has never been higher. By late 2023, almost 100 countries on four continents had operated a satellite at some point in time, with a distinct jump after 2012 (Figure 3.1). Lower-income countries are also better represented than before, with 12 new lower-middle and two low-income countries having operated their first satellite since 2012 (UCS, 2023[5]).

This diversity is also reflected in exploration and science missions, with increasingly ambitious projects pursued by emerging and commercial actors (see Table 3.1).

Table 3.1. Selected "firsts" in lunar exploration

Years of first successful missions. Selected unsuccessful attempts are in brackets

Country/region	Flyby	Orbiter	Impactor	Lander	Robotic sample return	Rover	Crewed lander
United States		1966	1964	1966		1971	1969
Russia/USSR	1959	1966	1959	1966	1970	1970	
Japan	1998	1990		(2022)		(2022)	
Europe		2003					
China		2007		2013	2020	2013	
India		2008	2008 (first to impact on the lunar South Pole)	2023 (first to land in the lunar polar region)		2023	
Luxembourg	2014						
Israel				(2019) First privately funded lander mission			
Italy	2022						
Korea		2022					
United Arab Emirates						(2022) Lost with Japanese lander	

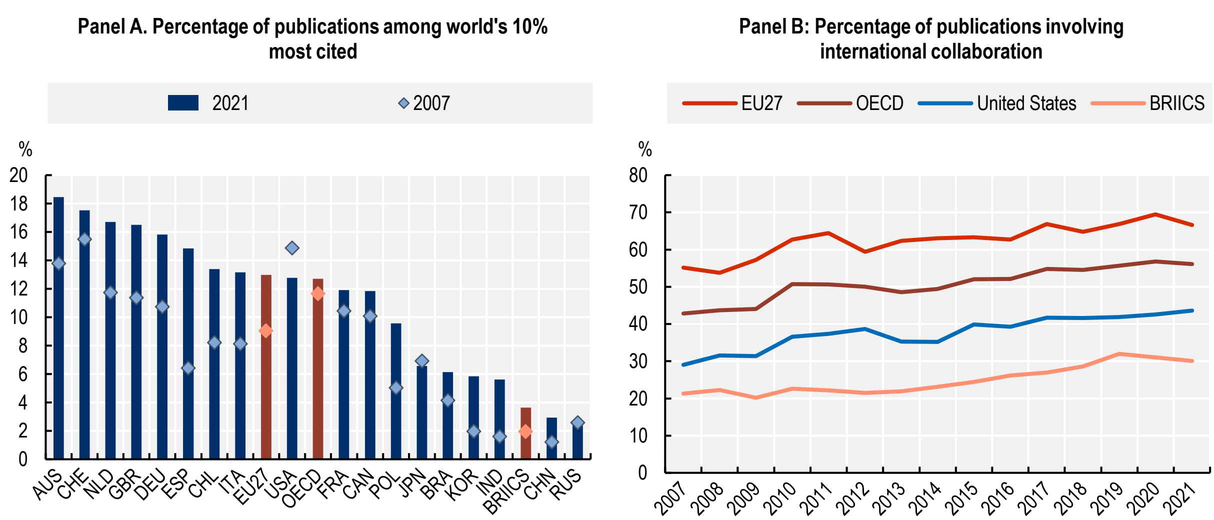
Take for example lunar exploration, where several newcomers have launched independent missions or contributed landers and rovers in the last two decades. The strategic objectives of these actors are mixed, including prestige, science, technology demonstration and the preparation of steps for further exploration and resource exploitation. India’s 2009 mission found traces of water on the lunar poles, which spurred additional research efforts in the following years.

Japan was the first country after the United States and the Russian Federation [hereafter ‘Russia’]/USSR to carry out a successful mission to the Moon (orbiter) in 1990. The European Space Agency, the People’s Republic of China [hereafter ‘China’] and India followed in 2003, 2007 and 2008, respectively. A Luxembourg flyby mission was successfully launched by a Chinese spacecraft in 2014, while Israel had an unsuccessful landing attempt in 2019 – this was the first-ever privately funded lunar lander mission. Also in 2019, the Chinese Chang’e 4 spacecraft made a historic first landing on the “dark side” of the Moon, a technological feat requiring a relay satellite and considerable system autonomy, as the lunar surface blocks the line-of-sight and direct communication lines with Earth. In 2022 there were missions by three country newcomers: Italy, Korea and the United Arab Emirates, as well as several commercial participants in NASA’s Commercial Lunar Payload Services programme. The Emirate rover was lost with its (commercial) Japanese landing craft.

Established actors are also taking a renewed interest in the Moon. The US Artemis programme, including both robotic and human exploration, was launched in 2017. Russia launched a lunar mission in 2023 for the first time in 45 years (which failed) and is planning a crewed mission by 2030, as are the United States and China.

Figure 3.2. Greater geographic spread in scientific excellence in space and planetary science

Citations (left panel) and international co-authorships (right panel) in scientific publications



Notes: For countries with 100 or more scientific publications in 2021, fractional counts. Publications are attributed to countries based on the authors’ institutional affiliations. BRIICS: Brazil, Russia, India, Indonesia, China and South Africa.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

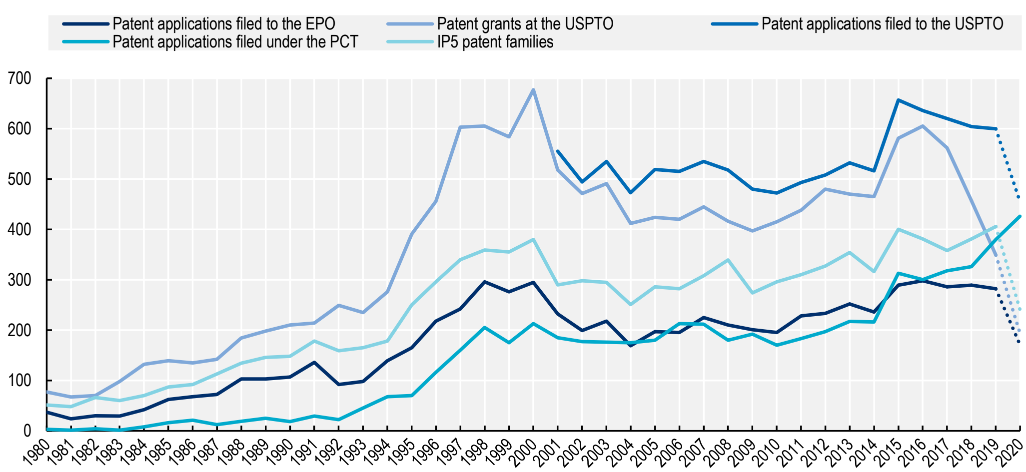
As for the exploration of Mars, the European Space Agency became the third country/country grouping with a successful Mars orbiter mission in 2003 (the accompanying lander, Beagle-2, failed), after the United States and Russia, and was followed by orbiters of India (Mars Orbiter Mission orbiter in 2013) and the United Arab Emirates (Hope, 2020). China had its first successful Mars mission in 2021, including an orbiter, lander and rover, making it the second country to successfully deploy a rover on Mars. Japan plans a mission in 2024 to explore Mars' moons, including a sample return. The European ExoMars Rosalind Franklin mission, including the first European rover on Mars, is currently scheduled to launch in 2028, after delays caused by COVID-19 and the war in Ukraine. Meanwhile, NASA's Ingenuity helicopter, part of its Mars 2020 mission, had completed more than 50 flights by 2023 and is the first aircraft to achieve powered, controlled flight on a different planet.

In astronomy and astrophysics, the US James Webb telescope, with contributions from Canada and Europe, was finally launched in 2022 and has already produced imagery of unprecedented detail. Other space-based telescopes from Japan (XRISM) and Europe (Euclid) will be launched in 2023. China's Xuntian telescope is scheduled for launch in 2024.There are also several recent and future missions to study the Sun and the heliosphere, such as the US Parker Solar Probe and the Chinese ASO-S observatory launched in 2022.

Finally, several powerful Earth-based observatories were near finalisation in 2023, including the optical/near-infrared Extremely Large Telescope in Chile, operated by the European Southern Observatory, and the Square Kilometre Array in Australia and South Africa, a network of thousands of antennas simulating one giant radio telescope. It is worth noting that the increased number of satellites in low-earth orbit leads to more light pollution and radio interference, which could be harmful to optical and radio astronomy (more on this in Chapter 4).

Figure 3.3. Evolution of space-related patents

Number of patents, by patent offices and priority date

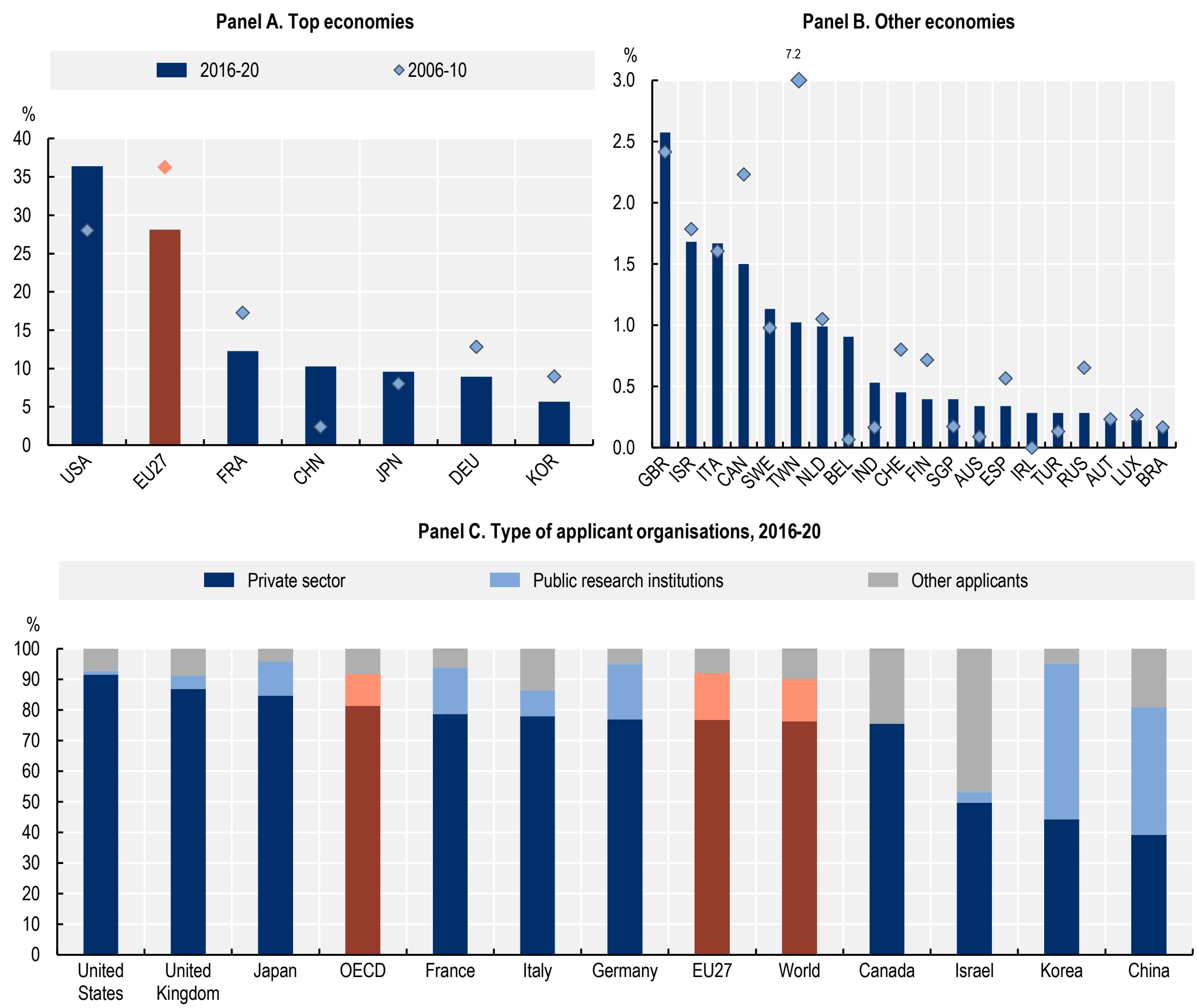


Notes: Partial information for patent applications filed to the EPO and for IP5 patent families from priority year 2019 and partial information on USPTO patents for the latest years. IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO).
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Increased international participation in space activities creates new opportunities further downstream, with new actors intervening now in space sciences and engineering, as well as research and development. Figure 3.2 shows how many countries and economies have seen an increase in their scientific publications that are among the world's top-cited in space and planetary science since 2006 (Panel A). This could, among other things, be linked to the increase in international collaboration and co-authorships (Panel B). Among BRIICS economies (comprising Brazil, Russia, India, Indonesia, China and South Africa), the share of scientific publications in space and planetary science with international co-authors grew from 21% in 2007 to 30% in 2021. In the OECD area, more than half (56%) of scientific publications in this field had international co-authors in 2021. Publications in the European Union had the highest share of international collaboration (67%) among the groups of economies, reflecting the high share of international co-operation in European space activities more generally through the European Space Agency, as well as European participation in US science projects.

Figure 3.4. Patents for space-related technologies per economy

IP5 patent families, by priority date and applicant's location, using fractional counts



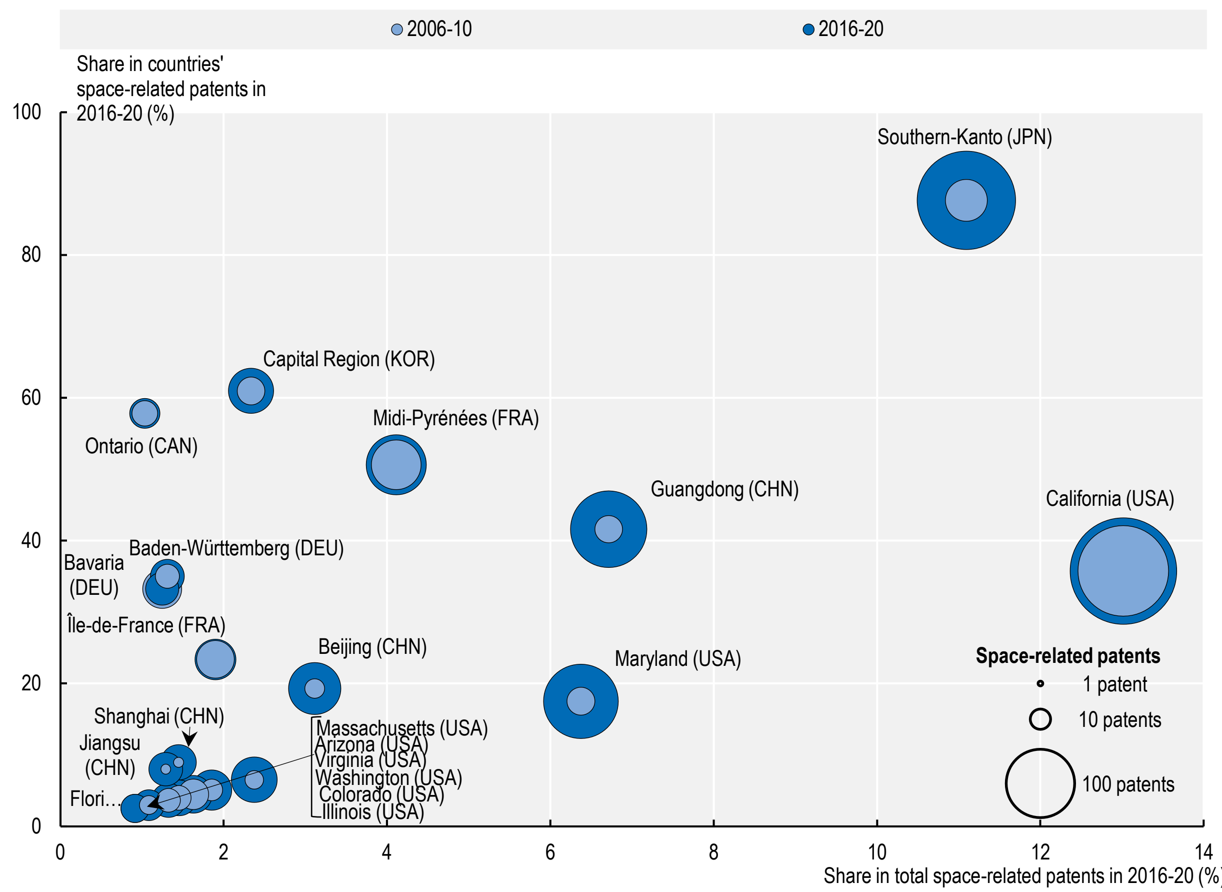
Notes: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Figure 3.3 tracks the number of space-related patent applications filed at patent offices worldwide between 1980 and 2020, reaching some 600 applications to the US Patent Office (USPTO) in 2019, as recorded by OECD analysis based on a combination of keyword and technical category searches (for the full search methodology, see (OECD, 2022[6])). There has been a notable increase in applications in the last 10-12 years (after a post-dot.com bubble slump in the early 2000s), coinciding with the growth in the "new space" innovation ecosystem and the expansion of space programmes in economies such as India and China. Other patent analyses that include national patent filings (giving only domestic patent protection) at the China National Intellectual Property Administration find explosive growth in Chinese space-related patents (Clarke et al., 2021[7]).

The share of applications in "cosmonautics" has grown considerably in the last decade, reaching 38-42% of applications in the 2016-20 period, up from 19-26% in 2006-10. Cosmonautics refer to technologies associated with spacecraft manufacturing, launch and control, such as propulsion systems and structures (Clarke et al., 2021[7]). Meanwhile, the share of applications associated with satellite navigation has more than halved, from 33% of space-related applications filed to the US patent office in 2006-10 to 12.6% in 2016-10.

Figure 3.5. Top 20 regions in space-related patents

Patent applications filed under the Patent Cooperation Treaty (PCT) by inventor's residence and priority date, 2006-10 and 2016-20



Note: Data refers to patent applications filed under the Patent Cooperation Treaty (PCT), by the inventor's region at Territory Level 2 (TL2) and priority date.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

At the national level (Figure 3.4), patenting activity has slowed down in Western Europe and Russia in particular, coinciding with strong growth in China, India and the United States. In the 2016-20 period, the majority of applicant organisations were business firms, but public research organisations accounted for a notable share in several economies, in particular in China and Korea. In addition to business firms and public research organisations, patent applications can also be filed by private individuals, universities and private non-profit organisations, accounting for the "other applicants" category in the figure.

Figure 3.5 shows patent applications at the regional level, notably their share in countries' space-related patents (y-axis) and the total number of space-related patents (x-axis). Patent analysis at this level of granularity reveals important industrial clusters such as the French Southwest (Midi-Pyrénées) and Guangdong in China. In 2016-20, US regions accounted for nine out of the top 20 patent-filing regions, followed by China (4). Four European regions (in France and Germany) were among the top 20 in 2016-20, compared to eight in 2006-10. Other notable regions include Southern Kanto in Japan, Capital Region in Korea and Ontario in Canada, each home to inventors filing the majority of space-related patent applications in their respective countries.

First come – first served with Earth's orbits up for grabs

Strategic competition in space activities is not new; it fuelled considerable innovation activity during the Cold War. However, in the last five years, there have been several profound changes in space launch activity with long-term impacts that are yet to be felt in the space community and beyond. First, in terms of launch frequency and the unprecedented volume of launched objects; second, in launches by country, which has important geopolitical implications; and finally, in the growth of commercial activity, posing new questions about space access and ownership.

Strong growth in launch activity among "new" actors

Whereas a growing number of countries have demonstrated orbital launch capability, China and the United States carried out by far the highest number of launches in 2022. The United States carried out 76 successful launches, followed by China (62) and Russia (21), breaking the record of launches per year (McDowell, 2023[8]).

Most US launches were carried out by a relative newcomer, the private company Space Exploration Technologies Corporation [hereafter SpaceX], which with a record 61 launches accounted for 80% of the US total. US launch activity now surpasses previous peak years in the 1960s and 1990s, as illustrated in Figure 3.6.

China, with its 64 successful launches also set a record in 2022, surpassing the previous one of 48 in 2021. This is part of the country's ambitious space programme, comprising human spaceflight (its space station is completed and inhabited), exploration (it is the second country to successfully land a Mars rover) science, as well as various government applications. In addition, several Chinese commercial actors have emerged since the deregulation of Chinese space activities in 2015 (OECD, 2019[9]). Combined commercial and government launches may surpass 70 in 2023 (Jones, 2023[10]).

New Zealand is a recent addition to the international launch scene. Original home to the US-headquartered firm Rocket Lab, the country carried out nine successful launches from its North Island launch base in 2022.

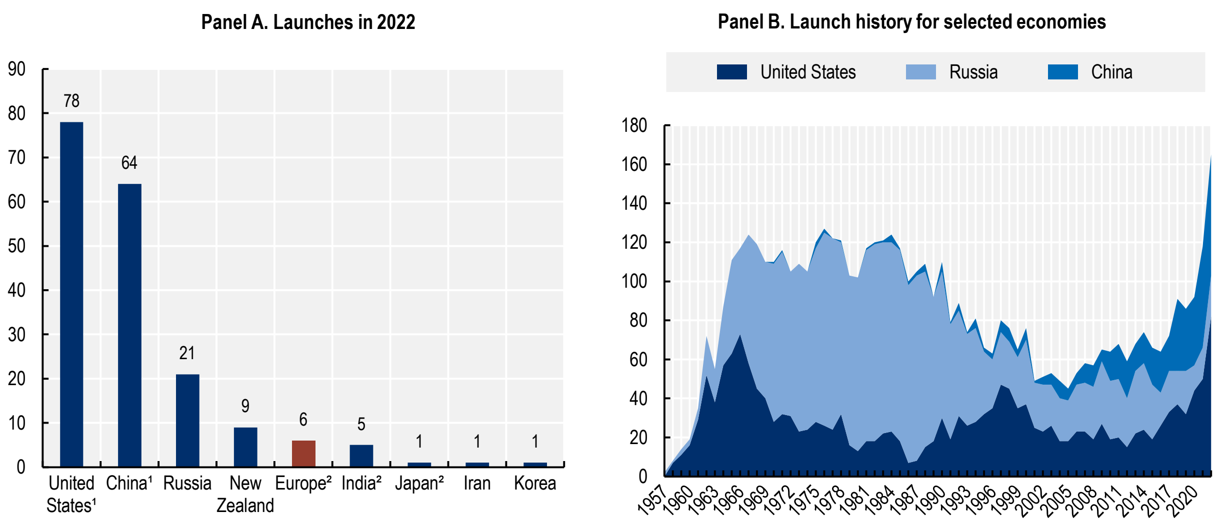
In contrast, Europe, using the Guiana Space Centre in French Guiana, carried out only six launches in 2022, with one launch failure of the new Vega-C in December 2022. In July 2023, Ariane 5 had its final flight, closing a 27-year successful chapter of Europe's access to space. The inaugural flight of Ariane 6 is now expected in 2024. Europe also lost access to the Russian Soyuz launcher following the invasion of Ukraine. As the European Space Agency prepares for Vega-C's safe return after a launch failure, it is proceeding with launch campaigns for the Vega launcher (Vega-C's more lightweight predecessor). In October 2023, Vega mission VV23 successfully lifted off the Guiana Space Centre, carrying Thailand's

THEOS-2 earth observation satellite, Chinese Taipei's FORMOSAT-7R/Triton weather satellite and ten nanosatellites from various operators.

India carried out five launches, including the first flight of the small new satellite launch vehicle SSLV; and the Islamic Republic of Iran [hereafter Iran], Japan and Korea each carried out one launch. Korea's launch was the first successful attempt of the new domestic Nuri launch vehicle to reach orbital velocity after a failure in 2021.

Figure 3.6. Recent and longer-term orbital launch trends

Number of launches



1. Includes two launch failures, 2. Includes one launch failure.
Sources: McDowell (2023[8]), "Space activities in 2022", https://planet4589.org/space/papers/space22.pdf and (US Space Force, 2022[11])

Despite this diversity of players, just two countries – the United States and China – currently dominate launch activities, the bulk of which is devoted to the deployment of commercial broadband services (see Chapter 1). These satellites, while weighing more than 100kg, are still considered "small" and can be stacked within the launch vehicle and sent into orbit in batches, 40-50 satellites at a time.

Renewed interest in launch opportunities across the world

The intensified use of the low-earth orbit with constellations of dozens, hundreds or thousands of satellites that need to be regularly launched and replaced (see Chapter 1), is considerably expanding the potential market for launch services. The result has been a marked growth in commercial launcher developments in the last five years.

A growing number of countries (or regional authorities) also seek to develop spaceports to exploit a favourable geographic location and to get a share of this new economic opportunity.

Ever more spaceports

Between 2018 and mid-2023, 11 economies/regions have demonstrated orbital launch capabilities from one or several facilities: Six with only domestic (and mainly government) launches (Islamic Republic of Iran, Israel, the Democratic People's Republic of Korea, Korea, Japan and the Russian Federation) and five with both domestic and international customers: China, India, Europe (in French Guiana), New Zealand and the United States.

Several countries on four continents are planning new or extending existing spaceports or military/scientific facilities, thus exploiting distinct geographic advantages such as latitude, stable weather conditions, and an east-facing, coastal and/or sparsely populated location. Locations near Equator are generally favourable for most launches, in particular to the geostationary orbit and interplanetary missions, due to Earth's ellipsoidal shape (bulging at the middle), which increases rotational speed and gives additional momentum at launch. However, for several low-earth orbits (e.g. polar orbits, certain sun-synchronous orbits) and high-elliptical orbits, higher-latitude launch sites may be interesting.

In the Americas, the United States had 13 spaceports and launch/re-entry sites across nine federal states in 2023, including three for exclusive use by launch vehicle manufacturers SpaceX (2) and Blue Origin (FAA, 2023[12]). In Canada, the government announced in 2023 its intention to create a regulatory licensing framework for commercial launches (Transport Canada, 2023[13]). A spaceport is under construction in Nova Scotia. Meanwhile, Brazil is trying to attract international customers to its equatorial Alcântara Space Center (which is not yet operational for orbital flights). A Korean start-up carried out a suborbital launch at the site in 2023, and Brazil and the United States entered a technology safeguard agreement in 2019, which allows for US-licenced satellites or space vehicles to launch from Alcântara (US Department of State, 2019[14]).

In Western Europe, in addition to the existing equatorial Kourou Space Centre in French Guiana, some six countries (Germany, Norway, Portugal, Spain, Sweden, and the United Kingdom) are developing or considering commercial spaceports and building partnerships with different launch providers. In January 2023, the first orbital launch attempt from Western Europe (from Spaceport Cornwall, United Kingdom) failed, while another test flight, this time from the Andøya Space Centre in northern Norway, is also scheduled for 2023. This Norwegian launch site was officially opened in the second half of 2023.

In Asia, both China and India are strengthening their capabilities to attract commercial customers, both domestic and international. China opened for private space activities in 2014 and is building a new commercial launch facility next to its Wenchang spaceport, with activities set to commence in 2024 (Jones, 2023[15]). India has made several reforms in 2019/2020, enhancing the mandate of its NewSpace India Limited (NSIL) undertaking to commercialise Indian space services (including launch) and create the Indian National Space Promotion and Authorisation Centre (IN-SPACe) for facilitating private sector participation (ISRO, 2023[16]). India launched its first privately-made space rocket Prarambh (to 89.5km suborbital altitude) in 2022. In Southeast Asia, both Thailand and Viet Nam are studying the feasibility of domestic spaceports. In 2023, Thailand and Korea signed an implementation agreement for studying the feasibility of a Thai spaceport (Kim, 2023[17]), while private firm ThaiHoldings is considering building a spaceport for tourism on the Vietnamese island Phu Quoc by 2026 (Inoue and Shiga, 2023[18]).

Finally, in Oceania, New Zealand launched its first satellite in 2017 and is one of the spaceports of the operator Rocket Lab (which also has US operations). Australia launched its first satellite in 1967 and has multiple projects underway, including in the Northern Territory, Queensland and South Australia (BryceTech, 2023[19]).

A growing number of dedicated launchers for nanosatellites

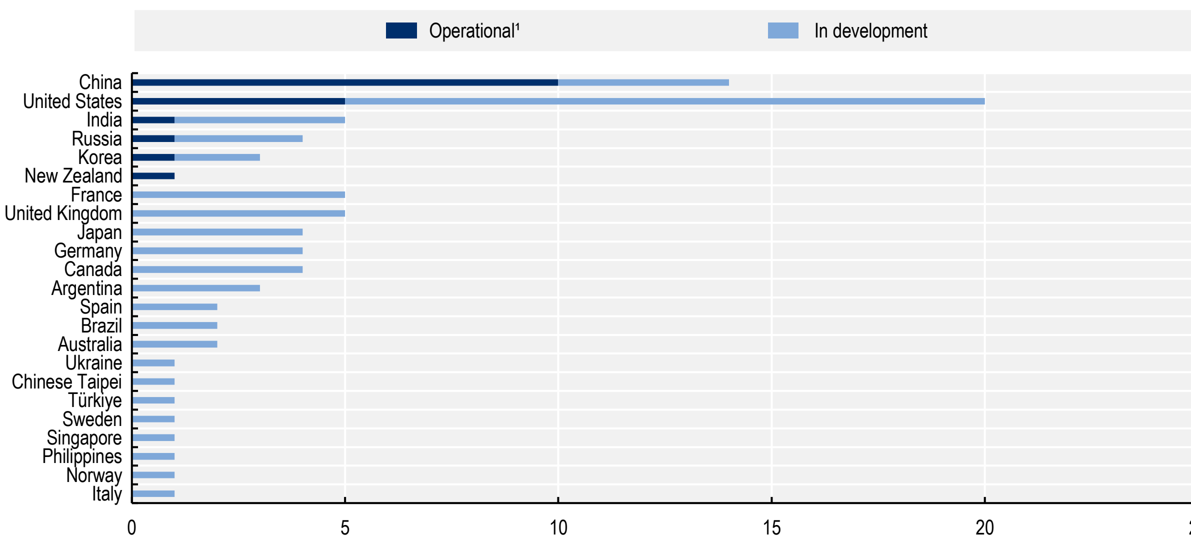
In close connection to the development of spaceports, a remarkable number and variety of small launchers specifically dedicated to the low-earth orbit market are currently being developed (Kulu, 2023[20]). Projects range from purely government-backed to fully privately-funded, some employing airborne launch systems while others launch vertically (including one using a catapult) with different degrees of reusability; and some in their very early stages while others have 100+ employees and have raised several hundred USD million in venture capital. About 19 rockets have been launched at least once, while at least another 60 launchers are in various stages of development – counting only those to be launched by 2030.

In Western Europe alone, there are at least 19 projects from France (5), Germany (4), Italy (1), Norway (1), Spain (2) and the United Kingdom (5) (Kulu, 2023[20]), as shown in Figure 3.7.

These projects fit into a broader ecosystem of actors exploiting the opportunities of low-earth orbits, with multiple nanosatellite operators and a growing number of spaceports at multiple locations (see the previous section). The objective is to provide flexible launch opportunities (compared to today's situation where it may take several months if not years to book a slot on a suitable launch). This applies particularly to actors with limited nearby launch options, such as those that are based in Europe.

Figure 3.7. Selected microlauncher projects

Number of launchers, data as of 01 January 2023



Notes: Microlaunchers" have a maximum launch capacity of 1 500 kg to sun-synchronous orbit (SSO); 1. Operational launchers have carried out at least one launch attempt (successful or unsuccessful).
Source: Adapted from Kulu, (2023[20]), "Small satellite launchers", *NewSpace Index website*, www.newspace.im/launchers.

However, competition will be fierce from medium and heavy-lift launchers capable of launching several dozens of satellites at the same time (i.e. providing "rideshare" services). Both SpaceX's Transporter rideshare programme and the Indian Polar Satellite Vehicle have launched more than 100 very small satellites (or payloads) in one go. In China, the China Great Wall Industry Corporation, which is the international and commercial branch of the China Aerospace Science and Technology Corporation (CASC), performed its third commercial rideshare mission in January 2023.

Growing pressure on medium- and heavy-lift launchers

The coming years' deployment of mega-constellations will rely on medium- and heavy-lift launchers capable of carrying up to 20 000 and 50 000kg to orbit, respectively, but supply is uncertain as legacy launchers are retiring and new projects face delays. The war in Ukraine is also limiting the use of Russian launchers and launch services internationally (Undseth and Jolly, 2022[2]).

As it stands, three reliable launchers, the European Ariane 5 launcher, US Atlas V and Japanese H-2A retired in 2023 or are set to retire towards 2025. Their replacements, European Ariane 6 and US Vulcan Centaur are scheduled to have their first flight in 2024. Several US commercial launchers are scheduled to enter the market in 2024 (Table 3.2).

In Japan, the H3 rocket had a failed launch attempt in March 2023. The Indian Space Research Organisation (ISRO) has also announced the eventual retirement and replacement of its Polar Satellite Launch Vehicle by a next-general launch vehicle without giving a specific end date, with private industry able to continue the production if there is commercial demand (The Hindu, 2022[21]).

Table 3.2. Medium- and heavy-lift launchers

Country	Organisation	Launch vehicle and first flight		Launcher category	Launch capacity
		Operational	Under development (early 2023)		
United States	United Launch Alliance	Atlas V (2002, retiring)			
		Delta IV Heavy (2004)		Heavy	28 790kg
			Vulcan Centaur (2024)	Heavy	25 000kg
	SpaceX	Falcon 9 Full Thrust (2015)		Heavy	22 800kg
		Falcon Heavy (2018)		Heavy	38-45 000kg
	Blue Origin		New Glenn (2024)		45 000kg
	Relativity Space		Terran R (2024)	Medium	20 000kg
	Rocket Lab				
China	China Academy of Launch Vehicle Technology	Long March 5/5B (2016)		Heavy	25 000kg
Russia	Khrunichev		Proton M (2001)	Heavy	23 000kg
		Angara-A5V (2014)		Heavy	38 000kg
Japan	Mitsubishi Heavy Industries	H2A (retiring)			
			H3		
India	ISRO		HLV (under consideration)	Medium	20 000kg
			SHLV (under consideration)	Heavy	41 300kg
Europe	ArianeGroup	Ariane 5 ECA (2002, retiring 2023)		Heavy	
			Ariane 6 (2024)	Heavy	21 650kg

More heavy-lift launchers to support exploration and space infrastructure development

With the low-earth orbit increasingly dominated by commercial activity, several governments have ambitious plans for crewed space exploration and space infrastructure expansion. This requires powerful rockets, so-called “superheavy” or super heavy-lift launchers that can carry more than 50 000kg to orbit (Table 3.3). Launchers in different stages of development include NASA’s Space Launch System (first launched in 2022), which will be instrumental in deploying the agency’s Artemis programme for lunar exploration, and the Lunar Gateway space station that will orbit the Moon; SpaceX’s Starship, destined for exploring Mars by the end of the decade (another US company, Relativity Space, has announced plans to reach Mars with its Terran R launcher in 2024). Europe will eventually roll out its Ariane 6 launcher in 2024 and China plans several heavy-lift launch vehicles by 2030.

In addition to a dramatically increased ability to transport heavy and voluminous objects, these launchers are expected to bring down launch costs, as discussed in Chapter 1. Applications of superheavy launchers include the possibility to deploy entire constellations of small satellites in one single launch; or to carry larger space infrastructures, instruments and systems (e.g. space stations, solar power stations). They could also support other experimental activities mentioned in Chapter 1, such as in-space manufacturing and, eventually, point-to-point suborbital travel.

Table 3.3. Selected super heavy-lift launch vehicles

Country	Organisation	Launch vehicle and first flight		Launch capacity
		Operational	In development (early 2023)	
United States	National Aeronautics and Space Administration	Space Launch System (2022)		95 000kg (Block 1)/ 105 000kg (Block 1B)/ 130 000kg (Block 2)
	Space X		Starship (2024)	150 000kg
China	China Academy of Launch Vehicle Technology		Long March 10 (2027)	70 000kg
			Long March 9 (2030)	150 000kg
Russia	JSC SRC Progress		Yenisei (2028)	103 000kg

Orbit occupancy is becoming more diverse and commercial, but also more concentrated

The lowering of launch costs has to a certain extent democratised access to space and attracted the interest of commercial actors.

Figure 3.8. Selected economies' share of operational satellites

Share (%) and number of operational satellites in orbit, as of 31 December 2022

1. ESA=European Space Agency.
Source: Union of Concerned Scientists, "UCS Satellite Database: 01 January 2023 update", https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database, data accessed 07 August 2023.

As a result, upper-middle income economies now account for 13% of operational satellites (mainly from China and Russia), while 100 operational satellites (or 1.9%) belong to low- and lower-middle income economies, as recorded by the satellite database of the Union of Concerned Scientists (2023[5]). This latter group includes most notably India, but also more recent space-faring economies such as Bangladesh and Ethiopia.

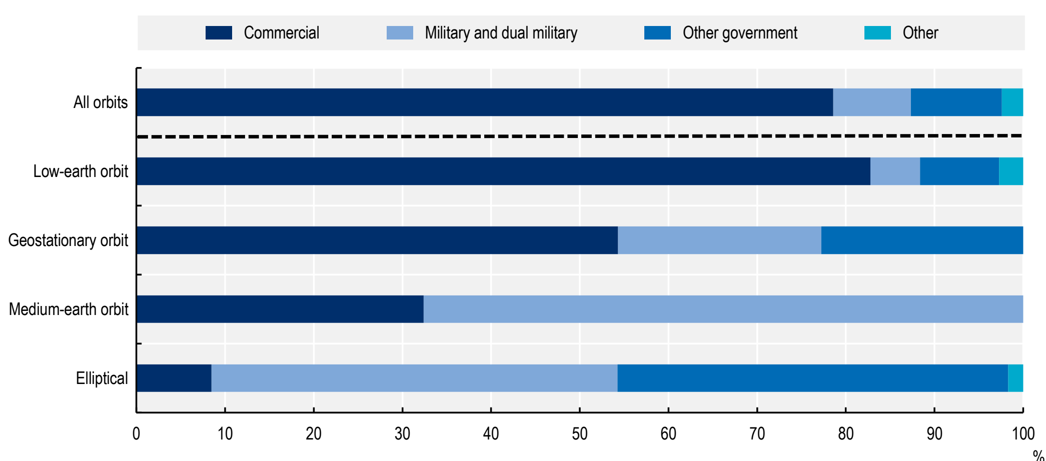
Still, big and mainly high-income economies remain the most important actors. As of the end of 2022, the United States accounted for more than 67% of the 6 700 operational satellites in orbit, followed by China (8.8%) and the United Kingdom (8.4%) (UCS, 2023[5]), as is shown in Figure 3.8.

As for the distribution of public and private applications, the satellites of commercial operators dominate in the low-earth and geostationary orbits (Figure 3.9), while government missions have a stronger presence in medium-earth and elliptical orbits.

The rollout of mega-constellations for satellite broadband in the low-earth orbit is leaving its marks. Two operators, SpaceX (United States) and OneWeb (United Kingdom) accounted by the end of 2022 for 74% of all operational commercial satellites. This is likely to even out somewhat when other operators start deploying their constellations (see Section on satellite telecommunications in Chapter 1). Still, first movers have important advantages in terms of slot occupancy, something that will be discussed in the next section.

Figure 3.9. Public and private uses of Earth's orbits

Breakdown of operational satellites by type of operator and orbit. Data as of 31 December 2022



Note: Military and dual military include fully military satellite missions, as well as military-civil, military-government and military-commercial, or a combination of the three.
Source: Union of Concerned Scientists (UCS, 2023[5]), "UCS Satellite Database: 01 January 2023 update", https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database, date accessed 07 August 2023.

Growing competition for orbital slots and frequencies

Space is big, but the demand for specific orbits or slots can surpass supply. Congestion is particularly dire in the geostationary orbit at 35 786 kilometres altitude, where satellites occupy a single ring above the Equator and where the most coveted slots (near specific terrestrial longitudes) are filling up quickly (Ogden, 2022[22]). The geostationary orbit is home to many commercial telecommunications satellites, but it also has important applications in meteorology and air traffic management.

The low-earth orbits have more available space, but also here some orbits are more advantageous than others, for example as regards proximity to Earth and latency of signals (NAPA, 2020[23]), revisit periods, etc.

The allocation of electromagnetic spectrum and access to orbits is managed by the International Telecommunication Union (ITU) at the international level and by various government agencies at the national level, such as the US Federal Communications Commission (FCC), UK communications regulator Ofcom, the Norwegian Communications Authority (Nkom), and so on. Two main principles guide these efforts: efficient use and equitable access (ITU, 2023[24]). Equitable access to resources for future use is ensured by *a priori* planning procedures, which include

- the Allotment Plan for the fixed-satellite service using part of the 4/6 and 10-11/12-13 gigahertz frequency bands (see Box 3.1 for an overview of satellite frequency bands)
- the Plan for the broadcasting-satellite service in the frequency band 11.7-12.7 gigahertz
- the associated Plan for feeder links in the 14 gigahertz and 17 gigahertz frequency bands.

The efficient use of existing resources is ensured by co-ordination procedures, notably

- advance publication and coordination procedures for geostationary-satellite networks (in all services and frequency bands) and non-geostationary-satellite networks in certain frequency bands governed by the No. 9.11A procedure
- an advance publication procedure before the notification for other non-geostationary-satellite networks (all pertinent services and certain frequency bands).

Box 3.1. Satellite frequency bands

The frequencies of the radio spectrum range from tremendously low (1-3 hertz) to tremendously high (300-3 000 gigahertz). Satellites use the 1-40 gigahertz super-high frequency portion of the spectrum to transmit signals, with bands designated by letters. For instance, navigation satellites use the L-band, with radio waves that can penetrate clouds, rain and vegetation (but not concrete buildings).

With the growth in space activities, these bands are in increasingly short supply, and congestion has become a significant issue in the lower frequency bands (e.g. the C-band). Higher frequency bands can give access to wider bandwidths but are also more susceptible to signal degradation (signals absorbed by rain, snow or ice). New technologies are being investigated to find ways to use even higher bands, within the extremely high frequency area of the spectrum, such as Q- and V-bands.

Source: ESA (2023[25]) "Satellite frequency bands", https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Satellite_frequency_bands.

ITU has taken several measures to make more space available in the geostationary orbit. First, it has made efforts to maximise the efficiency of existing slots, with changes in spacing between satellites from three to two degrees of longitude to make it possible to accommodate more satellite slots (up to 180 from 120) (Holmes, 2008[26]). Other technological advances regard ground station performance, satellites' abilities to exploit available spectrum, etc.

Second, to limit the occurrence of "warehousing" and "paper satellites" where companies file for slots and frequencies to prevent access by competitors, the 2019 World Radio Communications Conference introduced time limits for deployment. It was established that 10% of any constellation in the fixed, mobile, and broadcasting satellite services in the traditional Ku and Ka frequency bands, as well as in the higher

Q- and V-bands, must be in orbit within the first two years after the start of deployment, followed by 50% in five years and 100% in seven years (ITU, 2019[27]).

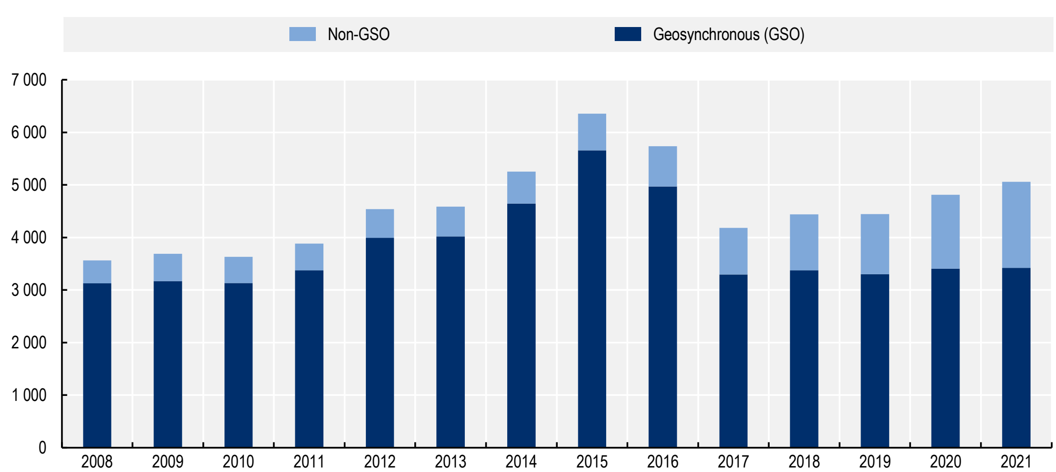
Inequitable distribution of slots and frequencies?

The introduction of measures should ensure more efficient use of Earth's orbits, but there is a risk that this comes at the expense of the access to space of new (small) entrants and lower-income countries. Indeed, there are considerable first mover advantages – slot occupation is free of charge and once operators obtain a slot, they tend to keep it indefinitely by refiling and replacing old satellites with new ones. Newcomers are faced with both technological and economic obstacles, and the regulatory process can be an additional hurdle. Depending on the country and operator, it can take almost a year to get regulatory approval for spectrum allocation (Bernstein, 2022[28]). It is worth noting that several government agencies in OECD countries are making efforts to simplify and accelerate this process, e.g. the Federal Communications Commission in the United States (Rainbow, 2023[29]).

Furthermore, policies that set time limits between filing and launching satellites are accused of being harmful for actors that do not have the technological abilities, knowhow, or capital to deploy satellites within the allotted time, and which are often based in lower-income countries. These actors furthermore tend to rely on specific frequencies (e.g. C-band for areas with frequent and heavy rainfall), that require more expensive and unwieldy equipment (Purity, 2020[30]). In 2020, 31 African countries launched a bid to protect their orbital slots.

Figure 3.10 shows satellite filings in the geosynchronous (geostationary) and non-geostationary orbits in 2022, showing a notable growth in filings for non-geostationary (referred by ITU as geosynchronous) orbits. The drop in filings for geostationary satellites may be linked to decreases in demand for commercial services in this orbit (see Chapter 1), but it may also be linked to the satellite filing restrictions introduced by WRC-2019.

Figure 3.10. Satellite filings by orbit



Source: (ITU, 2022[31]), "TU Radiocommunication Bureau (BR) 2021 Annual Space Services Report to the STSC 2022 Session on the use of the Geostationary-Satellite Orbit (GSO) and other orbits", https://www.itu.int/en/ITU-R/space/snl/SNLReport/SNS-ref-list-2021_e.pdf.

Fears of interference and terrestrial competition for spectrum

There is also the risk of radio frequency interference between satellites in similar orbits, between satellites in different orbits, and with ground stations. Furthermore, terrestrial, and space-based technologies are pitted against each other in the overall distribution of radio spectrum.

The current and planned deployment of communications satellites in the low-earth orbit (LEO) by the thousands is unprecedented, and proposed solutions for avoiding interference are untested. Problems may arise when LEO satellites traverse the signal beam between geostationary satellites and their terrestrial ground stations, and the higher density of satellites in similar orbits may also cause increased interferences between different constellations (Eves, 2021[32]).

There is also growing competition for spectrum from terrestrial operators. One of the items to be discussed during the 2023 World Radiocommunication Conference (WRC-22) is whether to make the upper 6GHz band – currently allocated to fixed satellite services among others – available to new 5G and 6G mobile systems by identifying it for International Mobile Telecommunications (IMT). Mobile telecommunications operators argue that most of the satellite uplink spectrum in C-band is currently not used, and that demand is declining (Euroconsult, 2022[33]). This frequency band is particularly interesting for mobile operators because they should be able to reuse their base stations while shifting from the current 3.7GHz frequency band (Mohyeldin, 2022[34]).

The satellite industry counters that sharing the 6Ghz frequency band with terrestrial operators would increase the risk of harmful interference for several critical space-based services. Affected applications include for instance satellite uplinks for maritime communications, satellite-based navigation augmentation systems and communications with spacecraft for station-keeping and manoeuvring (GSOA, 2022[35]). The upper 6GHz band is also important for radio astronomers, who use it to observe methanol spectral lines, and studies are underway to assess compatibility with mobile telecommunications (CRAF, 2021[36]). Signal interference for radio astronomy is further treated in Chapter 4.

At WRC-23, delegates will further decide whether to allocate additional radio spectrum for earth stations in motion, as well as evaluate progress on spectrum use by non-geostationary satellite constellations and on narrow-band transmissions for the satellite component of the Internet of Things (IoT).

Increased appetite for space-based "real estate" and resources

The intensification of space activities further challenges the principles of space ownership. Article II of the *Outer Space Treaty* (UNOOSA, 1967[37]) stipulates that:

> *"Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."*

It is therefore not possible to make territorial claims in space. *Objects launched into space*, on the other hand, are owned by the launching party or state, which would include satellites most obviously, as well as orbiting space stations and lunar bases, for instance.

What then about resources extracted from space? Ambiguity in international law opens for unilateral action. By 2022, the United States, Luxembourg, the United Arab Emirates and Japan had voted laws concerning resources extracted from celestial objects. In November 2022, Japan granted its first commercial license to ispace, a Japanese company, under the country's Space Resources Act. The license allows ispace to acquire regolith from the lunar surface and sell it to the US National Aeronautics and Space Administration (NASA) through an "in-place" ownership transfer (ispace, 2022[38]). As a result, more commercial actors become increasingly involved in space exploration (e.g. NASA's Commercial Lunar Payload Services initiative had signed up 14 commercial service providers in 2022).

The 1979 Moon treaty tried to address the exploitation of natural resources in space, but India is the only bigger space nation that has signed (but not ratified) the treaty. In May 2020, as part of the Artemis program, NASA announced the Artemis Accords, a set of principles grounded in the Outer Space Treaty of 1967, to create a safe, sustainable and transparent environment which facilitates exploration, science, and commercial space activities. The non-legally binding Artemis Accords was launched in October 2020 and has 29 signatories as of October 2023 (which does not include China and Russia).

Policy implications

Although the space sector is more diverse in 2023 than in previous decades, it is also more concentrated, with a small number of actors and economies dominating space launch activity, orbit occupancy and venture capital funding. As discussed in this chapter and elsewhere in the book, the space environment needs to be managed responsibly and sustainably for the benefit of all parts of society as well as for future generations.

Ensuring "healthy" levels of competition

An important contribution of "new space" to society is the rise in entrepreneurial activity and ensuing innovation in the global space sector. But this trend is fragile and could easily be reversed. The continuously high economic and regulatory barriers of certain space industry segments increase the risks of entrenchment. Furthermore, as the space sector becomes more digitised, the scalability of intangible digital assets makes "winner-takes-most" scenarios more probable (OECD, 2019[39]).

To sustain adequate levels of competition (see Box 3.2), policy makers are encouraged to make sure national regulatory regimes and procurement processes are favourable for market entrants and not giving incumbents undue advantages. One example is the growing use of Other Transaction Authority agreements by US government agencies (such as Space Act Agreements used for the COTS programme), which are exempt from the administrative requirements of federal procurement laws and regulations and therefore potentially remove some of the "red tape" and possible comparative administrative advantages of larger organisations with more resources and experience than smaller and younger firms (Undseth, Jolly and Olivari, 2021[1]). The US Defense Innovation Unit in the Department of Defense, which was established in 2015 to help young firms navigate the military procurement process, has prototype deals with several earth observation start-ups like BlackSky, Capella and Planet (Kinder, 2023[40]).

Box 3.2. The bidirectional link between innovation and competition

Competition affects innovation and vice versa.

First, one may assume an inverted U relationship between competition and innovation. When the degree of competition is low, there is a positive impact of increased competition on innovation efforts, as it pushes firms to differentiate, gain a competitive advantage and earn profits. However, at a certain level of competition, a further increase may lead to short-term thinking and discourage investments in longer-term riskier research and development, as it decreases laggard firms' short-term extra profit from catching up with the leader. The link between competition and innovation is further affected by the following factors:

- the market needs to be **contestable**, i.e. with low entry barriers and favourable business conditions
- firms need to be able to **appropriate** the benefits of their innovations
- the existence of **synergies,** i.e. the possibility of combining assets to produce greater benefits and enhance abilities to innovate.

Second, it is increasingly recognised that innovation drives competition as much as competition drives innovation. The extent of the innovation plays a key role as breakthrough innovations guarantee fewer threats of competition, while constant rates of innovation could be a method to secure competitive advantage in rapidly changing environments when the innovations are not as structural.

Source: OECD (2023[41]), *Competition and Innovation: A Theoretical Perspective*, OECD Competition Policy Roundtable Background Note, www.oecd.org/daf/competition/competition-and-innovation-atheoretical-perspective-2023.pdf.

Another interesting initiative is the UK "sliding scale" policy, which reduces or waives requirements to hold in-orbit third-party liability insurance for low-risk missions (UK Space Agency, 2018[42]). Funding agencies are also increasingly proposing new types of contractual arrangements for R&D procurement and collaboration that impose lesser burdens on firms (e.g. US Other Transaction Authority agreements and simplified contracts). In the United States, the Federal Communications Commission is streamlining its licensing rules for small satellites to make the process easier, faster and less expensive. Similarly, the National Oceanic and Atmospheric Administration now takes 15 days to issue a remote sensing licence, compared to 50-100 days in 2020, thanks to a more standardised treatment of companies and capabilities (Rainbow, 2023[29]).

Reinforcing efforts to better identify and track the outcomes and impacts of space activities

In an increasingly competitive environment where activities, sectors and countries are often pitted against each other – timely and high-quality data and statistics are more important than ever to underpin policy decisions and to understand the value that space brings to society.

Important efforts are underway to better document the role of space activities and space-based infrastructure in the overall economy and common measurement practices are beginning to emerge. Increasing the numbers of solid space economy surveys, for example, means that the quality and coverage of publicly available data and analysis are improving. However, key measurement challenges remain, and beyond strategic and short-term economic benefits, major long-term impacts such as those generated by space science advances in fundamental science, should not be ignored.

The *OECD Handbook on Measuring the Space Economy* (2022[6]) provides valuable guidance, with revised definitions of space economy terms and concepts, principles for space economy surveys and pointers to conduct impact assessments.

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4 The growth and sustainability of the space economy under threat

This chapter examines the longer-term sustainability of space activities and identifies key challenges to come for the sector, such as reinforcing the industrial base, filling recruitment gaps and making space infrastructure more resilient. It further draws attention to the growing negative externalities of conducting space activities, in space and on Earth.

Introduction

These preceding chapters have shown how some space programmes and infrastructure help in better managing several global challenges faced by our societies. However, this chapter argues that the sustainability of the space sector itself is not a given, as it faces a growing number of challenges.

The chapter first focuses on the considerable vulnerabilities that the recent growth in the sector has unveiled, in terms of a fragile industrial base for manufacturing, insufficient recruitment to the sector and an infrastructure vulnerable to natural and human-made hazards.

Furthermore, it takes a closer look at the environmental externalities resulting from space activities, which at current and expected future levels of activity can no longer be ignored. Orbital pollution, in the form of space debris, poses a serious threat to continued space activities and the crucial role they now play for many other sectors of the economy.

The entrepreneurial segments of the space industry ecosystem are vulnerable to economic shocks

The space industry supply chain and ecosystem dedicated to manufacturing spacecraft, launchers and associated subsystems and components is characterised by low production volumes and high specialisation (both in the use of materials and of industrial processes) as well as high R&D intensity. This leads to a high cost per weight for space components with a large share of the cost of custom-made materials dedicated to R&D activities as opposed to manufacturing (Wilson, 2022[1]). Technological, economic and regulatory barriers have traditionally limited the number of market entries.

Space manufacturers furthermore often rely on single, mainly government, sources of revenues. In upstream space activities, dominated by manufacturing and launch activities (see the *OECD Handbook on Measuring the Space Economy* for more details (2022[2])), public organisations sometimes account for some 60-70% of markets in both Europe and Asia. Below is a more detailed breakdown of data from 2021, with the share of revenue associated with sales to the public sector and public sector grants/subsidies.

- 40% of total upstream segment revenues in Canada (CSA, 2023[3])
- 69% of private sector domestic upstream revenues in Korea (Korean Ministry of Science and ICT, 2022[4])
- 70% of revenues in the upstream segment in Europe (Eurospace, 2022[5])
- 67% of domestic revenues in Japan (mainly upstream segment) (SJAC, 2023[6])
- Some 16% of US (mainly upstream) commercial respondents to the 2014 US industrial base deep dive survey declared themselves “dependent” on US government space programmes (US Department of Commerce, 2014[7]).

Available data also suggest a notable reliance on government funding of R&D. The most recent industry surveys show that externally funded R&D accounted for 24% of BERD in Canada (for 2021) and 51% in the United Kingdom (for 2020) (CSA, 2023[3]; know.space, 2023[8]).

Trade in space products and services has traditionally been limited because of export regulations and objectives to maintain domestic knowhow and expertise (OECD, 2020[9]). Still, 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[10]). For instance, the Japanese H-IIA and US Delta IV launchers share the same second-stage propellant tank configuration (OECD, 2014[11]) and two US launchers (Atlas V and Antares) use Russian-built engines. The European Space Agency also used the Russian medium-class Soyuz launcher between 2011 and 2022, e.g. for launching Copernicus and Galileo satellites.

From a structural point of view, small and medium-sized enterprises (SMEs) constitute the bulk of commercial actors in the space sector (e.g. some 94% in Canada, 92% in Korea) (OECD, 2020[9]), but bigger actors account for most of employment and revenues. In 2020, the ten largest space manufacturers in Europe accounted for 85% of revenues (ASD-Eurospace, 2021[12]). In Canada (also comprising other space activities such as satellite operations), the ten largest actors accounted for 84% of revenues in 2019 (CSA, 2021[13]).

The combination of these elements provides a heterogeneous defence against the succession of economic crises since 2019. On the one hand, government contracts provide a stable source of revenue in times of crisis. One could even note that certain space industry segments benefit from the current geopolitical climate with high counter-cyclical defence expenditure On the other hand, there are growing concerns about medium and long-term access to private as well as public sources of funding, as the projected economic slowdown in 2023, high inflation and rising debt service burdens could negatively affect public R&D budgets (OECD, 2023[14]). For instance, future US Department of Defense budgets are expected to be flat or declining in real terms (Butow et al., 2020[15]).

There is a risk that these could eliminate smaller and younger firms that are key sources of innovation, employment and economic growth (OECD, 2020[9]), as well as structural diversification and resilience. During the COVID-19 crisis, a German survey specifically targeting space start-ups revealed that almost 40% of respondents described the impacts of COVID-19 as “dramatic” and threatening the very existence of their firm (BDI, 2020[16]).

Ensuring sustained and diverse recruitment to the sector will be a challenge

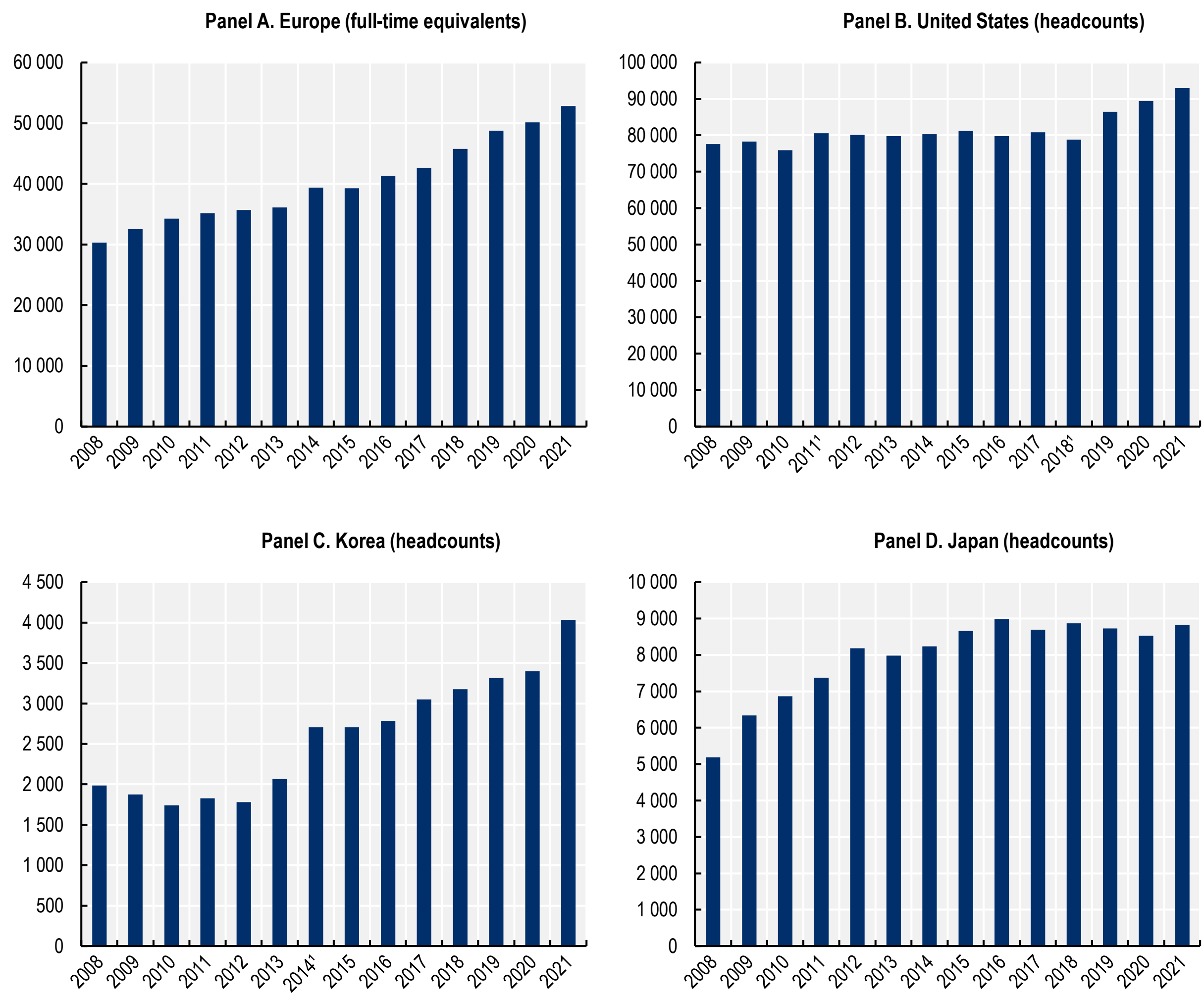
Space sector employment

As noted in Chapter 1 and the previous section, different segments of the space sector have very different characteristics. For example, what marks out the so-called "upstream" segment is not only the dominance of manufacturing and launch services and its low rate of annual outputs but also its high R&D intensity and heavy reliance on government funding. That sets it well apart from the downstream segment which, while also strong in manufacturing (e.g. components and devices such as set-top boxes for satellite TV, and receivers for satellite navigation), shares none of the other features that characterise the upstream segment. Such fundamental differences have important implications for employment, skills and recruitment.

Figure 4.1 shows recent trends in space manufacturing employment (including launch activities) in selected OECD countries and regions. Notable increases over the last decade can be found in Europe and Korea and can be linked to increased government funding, e.g. Galileo and Copernicus in Europe, and significant budget increases in Korea (see Chapter 1). More recently, European employment has been further boosted by smaller entrants to the sector backed by equity funding (Eurospace, 2022[5]). This could potentially also explain some of the recent growth in US employment.

Employment in other space industry segments has traditionally been more challenging to identify and track, for several reasons (e.g. the “space” component is often less clearly defined, limited or has no relationship with government agencies or industry associations) but more data are becoming available. Canada, the United Kingdom and Korea all monitor employment in the downstream segment, comprising space operations, the exploitation of satellite data and signals (e.g. satellite television) and associated equipment (e.g. GPS transmitters and chips). The size and nature of these activities vary significantly from country to country. As shown in Table 4.1, downstream activities accounted for 47% of employment in Canada and 53% in Korea in 2021 (mainly manufacturing of equipment for satellite broadcasting and navigation); and 67% in the United Kingdom in 2020 (mainly satellite television) (know.space, 2023[8]; Korean Ministry of Science and ICT, 2022[4]; CSA, 2023[3]). The European industry association for earth observation activities have estimated the overall workforce to amount to some 24 000 persons in 2020, in the private sector, government organisations and academia (EARSC, 2021[17]).

Figure 4.1. Space manufacturing employment in selected OECD countries/regions



1. Breaks in series (United States, 2011 and 2018).
Note: The countries/regions use different methodologies to define space manufacturing and are not directly comparable. For instance, employment in the United States includes missile manufacturing.
Source: OECD calculations based on country official statistics and/or space industry surveys.

The space sector workforce tends to be highly educated. In the United Kingdom, 77% of space industry employees had a bachelor's degree or higher in 2020, while the equivalent share for Canada was 67% in 2021 (know.space, 2023[8]; CSA, 2023[3]). In the United Kingdom, this average level of qualifications (based on a limited survey sample) surpasses that of any sector covered by the UK Office for National Statistics labour statistics. According to the Eurospace survey for 2021, 67% of the upstream segment workforce has at least three years of university education (Eurospace, 2022[5]). The industry surveys that distinguish between upstream and downstream activities find a concentration of the highly educated in the upstream sector.

Table 4.1. Employment in selected downstream activities and OECD countries

Country/region	Activity	Employment	Share of the space sector workforce
Canada	Space operations, satellite applications	4 954 full-time equivalents (2019)	47%
Europe	Earth observation	24 002 persons (estimation, 2020)	..
Korea	Space applications and equipment	4 858 persons (2021)	50%
United Kingdom	Space operations and applications (mainly satellite television)	36 048 persons (2020)	67%

Note: ..=not available;
Source: OECD calculations based on national space industry surveys.

Research, science and engineering play an important role. In the Japanese space industry survey, which focuses mainly on upstream activities, "R&D occupations" comprise 44% of the space workforce (SJAC, 2023[6]), whereas the Canadian space industry survey finds that "STEM" (science, technology, engineering and mathematics) occupations represent some 86% of the upstream workforce and 62% of the total space workforce (covering engineers, scientists, technicians, management, health professionals and students) (CSA, 2023[3]). In the United Kingdom, the great majority of the space industry workforce has a scientific or engineering academic background, with aerospace and electrical engineering, physics and geography and environmental sciences as the most typical entryways reported by survey respondents (Dudley and Thiemann, 2023[18]).

Recruitment and skills

The supply of skilled workers is a concern in many space-faring countries, as the space sector is expanding while facing strong competition from other high-technology sectors.

The availability of a skilled workforce depends on many factors. As for other high-technology sectors, the space sector faces strong structural challenges, such as STEM-related constraints and a notable gender gap in scientific and management occupations. The supply of university graduates in several space-related scientific disciplines (e.g. aerospace engineering), and STEM disciplines more generally, does not keep up with demand in several OECD countries.

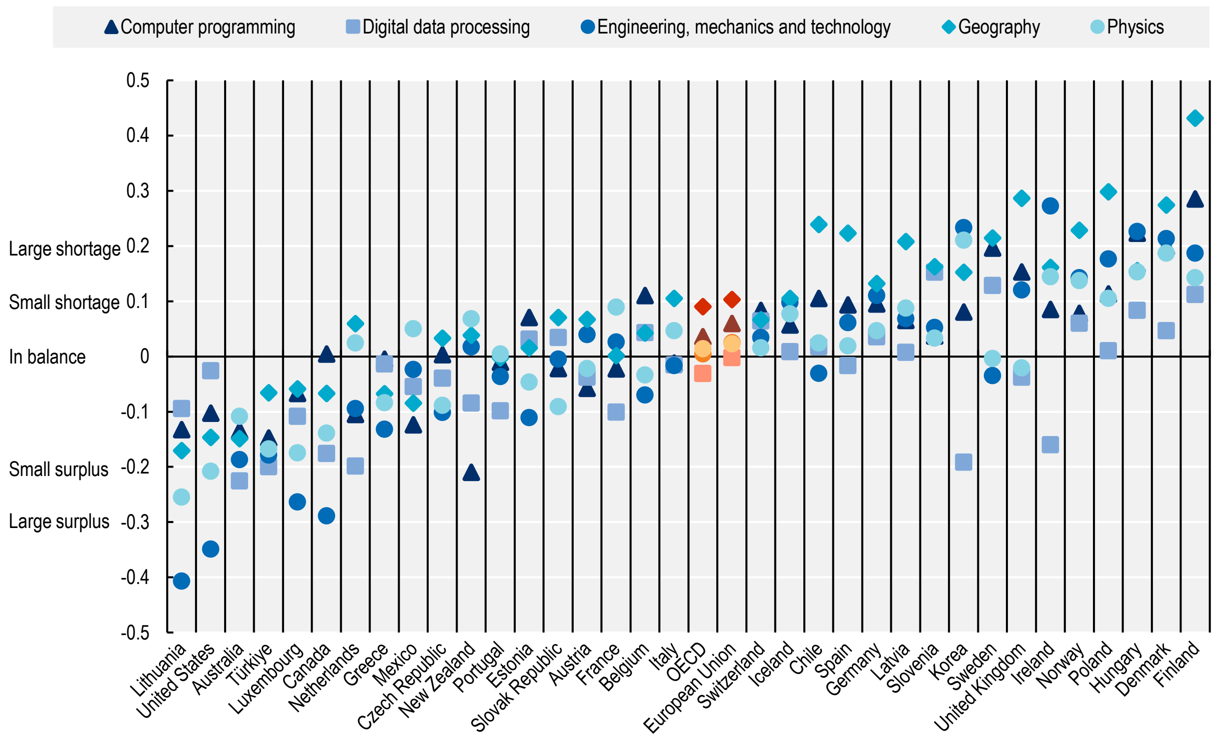
OECD's skill imbalance index (2022[19]) calculates skill surpluses and shortages. Figure 4.2 shows the results for skills that are important in space activities, notably several digital skills (programming, data processing), engineering and selected sciences (geography and physics). While subject to considerable national differences, the index shows small or severe shortages of engineering skills in about half of all OECD countries and a severe lack of geography skills in a majority of OECD countries. Some countries have a shortage of all the selected skills (e.g. Denmark, Finland, Norway).

Indeed, space Industry actors in several OECD countries report problems finding qualified staff.

The UK Space Agency's space sector skills survey (Sant et al., 2021[20]). identifies several challenges, notably recruitment problems, skills gaps (particularly in scientific, engineering and/or technical functions) and difficulties retaining staff. In Canada, 61% of space organisations reported difficulties hiring personnel in the annual industry survey carried out by the Canadian Space Agency in 2021 (CSA, 2023[3]). In Australia, a 2021 gap analysis conducted by the SmartSat Co-Operative Research Centre (CRC) found that out of the 319 identified skills used in the Australian space industry, all but nine are experiencing some level of shortage, with 86 requiring particular attention (due to e.g. high immediate demand or insufficient training provider capacity), as shown in Figure 4.3 (SmartSat, 2021[21]).

Figure 4.2. Selected skill needs in OECD countries

Data for 2019 or the latest available year

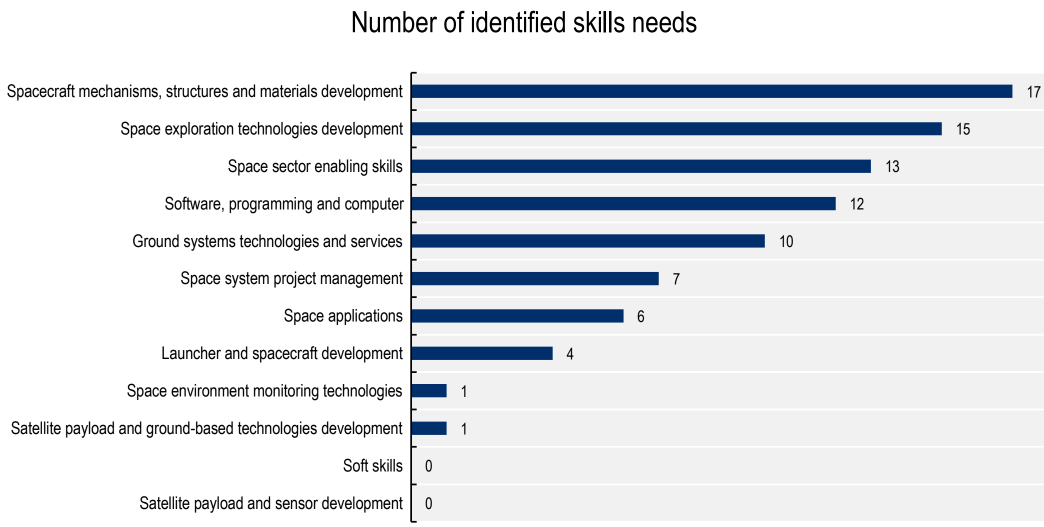


Notes: The index reposes on three fundamental pieces of information: i) the importance of that skill category in each occupation based on the normalised Relative Comparative Advantage (RCA – which relies here on cross-country pooled data), ii) a measure of the size of the occupational imbalance in the country (i.e. whether each occupation is in shortage or surplus), iii) and the relative size of the occupation in the country's total employment. The value of 1 represents the largest shortage and the value of -1 the largest surplus across OECD countries, skill categories and years. The graph shows each country's most recent available year before 2020, which is 2019 with the following exceptions: 2018 for CHE, FRA, IRL, ITA, POL, and THA; 2017 for DEU, GBR, KOR; 2016 for AUS; 2015 for BRA, TUR; and 2012 for ISL, SVN.
Source: OECD (2022[19]), *OECD Skills for Jobs Database*, https://www.oecdskillsforjobsdatabase.org/press.php#SE/_.

There may also be administrative obstacles. For certain space activities in the United States, for instance, security clearance requirements may complicate or even obstruct the employment of international staff (US Department of Commerce, 2014[22]). In 2021, 22% of all enrolled graduate students and 62% of doctoral students in aerospace engineering in the United States were temporary visa holders (NCSES, 2023[23]), significantly reducing the pool of eligible candidates. More generally, the increase in the number of engineering and ICT graduates since 2014 in the United States is primarily driven by international students, mainly from the People's Republic of China [hereafter 'China'] (National Science Board, National Science Foundation, 2022[24]).

The ageing of the space-related workforce is an issue in some OECD countries, especially in the upstream segment. In the United States, the 2013 space industrial base deep dive assessment found that 36% of the space-related workforce was 50 years or older (US Department of Commerce, 2014[22]). The European space manufacturing workforce has a similar "top-heavy" age structure, according to the 2021 Eurospace space industry survey, with a majority of workers in the 49-58 age bracket (Eurospace, 2022[5]). In contrast, the 50+ age group accounted for less than 11% of space industry workers in Korea in 2019, as reported by the Ministry of Science and ICT's latest space industry survey (2020[25])

Figure 4.3. High-intensity skill needs in the Australian space industry



Note: The list of skills is based on the Australian Space Skills Taxonomy, which comprises 12 high-level categories, 56 tier two sub-groupings and 319 tier three skills. "High intensity skills" refers to the 86 tier three skills that were identified as requiring attention due to current shortages or at risk of insufficient training provider capacity to deliver enough training for current and/or future skills growth needs.
Source: SmartSat (2021[21])," Space industry skills gap analysis", https://smartsatcrc.lbcdn.io/uploads/Space-Industry-Skills-Gap-Analysis-Final-Report.pdf.

Persistent gender gap in the space sector

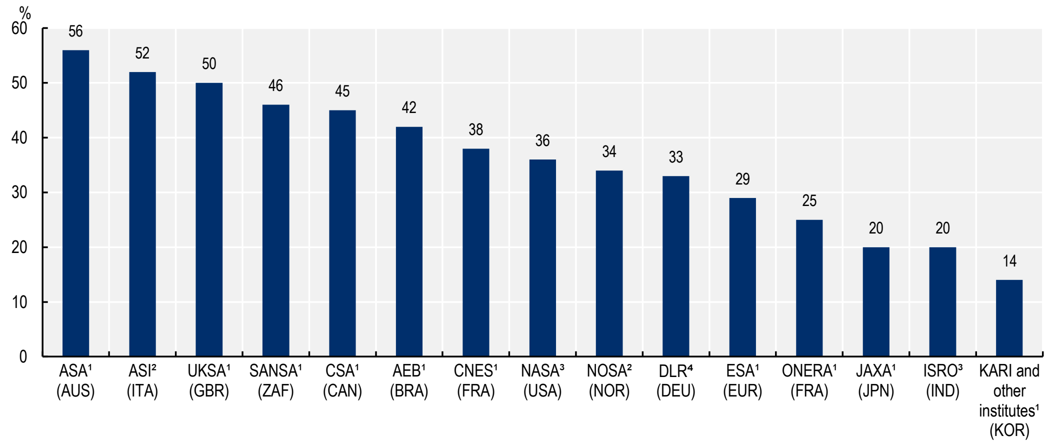
There is a persistent gender gap in both space-related employment and space-related fields of education. Overall, women are under-represented in all segments of the space sector, from government sector administration and research to private sector manufacturing and services provision, irrespective of fields. However, there is variation across countries and space activity segments, with some positive signs emerging. Thanks to the considerable statistical efforts of several organisations, there is more granular evidence on this issue than ever before, allowing a more precise analysis of data and a more targeted response.

Figure 4.4 shows female employment in selected space agencies and research organisations in both OECD countries and partner economies. Agencies with higher administrative and project management roles tend to have a higher share of women (e.g. space agencies in Australia, Norway and the United Kingdom).

The share tends to be lower in bigger agencies that also carry out science and engineering activities. Whereas the female shares of total staff at the Canadian Space Agency, the Centre National d'Etudes Spatiales (CNES) and the National Aeronautics and Space Agency (NASA) account for 45%, 39%, and 36%, respectively, this drops to 25% for "non-administrative or clerical occupations" (e.g scientists and engineers) (CSA, 2021[26]; CNES, 2022[27]; NASA, 2023[28]). As shown in Table 4.2, the South African National Space Agency is an exception, with a higher female share in skilled technical workers (49%) than in total staff (SANSA, 2022[29]). Female employment in space-related Korean government research institutes is generally very low (14% in 2021), but women account for 35% of the under-30 (Korean Ministry of Science and ICT, 2022[4]). However, it is too early to tell if this is a durable trend reflecting real gender advances, or if the share decreases as women age and take on more family responsibilities.

Figure 4.4. Share of female employment in selected space agencies and research organisations

2022 or latest available year



1. Data from 2021, 2. Data from 2020, 3. Data from 2022, 4. Data from 2019.
Notes: ASA: Australian Space Agency, ASI: Italian Space Agency, UKSA: UK Space Agency, SANSA: South African National Space Agency, AEB: Brazilian Space Agency, CNES: Centre National d'Etudes Spatiales, NASA: National Aeronautics and Space Administration, NOSA: Norwegian Space Agency, DLR: German Aerospace Centre, ESA: European Space Agency, ONERA: French Aerospace Lab, JAXA: Japan Aerospace Exploration Agency, ISRO: Indian Space Research Organisation, KARI; Korea Aerospace Research Institute.

Table 4.2. Share of female employment in different types of occupations, selected space organisations

Organisation	SANSA, ZAF (2021)	CSA, CAN (2020)	CNES, FRA (2021)	NASA, USA (2023)	DLR, DEU (2019)	ONERA, FRA (2021)	ISRO, IND (2022)	JAXA, JPN (2016)	KARI and other government institutes, KOR (2021)
Share of total staff (%)	46	45	39	36	33	25	20[2]	20	16
Share of "non-administrative and/or non-clerical staff"[1] (%)	49	26	26	25	22	22	13[2]	12	10

1. This category typically refers to women in science and engineering occupations, but definitions and data availability vary across organisations.
2. Human resources account for all centres and units of ISRO.
Notes: SANSA: South African National Space Agency, CSA: Canadian Space Agency, NASA: National Aeronautics and Space Administration, DLR: German Aerospace Centre, ONERA: French Aerospace Lab, ISRO: Indian Space Research Organisation, JAXA: Japan Aerospace Exploration Agency, KARI: Korea Aerospace Research Institute.

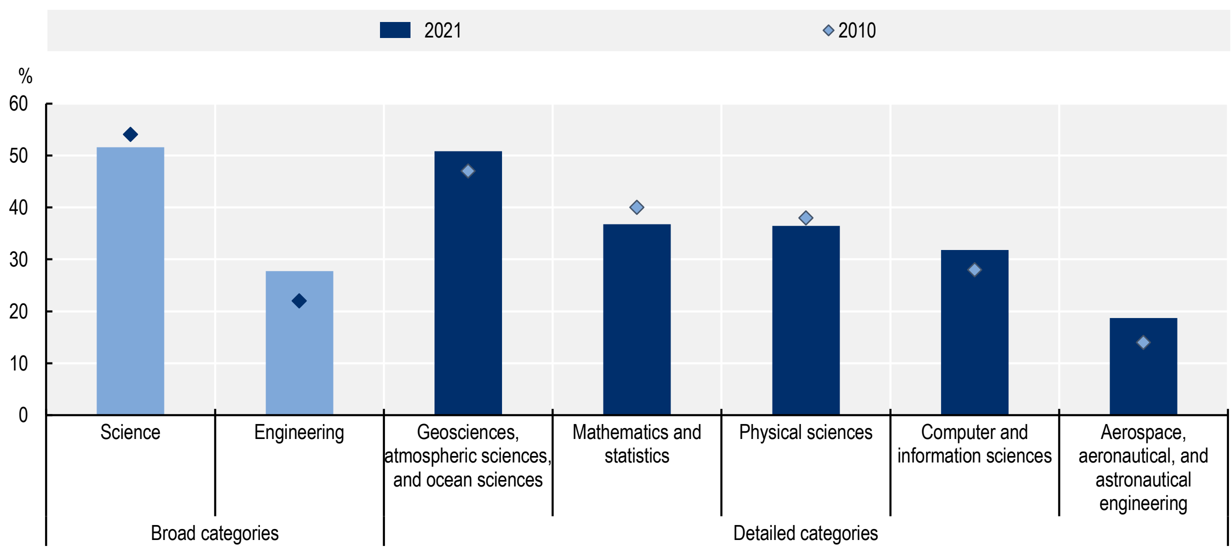
Women are also under-represented in the private sector, particularly in the upstream segment of space manufacturing and launch. Women accounted for roughly 23% of employment in the upstream segment in Europe in 2021 (Eurospace, 2022[5]), a share that has remained stable over the last decade, and 34% of aerospace manufacturing in the United States (compared to 19.5% in 2017) (US Bureau of Labor Statistics, 2023[30]). In Canada, Korea and the United Kingdom, where industry surveys cover both upstream and downstream activities, women represented 29%,15% (in 2021) and 24% (in 2020), respectively, of the space industry workforce (Korean Ministry of Science and ICT, 2022[4]; CSA, 2023[3]; know.space, 2023[8]). In Australia and the United Kingdom, women represented 20% of the total space research industry in 2020 (Australia's Chief Scientist, 2021[31]). When looking at female representation by age cohorts, women generally account for a larger share of the younger workforce (e.g. in Korea they represent 28% of employees younger than 30, compared to 15% of the total).

The three countries also provide data on female employment in specific fields (e.g. earth observation, space exploration) and along the value chain (e.g. research and engineering, space manufacturing, space operations) showing a strong under-representation of women in some of the most specialised engineering activities (space launch, satellite operations, instrument manufacturing) and fields (space exploration), with relatively more women (unsurprisingly) employed in education and administration, as well as science.

More granular data from Korea looking at the gender distribution of the space industry by educational background shows that women accounted for only 7% of employed majors from departments related to mechanical/material engineering, 20% of majors from natural science-related departments and 37% of majors from "non-related" departments (Korean Ministry of Science and ICT, 2022[4]).

Figure 4.5. Female graduate students in space-related fields of education in, the United States

Share of female students enrolled in master's and doctoral programmes



Note: "Science" includes agricultural and veterinary sciences; biological and biomedical sciences; computer and information sciences; geosciences, atmospheric sciences, and ocean sciences; mathematics and statistics; multidisciplinary and interdisciplinary studies; natural resources and conservation; physical sciences; psychology; and social sciences.
Source: NCSES (2023[23]), *Diversity and STEM: Women, Minorities, and Persons with Disabilities 2023*, https://ncses.nsf.gov/pubs/nsf23315/.

These employment patterns are reflected in women's educational choices. Figure 4.5 shows the share of female graduate students in space-related science and engineering fields in the United States, one of the very few countries to regularly collect granular statistics by field and gender. The 2021 data show how women account for more than half of all graduate students in geosciences, atmospheric sciences and ocean sciences but continue to be under-represented in computer and information sciences and especially in aerospace engineering (and engineering more generally (NCSES, 2023[23]). Still, the trend is positive – the share of women graduate students in aerospace engineering has grown from 14% in 2010 to almost 19% in 2021.

The Korean space survey tracks graduation trends of students in dedicated "space" fields and departments (comprising aerospace engineering, space science and astronomy) and of students involved in space-related research in departments such as physics, mechanical engineering, electrical engineering, etc. In 2021, women accounted for 21% of space department graduates and 39% of "space-related" graduates, compared to 18% and 33% respectively, in 2019 (Korean Ministry of Science and ICT, 2020[25]; 2022[4]).

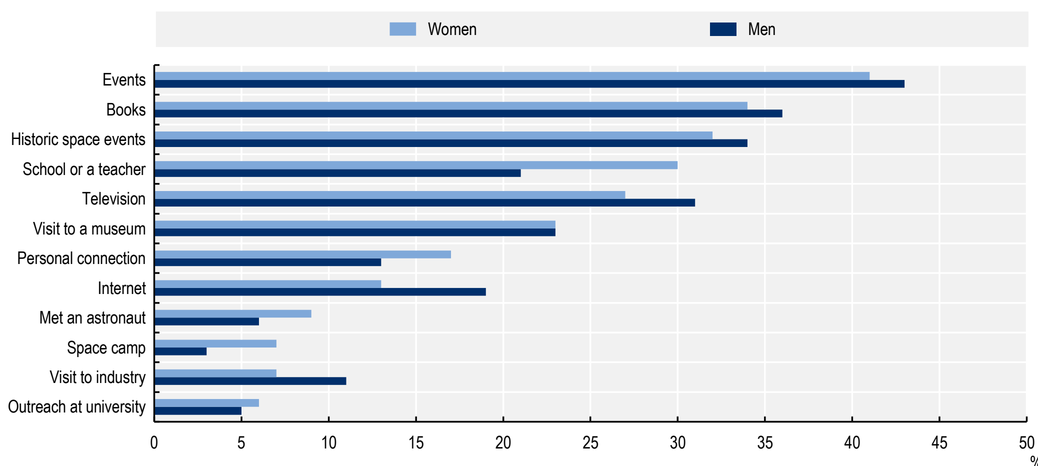
Public and private responses typically include educator resources and training, outreach and awareness-raising events at primary, secondary and higher education levels, scholarships, conditional grants and workplace initiatives (see OECD (2019[32]) for examples). There is finally more available data on the potential effects of these policies, some of which have been running for decades, as well as possible existing barriers to success.

A comprehensive UK survey sheds light on workplace discrimination (Space Skills Alliance, 2021[33]). The 2020 Space Census on the UK space workforce reports that only 47% of female respondents feel "always" welcome in the sector, compared to 79% of male respondents. This is especially true for those employed in academia and in small and micro-sized firms. From a race/ethnicity standpoint, only 38% of female respondents and 44% of male respondents of colour feel "always welcome".

The UK survey furthermore provides important pointers on what motivates women to enter the space sector, as shown in Figure 4.6 (Dudley and Thiemann, 2023[18]). Gender differences are quite small, but female respondents are more likely to be inspired at school or by a teacher or at a space camp (7% versus 3%) and male respondents are more likely to be inspired by the internet (13% versus 19%). According to survey respondents, the impact of public and private outreach events (e.g. industry days, space camps) is relatively limited.

Figure 4.6. Influences to join the space sector by gender in the United Kingdom

Survey data from 2020



Note: n (All) = 1165, n (Men) = 809, n (Women) = 342.
Source: Dudley and Thiemann (2023[18]), "How and why people join the UK space sector", https://spaceskills.org/census-routes.

As highlighted in the previous paragraphs, existing statistics show a persistent gender gap in the space sector for science and engineering activities and occupations, but one that varies significantly between countries, and across different types of organisations and technical fields. Also, there are several positive signs when it comes to the share of female employment as well as graduates in space-related fields, including in engineering. As the space sector evolves, with increasing commercialisation and digitalisation of activities, more and more granular data are needed to adequately track the participation and experiences of women in the space sector as well as the outcomes and effectiveness of policies targeting gender imbalances.

Global space infrastructure facing ever-more natural and human-made threats

As described in previous chapters of this book, the importance of space infrastructure and space activities more generally is growing. 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 make it difficult to protect them from human-made and natural threats (e.g. space debris).

Natural threats

Space infrastructure is exposed to multiple natural threats in the space environment, which are not affected by human activity (NASA, 2015[34]). These include the hard vacuum of space, ultraviolet and particulate radiation, charged plasma and extreme temperature fluctuations, all of which can damage and erode surfaces and components and cause system malfunctions. Furthermore, meteoroids, small and solid particles created by asteroid collisions and decayed comets, can hit spacecraft at exceptional speed (sometimes 60km per second (km/s), compared to space debris' average velocity of 10km/s).

Space weather probably poses the greatest natural threat to space infrastructure. Lower-level space weather-related incidents are relatively frequent, mainly affecting space-based infrastructure (e.g. signal disruptions and other anomalies, although a systematic mapping of incidents is not available) and occasionally systems on Earth, which are normally protected by the Earth's magnetic field. In 2006, a solar flare disrupted satellite-to-ground communications and Global Positioning System (GPS) signals for some ten minutes (Cerruti et al., 2008[35]). And more recently in 2022, a coronal mass ejection and the accompanying increase in atmospheric temperature and density caused the first recorded mass satellite failure as it deorbited 40 out of 49 recently launched Starlink satellites, belonging to US operator SpaceX (SpaceX, 2022[36]).

Major events are much rarer, but there is limited knowledge about their frequency since recording only started with the electrification of society in the second half of the 19th century. Indeed, one of the largest geomagnetic storms ever recorded occurred in 1859, disabling telegraph systems in North America and Europe and producing auroras visible in Hawaii and Queensland, Australia, but it had otherwise limited impact. A coronal mass ejection of similar magnitude missed the Earth by a week in 2012 (NASA, 2014[37]). The most severe incident in modern times occurred in Canada in 1989 and disabled Hydro Québec's electrical grid. This left 6 million people without electricity for nine hours (OECD, 2020[9]).

Space weather services in several OECD countries provide short- and medium-term space weather forecasts, allowing operators to put exposed infrastructure in safe mode when possible. However, forecasting ability is limited. There is a 6-8 hour forecast accuracy for coronal mass ejections (which transit relatively slowly through space) but definitive forecasts determining the direction of their magnetic field lie in the range of 15-30 minutes – and solar flares and solar particle ejections, which travel with the speed of light, cannot be forecasted at all (RAE, 2013[38]).

Human-made threats

Space-based systems are designed to resist the multiple stresses of launch as well as the extreme natural conditions 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[39]). Several economies have demonstrated anti-satellite capabilities in recent years, including China, India, the United States, and most recently, the Russian Federation.

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[40]). 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[41]; Foust and Berger, 2022[42]). 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[43]).

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).

Space activities produce debris and other types of pollution

Space debris

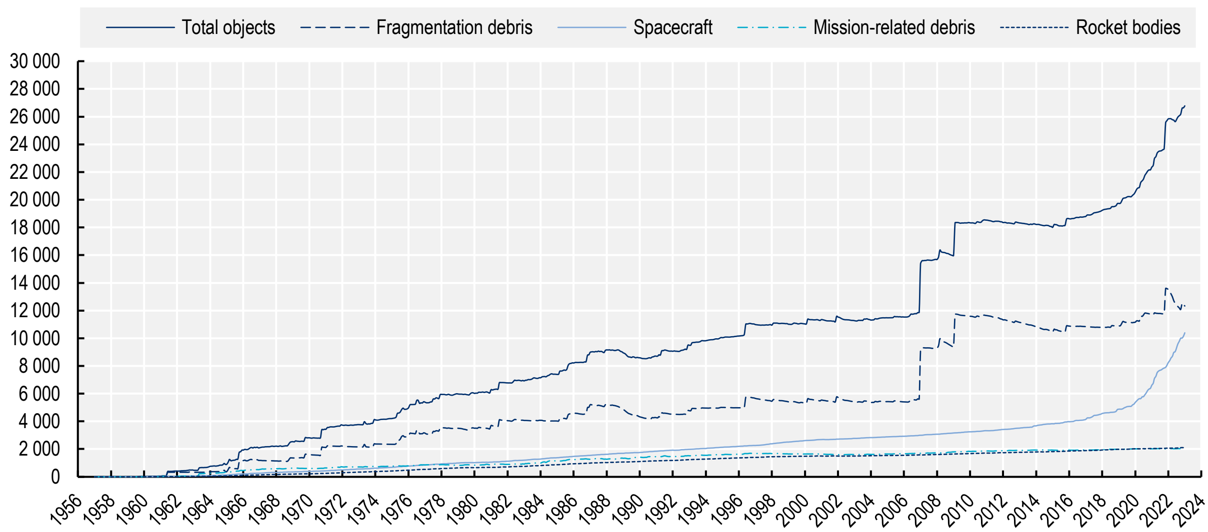
Space debris poses the biggest threat to space infrastructure and the volume of tracked debris objects has increased significantly in the last two decades. Figure 4.7 shows the evolution of space objects catalogued by the US Space Force, including operational and defunct spacecraft, fragmentation and mission-related debris. In March 2022, the US Space Force tracked more than 25 000 identifiable debris objects mainly with a 10 cm diameter or bigger (gradually phasing in smaller objects thanks to a new ground radar) (NASA, 2022[44]). The total untracked number of debris probably counts in the hundreds of millions (ESA, 2021[45]).

Space debris includes operational and defunct spacecraft, fragmentation debris from collisions and in-orbit explosions (e.g. of rocket fuel tanks), mission-related debris such as objects intentionally released during deployment and operations (e.g. lens caps), and various stages of rocket bodies. Rocket bodies account for only around 10% of tracked objects, but almost 40% of mass (ESA, 2019[46]). Lower altitude orbital debris objects decay as they are pulled to Earth by atmospheric drag and other natural processes and destroyed when entering the atmosphere. Decay timelines can be counted in days (orbits closest to Earth), in years (in orbits less than 600 km), or in centuries (more than 1 000 km). In the geostationary orbit, debris remains in orbit unless they are moved to dedicated "graveyard" orbits. Debris belts are mainly located in the low-earth orbit, between 800 and 1 000 km, but also at an altitude of almost 1 400 km. There are additional concentrations of space debris close to the orbits of the existing navigation satellite constellations (19 000-23 000 km), and the geostationary orbit (35 785km)

The operational life of a satellite varies quite significantly according to its orbit and is linked to the cost of launching it and keeping it in place in its orbital slot. Satellites located in the geostationary orbits have traditionally been built for some 15-20 years of operations, while satellites in the lower earth orbits may remain operational for only a couple of years. From a regulatory standpoint, payloads are supposed to clear their orbits at the latest 25 years after the end of operations (IADC, 2007[47]). This means that Earth's orbits are occupied by satellites in various stages of their operational lives, by non-operational satellites in the process of clearing their orbit, as well as different categories of debris.

Figure 4.7. Number of objects in Earth's orbits by object type

Historical increase of the catalogued objects based on data available on 3 February 2023



-Note: This chart displays a summary of all objects in Earth orbit officially catalogued by the US Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.
Source: NASA (NASA, 2023[48]), *Orbital Debris Quarterly News*, 27:1, https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv27i1.pdf.

The accumulation of space debris constitutes a major threat to space-based infrastructure and could have severe socio-economic consequences (OECD, 2022[49]). In a worst-case scenario, debris objects reach unsustainable levels of concentration that trigger an irreversible chain reaction of in-orbit collisions, the so-called Kessler Syndrome (Kessler and Cour-Palais, 1978[50]), which may render certain orbits unusable. If or when this could happen remains unknown, but there is a theoretical possibility that it could occur within the next few decades (National Research Council, 2011[51]). Vittori et al. (2022[52]) estimates the monetary losses in the case of Kessler Syndrome to some USD 191.3 billion,

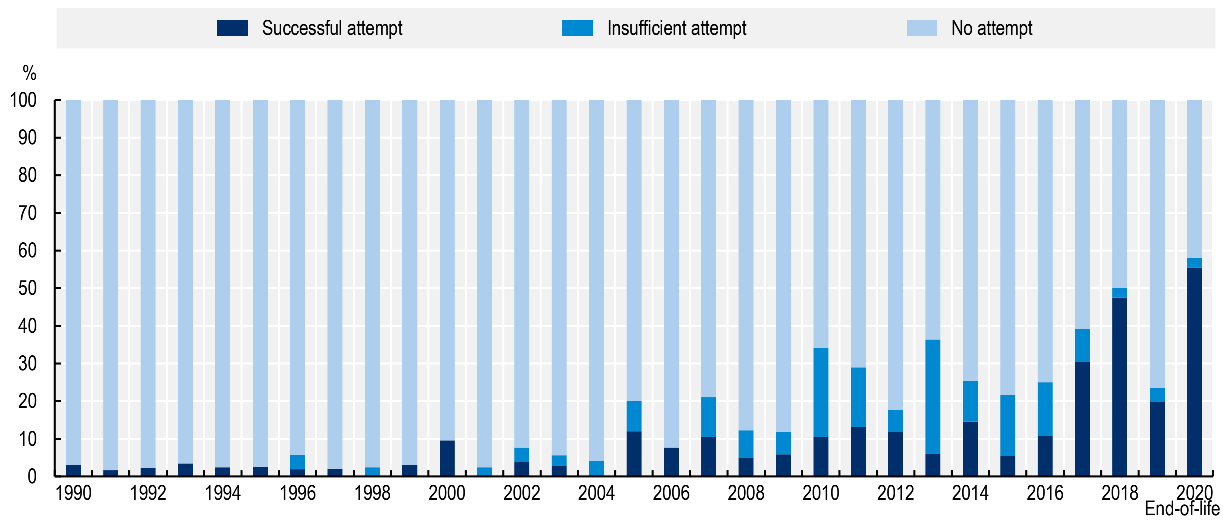
The orbits most likely to be disrupted by the Kessler Syndrome are those with the thickest existing debris belts and are located at 650-1 000 km and ~1 400 km altitudes. These orbits are used by many of the weather and earth observation satellites described in Chapter 2, which make unique contributions to weather forecasting and climate change observations and research. Furthermore, communications satellites in orbits above the debris belts would be affected during orbit-raising.

National and international efforts that address this problem include international guidelines on sustainable conduct (UN COPUOS, 2018[53]) and debris mitigation (IADC, 2007[47]); increasingly advanced monitoring systems, government and industry efforts to improve data sharing and space traffic management; active debris removal, etc., but they face considerable legal, economic and technological hurdles including the inability to enforce legal frameworks and attribute actions and debris to specific operators. Although the trend is positive, operator compliance with orbit clearance guidelines for satellites in orbits above 650 km, which requires active deorbit systems and adds costs and complexity to the mission, remains at a low and unsustainable level, as shown in Figure 4.8 (ESA, 2022[54]).

The figure shows the levels of compliance of satellites in orbits above 650km altitude that has been cleared or that should have been cleared (i.e. that they have remained in orbit 25 years beyond the end of their mission). The higher compliance in recent years is associated with the good performance of mega-constellation operators (e.g. SpaceX).

Figure 4.8. Not enough satellites are cleared from low-earth orbits within recommended time limits

Payload clearance attempts in low-earth orbits above 650 km altitude



Notes: Payloads refer to space objects designed to perform a specific function in space, excluding launch functionality (e.g. satellites, space probes). Payload clearance in the low-earth orbit compliant with debris mitigation guidelines involves deorbiting within 25 years of mission completion. Objects may be naturally compliant (cleared from orbit by atmospheric drag), but clearance above 650 km altitude requires a disposal action for it to occur within the recommended period.
Source: Data from ESA's -*Annual Space Environment Report* (2022[54]), published in OECD (2022[49]), *Earth's Orbits at Risk: The Economics of Space Sustainability*, https://doi.org/10.1787/16543990-en.

Light pollution and radio interference affecting astronomical research

When sunlight is reflected on satellite bodies and orbital debris, it increases the brightness of the night sky, which may have serious implications for different types of astronomical observations, as it lowers the contrast between astronomical objects and their foreground and increases the risk of bright satellite "streaks" in frames. Kocifaj et al. estimate that the combined body of existing satellites and debris already increases the brightness of the night sky by at least 10%, which qualifies it as "light polluted" and exceeds the threshold of acceptable light pollution (or artificial brightness) at astronomical observatory sites (Kocifaj et al., 2021[55]). As discussed previously, the number of satellites in orbit is expected to grow exponentially in the coming years, so this problem is only in its early stages.

Since the launch of the first satellites for broadband mega-constellations in 2019, the science community has identified several potential impacts of the high orbital density of satellites on astronomical observations depending on satellites' orbits and design; the timing of the observation; and the type of telescopic astronomic observation and length of exposure (Hainaut and Williams, 2020[56]).

- The higher the orbit of the satellite (above 600km altitude), the longer they are visible during the night (in summer, all night in some cases). In 2023, at least four mega-constellation projects in different stages of development were planning to use orbits at this altitude or higher. The UK constellation OneWeb intends to place all its 600+ satellites at 1 200 km altitude).
- The periods of the day with the highest risk of satellite-induced light pollution are when the sun is 18 degrees or farther below the horizon (latest hours of the astronomical night), or 12-18 degrees below the horizon (astronomical twilights). Certain research programmes specifically require twilight observations, such as searches for potentially Earth-threatening asteroids and comets,

outer solar system objects, and visible-light counterparts of fleeting gravitational-wave sources (AAS, 2020[57]).

- Observations using a large field of view and long exposure times could be considerably affected. For instance, simulations for the USD 500 million Vera C. Rubin Observatory currently under construction in Chile and the top-ranked large ground-based astronomy project in the US 2010 Astronomy and Astrophysics decadal survey, indicate that some 30-40% of exposures during the first and last hours of the night could be compromised (Hainaut and Williams, 2020[56]). Images on a test version of the camera show very bright and wide satellite trails, covering several pixels (Clery, 2020[58]).
- Modelling shows that the effects of satellite-generated light pollution will be unequally geographically distributed, with 50°north and south latitudes experiencing some of the worst effects of light pollution. This would for instance affect the populations and multiple observation facilities in North America and Europe (Lawler, Boley and Rein, 2021[59])

This issue is not only a problem for terrestrial observatories. Kruk et al. (2023[60]) show that space-based observatories such as the Hubble Space Telescope are also affected.

The massive growth in satellites in orbit could also negatively affect radio astronomy observations. Radio astronomy observes the radio portion of the electromagnetic spectrum (see Box 3.1 in Chapter 3) that is emitted by celestial objects such as neutron stars, planets, gas clouds, galaxies, etc. While generally less known than optical astronomy, radio astronomy observations have contributed to four Nobel prizes in physics between 1974 and 2020, including one for the discovery of the Big Bang in 1978 (IAU, 2021[61]). Radio astronomy also contributes to early warning systems by monitoring solar radio flares, measuring Earth's plate tectonics and providing crucial positioning inputs to global navigation satellite systems (NTIA, 2021[62]).

Observed wavelengths in radio astronomy typically range from millimetres to several metres. The International Telecommunications Union has allocated 21 bands exclusively to passive science services (also including passive remote sensing), but most frequencies are shared with other services (IAU, 2021[61]). Notable observatories include the Atacama Large Millimetre Array (ALMA) comprising 66 radio telescopes in Chile; the Five-hundred-meter Aperture Spherical Telescope (FAST) in China and the Square Kilometre Array Observatory (SKAO) project under development in Australia and South Africa, which connects arrays of 131 000 and 197 dish antennas, respectively (SKAO, 2023[63]).

Radio astronomy is particularly vulnerable to interference from other users of the electromagnetic spectrum because measurements are extremely sensitive as signals are very weak, often involving large receiver bandwidths and integration and correlation of signals over hours or days (ITU, 2001[64]). Interference in "protected" bands can occur if transmitters using frequencies in adjacent frequency bands spill over into neighbouring frequencies (NRAO, 2023[65]). Alternatively, transmitters emit outside their intended range. For example, continued interference from the constellation of US satellite mobile phone operator Iridium has made it impossible to observe hydroxide (OH) molecules in the envelopes of evolved stars using the protected radio astronomy band at 1610.6-1613.8 megahertz for the last 22 years, although the satellite constellation is to be allowed to operate only above 1617.8 megahertz (IAU, 2021[61]).

To avoid interference in shared bands, radio observatories are sometimes located in "radio quiet zones", where certain activities (e.g. air traffic) or the use of specific devices (e.g. cellular phones, in some cases even microwave ovens) are restricted. However, satellites (and other airborne systems) can cause interference even with hundreds or thousands of kilometres of separation (NTIA, 1998[66]). Whereas it is relatively easy to mitigate interference from geostationary satellites (low count of visible satellites all using the same frequencies in a well-defined orbit), the increased use of the low-earth orbit is much more problematic, with multiple, and in the future perhaps hundreds or thousands, satellites above the horizon simultaneously. A special concern is main beam illuminations, especially from radar and other high-power applications capable of burning out radio astronomy receivers (IAU, 2021[61]).

Growing focus on atmospheric pollution

Space activities generate multiple negative environmental effects on Earth and in the atmosphere, including stratospheric ozone depletion, air acidification, smog, toxic waste spills, water pollution, noise pollution, water consumption, and various types of material demands which can contribute to resource depletion (Miraux, Wilson and Dominguez Calabuig, 2022[67]).

There is growing awareness within the sector to reduce its environmental footprint. For instance, the European Space Agency (ESA) launched its Clean Space initiative in 2009, focusing among other things on "eco-design", looking at the effects on the atmosphere, and environmental regulations and performing full mission lifecycle assessments, creating a lifecycle assessment database in the process as well as guidelines for carrying out lifecycle assessments (ESA, 2023[68]).

However, Identifying and assessing the full environmental impacts on Earth and in the atmosphere is challenging, because of a lack of observational data and, a lack of comparability with other sectors (due to the unique characteristics of space activities such as low production rates, long development cycles, specialised materials and industrial processes) and limited access to industry data (e.g. on satellite composition) (Wilson et al., 2022[69]; Miraux, Wilson and Dominguez Calabuig, 2022[67]; GAO, 2022[70]).

Despite these caveats, there is a growing body of evidence providing insights into the most polluting phases of space activities, now and in the future, with researchers assessing the environmental effects of space launch, the carbon footprint of specific facilities, or even the full lifecycle impacts of space activities.

- The US Government Accountability Office (2022[70]) summarises multiple studies on the atmospheric effects of rocket launches and satellite re-entries, with different types of rocket propellant producing carbon dioxide, water vapour, black carbon, aluminium oxide, chlorine chemicals and nitrogen oxides; and satellites emitting aluminium, nickel, titanium, iron, silicon, etc., as well as potentially toxic and radioactive metals (depending on satellites' composition) as they burn up on entering Earth's atmosphere. However, estimates tend to heavily rely on assumptions because of the data caveats mentioned above, in particular the lack of observational data and data on space vehicle composition.
- Maury et al. (2020[71]) review the literature on lifecycle assessments and identify environmental "hotspots" in complete space missions. The launcher represents 99% of space mission mass and 50-70% of the global warming potential; control centres and ground stations account for most of the energy consumption for operations and 50% of toxicity/ecotoxicity potentials; the propellant-burning launch event covers nearly 100% of the potential for ozone depletion; and the production of solar cells for photovoltaic systems accounts for practically all the potential for mineral resource depletion.
- Available scientific evidence suggests that the composition of rocket fuel could change its environmental footprint, with hydrogen fuels (emitting mostly water vapour) being less harmful than kerosene-, hypergolic-, solid- (and eventually methane)-based fuels (The Aerospace Corporation, 2022[72])
- Focusing specifically on carbon emissions, Knödlseder et al. (2022[73]) uses economic input-output analysis to estimate the footprint of astronomical research and finds that the combined lifecycle impact of ground- and space-based astronomical research infrastructures (excluding travel, supercomputing and office heating) accounts for the largest share of overall emissions and is comparable to the annual emissions of a small European country (Greenfieldboyce, 2022[74]). It is worth noting that the methodological input-output approach, used specifically to circumvent the aforementioned data gaps, is associated with large uncertainties (80%) due to the large variations in activity, products and monetary flows from one facility or field of activity to another (Knödlseder et al., 2022[73]; Wilson, 2022[1]). In any case, the authors make a strong case for greater transparency on the carbon intensity of the space sector.

- Finally, Miraux, Wilson and Dominguez-Calabuig (2022[67]) estimate the full environmental lifecycle impact of both existing and potential space activities up until 2050. The 2021 baseline scenario (excluding mega-constellations) indicates a low overall impact except for ozone depletion, where the estimated impact represents 0.4% of the accumulated impact from *all* anthropogenic activities over a year. However, both the moderate and high growth scenarios foresee significant future impacts on several aspects of atmospheric pollution (air acidification, ozone depletion, photochemical oxidation) as well as notable contributions to global warming (climate change), as shown in Table 4.3.

Table 4.3. Environmental lifecycle impact of existing and potential space activities until 2050

Estimated environmental sustainability in three scenarios of implementation of proposed plans

Impact category	Unit	Low growth scenario		Moderate growth scenario		High growth scenario	
		Annual global impact	Planetary boundary	Annual global impact	Planetary boundary	Annual global impact	Planetary boundary
Aluminium oxide	kg Al_2O_3	..	..	..	..	..	..
Black carbon	kg	..	..	..	..	..	..
Air acidification	kg SO_2 equivalents	0.16%	0.06%	3.75%	1.44%	25.05%	9.63%
Climate change	kg CO_2 equivalents	0.01%	0.06%	0.20%	1.68%	1.32%	11.25%
Ozone depletion	kg CFC-11 equivalents	5.70%	1.78%	279.33%	87.23%	1903.84%	594.51%
Particulate matter	kg PM_{10} equivalents	..	..	..	..	..	..
Photochemical oxidation	kg NMVOC equivalents	0.01%	0.06%	0.18%	1.92%	1.21%	12.95%
Resource depletion	kg Sb equivalents	0.14%	..	0.50%	..	2.41%	..

Notes: .. = Not available. NMVOC: Non-methane volatile organic compounds.
Source: Adapted from Miraux, Wilson, and Dominguez Calabuig (2022[67]), "Environmental sustainability of future proposed space activities, *Acta Astronautica*, https://doi.org/10.1016/j.actaastro.2022.07.034.

Policy implications

This chapter has treated several topics that require government attention, most notably the issue of space debris. While not a recent concern, solutions to the problem are technically and geopolitically challenging and costly (more information on policy responses and recent initiatives such as active debris removal and environmental certification schemes can be found in OECD (2022[49]) and Undseth, Jolly and Olivari (2020[75])). As with all other policy challenges mentioned in this book, greater involvement from private actors, international consensus-building, and improved data collection and sharing will be required.

- There are some positive signs of stakeholder collaboration to address the negative externalities of space activities. Several satellite operators work along with the science community to mitigate light pollution and radio interference. For instance, the US National Science Foundation and satellite operator SpaceX have an astronomy coordination agreement concerning both optical and radio astronomy (NSF, 2023[76]). This includes operator efforts to follow science community recommendations on satellite and constellation design to reduce light pollution; publish orbital paths to facilitate the scheduling of observations; ensure continued protection of protected frequency bands; co-ordinate with radio astronomy facilities to avoid main beam illuminations during observations at key facilities; conduct field tests to assess interference levels, etc. (NSF, 2023[76]).

- Considering the need for more transparency and data, several space agencies make important efforts to monitor and report on the environmental performance of their facilities, which play an important role in the lifecycle not only of agency missions but also in that of many other space organisations that also access these facilities for product development and testing (OECD, 2016[77]; Olivari, Jolly and Undseth, 2021[78]). The German Aerospace Center (DLR) and NASA regularly publish the environmental performance of their respective facilities and ESA intends to reduce its facilities' consumption of electricity, gas and fuel by 46% by 2030, with a 100% shift to renewable energy (ESA, 2022[79]). This is part of ESA's "Green Agenda", intended to reduce the agency's environmental footprint overall and foster its contribution to the sustainable development of society. In its annual space industry survey, the UK Space Agency has introduced questions on industry carbon emissions, with 31% of survey respondents monitoring emissions (know.space, 2023[8]).

The vulnerability of space-based infrastructure also needs to be taken seriously, particularly when seen against the backdrop of mounting geopolitical tensions, also in the space environment. Many potential space-based military targets are dual use, including several navigation satellite constellations such as the US Global Positioning System, as well as certain commercial products and services heavily used by military customers. One example is Ukrainian military forces' reliance on commercial satellite broadband, but it also applies to earth observation satellites. As noted in previous chapters of this book, similar earth observation imagery can be used for environmental monitoring, disaster relief and humanitarian assistance. OECD provides several relevant resources to support work on critical infrastructure resilience and digital security, such as the *Recommendation of the Council on Digital Security of Critical Activities* (OECD, 2019[80]) and the *OECD Policy Toolkit on Governance of Critical Infrastructure Resilience* (OECD, 2019[81]).

The potential negative impacts of major space weather events are increasingly recognised in OECD countries (see for instance, (RAE, 2013[38]; PwC, 2016[82]) and several countries are improving their response systems and strategies. The US federal government identified space weather as one of the grand challenges for disaster risk reduction in its 2015 Space Weather Strategy (US National Science and Technology Council, 2015[83]) and the UK government issued a Severe Space Weather Preparedness Strategy in 2021 to increase the country's preparedness and resilience (BEIS, 2021[84]). However, there is a considerable need for more evidence both on the occurrence and recurrence of events as well as recorded impacts.

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5 Guide to the profiles

The following chapters present selected country profiles, focusing on members of the OECD Space Forum. The countries covered are (in alphabetical order): Canada, France, Germany, Italy, Korea, the Netherlands, Norway, Switzerland, the United Kingdom, and the United States.

Using a common framework to present information, country profiles provide facts and indicators for countries that are members of the OECD Space Forum. The country profiles provide a quick, at-a-glance, overview of important activities and trends related to the key themes of this book and include both long-standing and new indicators developed by the OECD Space Forum.

Each profile provides information on the state of the country's space sector; space-related government budgets, recent policy developments, as well as key commercial activities. These findings are supported by a selection of internationally comparable indicators, subject to data availability:

- "fast facts" indicators
- space budget trends and main programmes
- top applicants of space-related patents
- space-related official development assistance commitments
- production and excellence in space-related scientific journal categories.

Although the issue of international comparability is improving, national data on space industry employment and revenues are still not always directly comparable, due to structural differences in the composition of countries' respective space industries (e.g. the presence of satellite television providers will lead to higher revenue aggregates) as well as the scope of the underlying industry survey/data collection (which industry segments, inclusion of higher education and research institutes). The coverage and scope of data are identified in the text.

Throughout the country profiles, three-letter ISO country name abbreviations have been used. A list of country codes is provided at the beginning of the report, under Acronyms and abbreviations.

"Fast facts" indicators

The Fast facts boxes summarise indicators found in different chapters of the publication.

- The launch year of the first (successfully launched) satellite is a high-visibility marker of a country's space programme. The satellite can be domestically developed or purchased from abroad; in both cases, it represents significant investments and new technical capabilities.
- Orbital launch capability is a marker of high technological sophistication and national ambition. As of 2023, only 11 countries worldwide have demonstrated orbital launch capabilities, but this may change with OECD countries and other economies currently developing spaceports.
- A country's number of operational satellites in orbit is a proxy for a country's regulatory responsibilities and economic stakes in the future of the space economy and the orbital environment.
- The country's institutional space budget (in current USD) as a share of gross domestic product (GDP) is based on government sources and OECD calculations.
- The per capita space budget (in current USD) is intended as a quick and intuitive comparative indicator of the investments in institutional space programmes. The demographic data come from OECD databases

Space budget trends and main programmes

The indicator on institutional budgets provides a conservative estimate of the inflation-adjusted evolution of space programmes between 2015 and 2022. Also included is an overview of main space agency programmes for 2022 or the latest available year, subject to availability, which may indicate some of the key national priorities. Data come from government sources.

Budget trends are provided in both constant national currencies and in constant US dollars in order to give an indication of the currencies' fluctuations, as many space budgets are affected by exchange rates. For calculations, this report makes use of the consumer price index (all items) as a deflator and exchange rates from the *OECD Main Economic Indicators (MEI)* database.

Top applicants of space-related patents

The indicator on space-related patent applications tracks innovation activities in the space sector. Patent applicants are often business firms but can also be based in research organisations or higher education institutions.

Space-related patent applications are identified using a combination of codes from the International Patent Classification (IPC) and keyword searches in the patent title. Data refer to IP5 patent families (inventions patented in the five top IP offices) filed between 2006-10 and 2016-20, by first filing date and according to the inventor's residence, using fractional counts.

Space-related scientific excellence, international collaboration and production

Similar to patent indicators, bibliometric indicators on scientific paper production and citations also serve as proxies for innovation activities. Authors of scientific papers are most likely found in higher education institutions and research organisations.

The analysis is based on documents (i.e. papers in scientific journals and conference papers) in four selected space-related journal categories from Elsevier's Scopus Custom Data database, notably "aerospace engineering", "astronomy", "atmospheric science", and "space and planetary science". Categories can be overlapping, i.e. papers can be in more than one journal category. All analysis is based on fractional counts of papers by authors affiliated to institutions.

Top 10% most cited: The top 10% most cited documents is an indicator of excellence. This rate indicates the amount (in percentages) of a country's scientific output that is included into the group of the 10% of the most cited papers in their respective scientific fields. It is a measure of high quality of research output. The world average is 10% for the period.

International collaboration: Percentage of scientific publications involving international collaboration. International collaboration refers to publications co-authored among institutions in different countries. Estimates are computed for each country by counting documents for which the set of listed affiliations includes at least one address within the country and one outside. Single-authored documents with multiple affiliations in different countries count as institutional international collaboration.

Scientific production: Total number of scientific publications, fractional counts. Publications are attributed to countries based on the authors' institutional affiliations. Publications were fractionalised by contributing units (countries); so that reported figures add up to the total number of publications (each document has the same weight). Fractional counts can be aggregated. To improve comparability, country output was estimated per 100 000 inhabitants.

The Scopus Custom Data database allocates papers to scientific fields using the All Science Journal Classification (ASJC). It includes scientific publications in English (the majority) as well as other languages.

Space-related official development assistance commitments

This indicator identifies the main thematic sector and donors of space-related official development assistance (ODA) committed over the period 2000-21, as reported in the databases of the OECD Development Assistance Committee (DAC). It contributes to tracking the actual use of space technologies to address socio-economic challenges in developing countries.

The OECD's Development Co-operation Directorate has been in charge of measuring resource flows to developing countries since 1961, with particular attention given to the official and concessional part of this flow, defined as "official development assistance".

In close collaboration with DAC colleagues, the OECD Space Forum Secretariat has explored the databases using keyword searches. The original dataset has been manually checked and cleaned in order to identify and retain only the projects effectively dealing with space-related initiatives. More than 2 200 ODA projects employing space applications or technologies were identified over the period.

Data are reported by donor country and/or organisation, in deflated USD million, with 2021 as reference year. In some cases, the recipient cannot be identified, either because it was not specified by the donor country or because the ODA was not designating a specific recipient). The list of thematic sectors (e.g. general environment protection, telecommunications) is defined by DAC and attributed to a project when it is entered into the DAC database.

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6 Canada

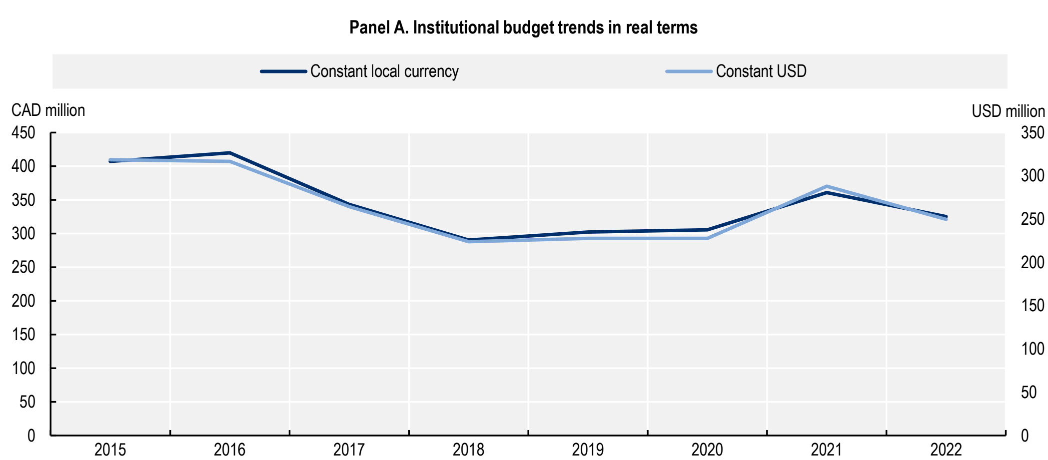
Table 6.1. Canada: At a glance

2022 or latest available year

First satellite in orbit	Alouette 1 (1962)
Number of satellites in orbit (as of 31 December 2022)	59
Number of spaceports	1 (under development)
Space-related workforce (2021)	11 600 (full-time equivalents)
Space-related commercial revenues (2021)	USD 3.9 billion
Institutional space budget as a share of gross domestic product	0.014
Institutional space budget per capita	7.7

Canada counts among the most experienced space nations with its first satellite launched in 1962, and continues to demonstrate excellence in several space domains, including earth observation, space robotics and satellite communications. The country has sent nine astronauts to space under US programmes, with a tenth astronaut participating in Artemis 2, scheduled for 2024, the first crewed mission to the Moon since 1972. Canada is a trusted partner in international space exploration programmes with participations in the International Space Station and the US-led Lunar Gateway program.

Figure 6.1. Canada: Space budget trends



Source: OECD analysis based on institutional sources.

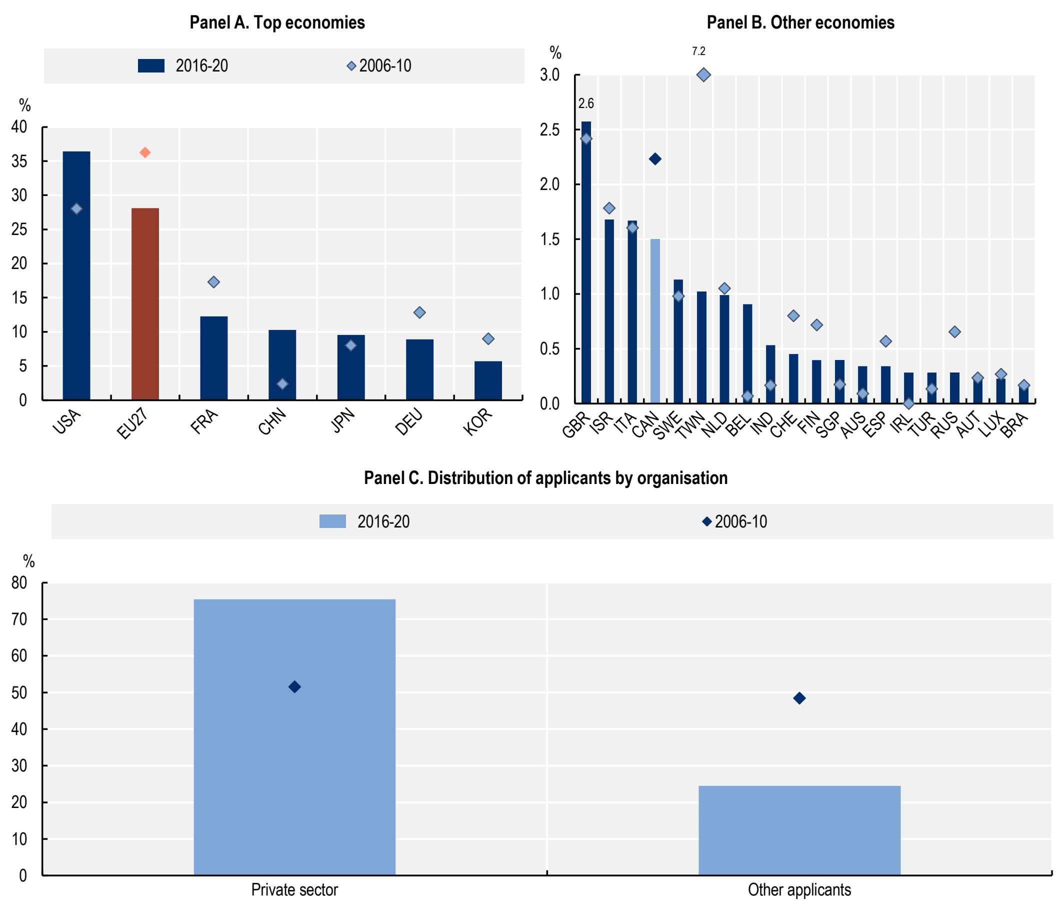
In 2022, Canada's institutional space budget amounted to USD 298 (CAD 388 million), representing 0.014% of Canada's gross domestic product. The budget has experienced a 3.2% yearly average decrease since 2015 in real terms (Figure 6.1). Key priorities include space exploration through the Lunar Programme, e.g. with the development of the robotic Canadarm3 to the US Lunar Gateway space station;

adapting to climate change with space-based data; and leveraging deep-space health and food innovations to deliver benefits on Earth.

According to Canada's space industry survey, the space sector generated USD 3.9 billion (CAD 4.9 billion) in revenues in 2021, which is a decline compared with pre-COVID-19 levels and linked to reduced export activity. Satellite communications represented 79% of revenues. The Canadian space sector employed 11 600 full-time equivalents in 2021, mainly in the regions of Quebec and Ontario. Canadian space operator Telesat is developing a constellation in the low-earth orbit for satellite broadband and has received CAD 1.4 billion in support by the Canadian government, partly as a loan and partly as an equity share investment, to provide satellite broadband to remote parts of Canada. Canada's first commercial spaceport is also under development on the eastern coast, in Nova Scotia, with the first launch planned in 2024.

Figure 6.2. Canada: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts



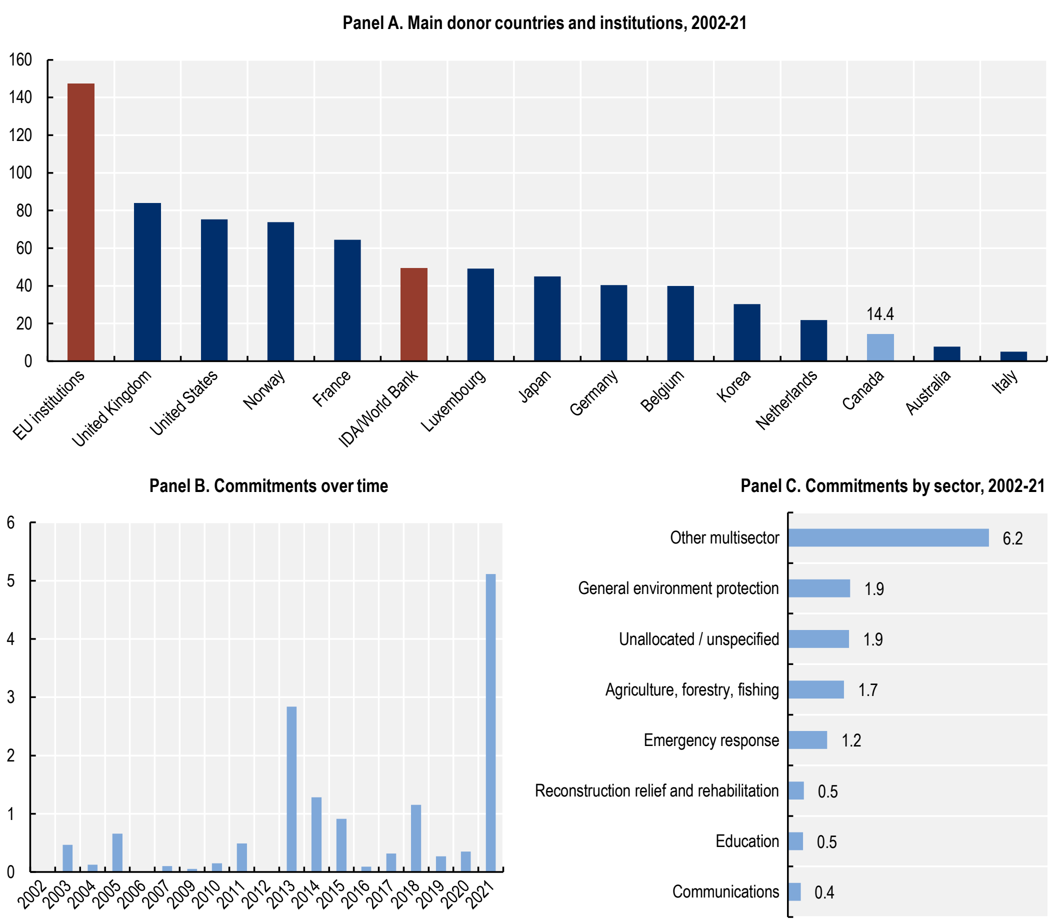
Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Canada’s share of space-related patent applications worldwide reached 1.5% in the 2016-20 period, which is a decline compared with 2006-10, as shown in Figure 6.2. A majority of applications (76%) were filed by private firms in 2016-20. “Other applicants” refer to higher education institutions and individuals.

Based on data in the OECD Development Assistance Committee Creditor Reporting System database, Canada committed some 14 million constant US dollars in space-related official development assistance over the 2002-21 period, (Figure 6.3). Commitments mainly focused on the use of space technologies for multi-sector aid and disaster risk reduction (“other multisector”); environmental policy and management (“general environment protection”); and to preserve agricultural land and water resources and support food crop production (“agriculture, forestry, fishing”).

Figure 6.3. Canada: Space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), “Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In terms of scientific output and excellence (Table 6.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at Canada-affiliated institutions performed above OECD average in 2021 for aerospace engineering, and slightly below average for the other space-related journal categories.

Table 6.2. Canada: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	Canada	OECD	**Canada**	OECD	**Canada**	OECD	**Canada**	OECD
Percentage of scientific publications among the world's 10% top-cited publications	**13.1**	12.8	**11.3**	12.7	**8.6**	9.8	**11.8**	12.7
Percentage of scientific publications involving international collaboration	**28.2**	18.0	**65.1**	60.9	**49.0**	42.3	**61.7**	56.1
Publications per 100 000 inhabitants	**0.5**	0.4	**0.4**	0.5	**0.6**	0.4	**0.5**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts. The data are subject to significant fluctuations due to a low yearly number of publications.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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7 France

Table 7.1. France: At a glance

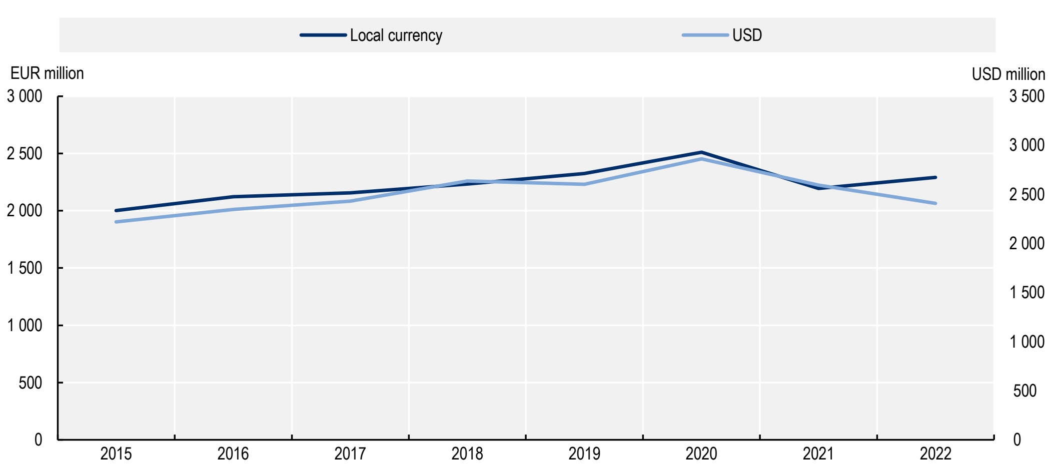
2022 or latest available year

First satellite in orbit	Astérix (1965)
First successful orbital launch	1965 (Diamant A)
Number of satellites in orbit	37
Number of spaceports	1 (Kourou Space Centre in French Guiana)
Space-related workforce (2020)	32 200 persons
Space-related commercial revenues (2020)	USD 12.3 billion
Institutional space budget as a share of gross domestic product	0.097%
Institutional space budget per capita	39.4

France is one of the world's leading space nations, home to the European Spaceport in French Guiana and one of the biggest contributors to the European Space Agency, headquartered in Paris; as well as an active partner in multiple other international missions. The country has a strong space manufacturing base often associated with the aeronautical industry, with the biggest space-related manufacturing workforce in Europe.

Figure 7.1. France: Space budget trends

In constant USD and national currency (base year: 2015)

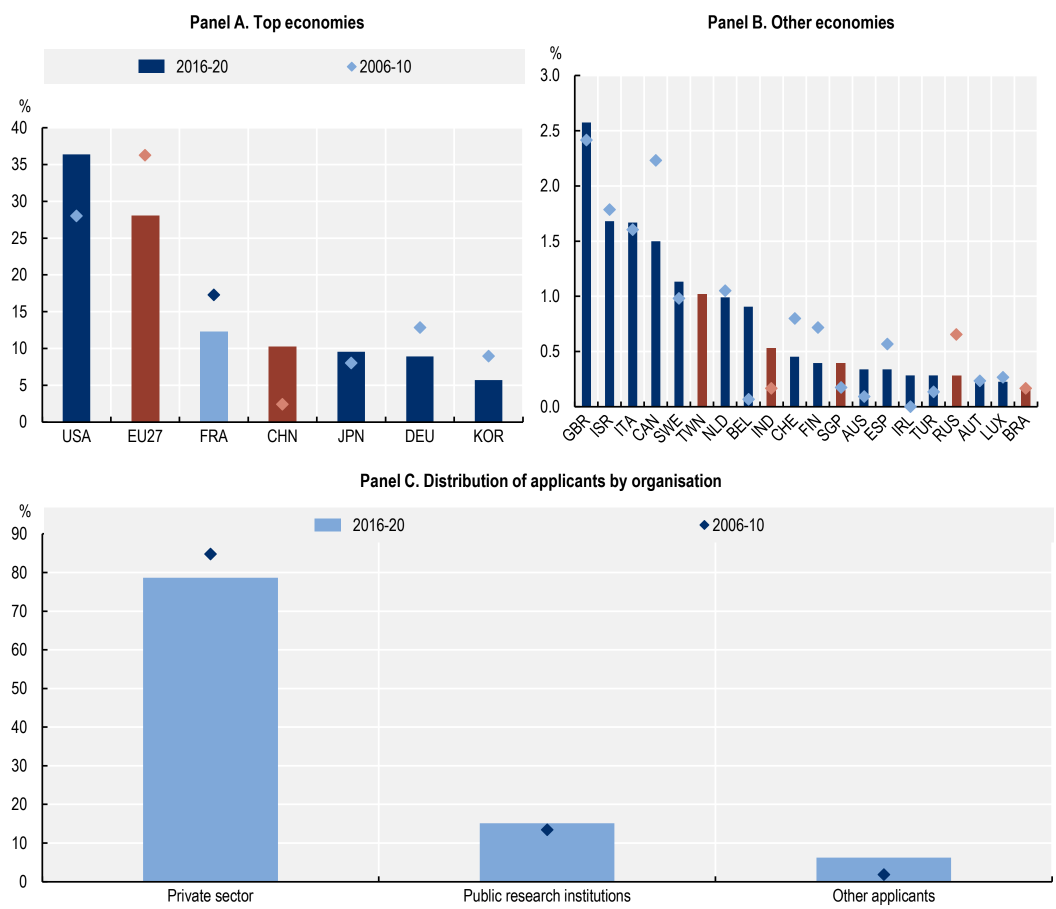


Note: Data include contributions to the European Space Agency and Eumetsat.
Source: OECD analysis based on institutional sources.

In 2022, France's institutional space budget reached USD 2 698.5 million (EUR 2 566 million), following a 1.9% yearly increase since 2015 in real terms (Figure 7.1). Contributions to the European Space Agency and Eumetsat accounted for 48.5% of the budget, with national and multilateral projects and activities covering the rest. Key strategic objectives of France include strengthening European autonomy in terms of launchers and access to space; raising competitiveness in telecommunications and earth observations; and improving space' contribution to the fight against climate change and applications benefiting the public. Overall, the institutional space budget accounted for 0.97% of France' gross domestic product in 2022. As part of the country's "France 2030" COVID-19 recovery package, EUR 1 550 million (2.9% of the total) have been earmarked for space activities in the coming years.

Figure 7.2. France: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts



Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

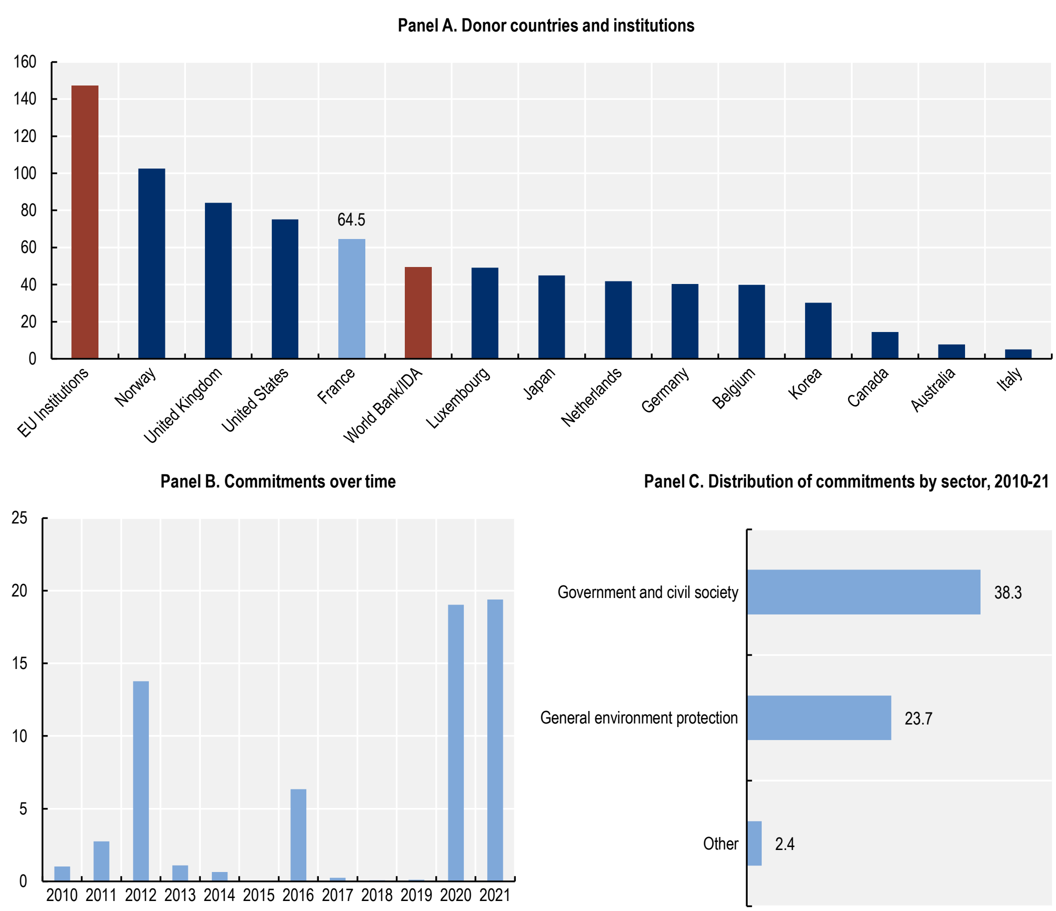
French statistical agency INSEE and CNES, France's space agency, conducted the first country-wide mapping of the French space manufacturing industry in 2022, identifying 1 700 firms involved in the sector in 2020, employing 33 200 people, and generating USD 12.3 billion (EUR 10.3 billion) in revenues, equally distributed between manufacturing and services (e.g. engineering and IT services). The Occitanie region in the southwestern part of the country accounted for a third of the space sector's workforce. These statistics do not include employment and revenues from activities such as satellite operations and satellite data/signal exploitation. The Space Economy Observatory, established in 2020, is providing new evidence on the French space sector, including growth among so-called "new space" actors (some 140 firms created between 2010 and 2022).

In the 2016-20 period, France was the third global applicant for patents in space-related technologies, as shown in Figure 7.2, accounting for 12% of applications worldwide, with a majority of applications filed by private firms (78.7%). This is a reduction compared with 2006-10.

Based on the data in the OECD Development Assistance Committee Creditor Reporting System database, France was among the OECD top-five country donors in space-related official development assistance over the 2002-21 period, with a total of 64.5 million constant US dollars committed (Figure 7.3). Commitments mainly focused on satellite transmission of Radio France Internationale ("government and civil society") and the provision of satellite data for forest monitoring ("general environment protection"), with recipient countries concentrated in Africa.

Figure 7.3. France: Trends in space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In terms of scientific output and excellence (Table 7.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at France-affiliated institutions performed at or above the OECD average for international collaboration and output in 2021, and slightly below for the percentage of publications among the world's top-cited publications.

Table 7.2. France: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	France	OECD	**France**	OECD	**France**	OECD	**France**	OECD
Percentage of scientific publications among the world's 10% top-cited publications	**9.1**	12.8	**9.9**	12.7	**8.3**	9.8	**11.9**	12.7
Percentage of scientific publications involving international collaboration	**39.0**	18.0	**69.4**	60.9	**53.4**	42.3	**70.0**	56.1
Publications per 100 000 inhabitants	**0.3**	0.4	**0.6**	0.5	**0.4**	0.4	**0.6**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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8 Germany

Table 8.1. Germany: At a glance

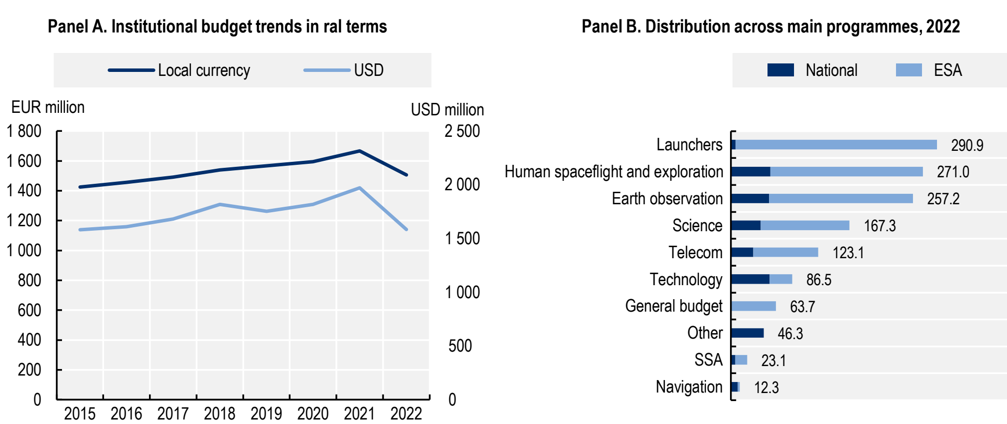
2022 or latest available year

First satellite in orbit	Azur (1969)
Number of satellites in orbit	51
Number of spaceports	1 (under consideration)
Space-related workforce (2021)	9 200
Space-related commercial revenues (2021)	USD 2.8 billion
Institutional space budget as a share of gross domestic product	0.045%
Institutional space budget per capita	22.0

Germany is one of the leading space actors in Europe together with France in terms of contributions to the European Space Agency. The country hosts the European Organisation for the Exploitation of Meteorological Satellites and the European Southern Observatory, as well as the European Space Agency's Space Operations Centre.

Figure 8.1. Germany: Space budget trends

In constant USD and national currency (base year: 2015)



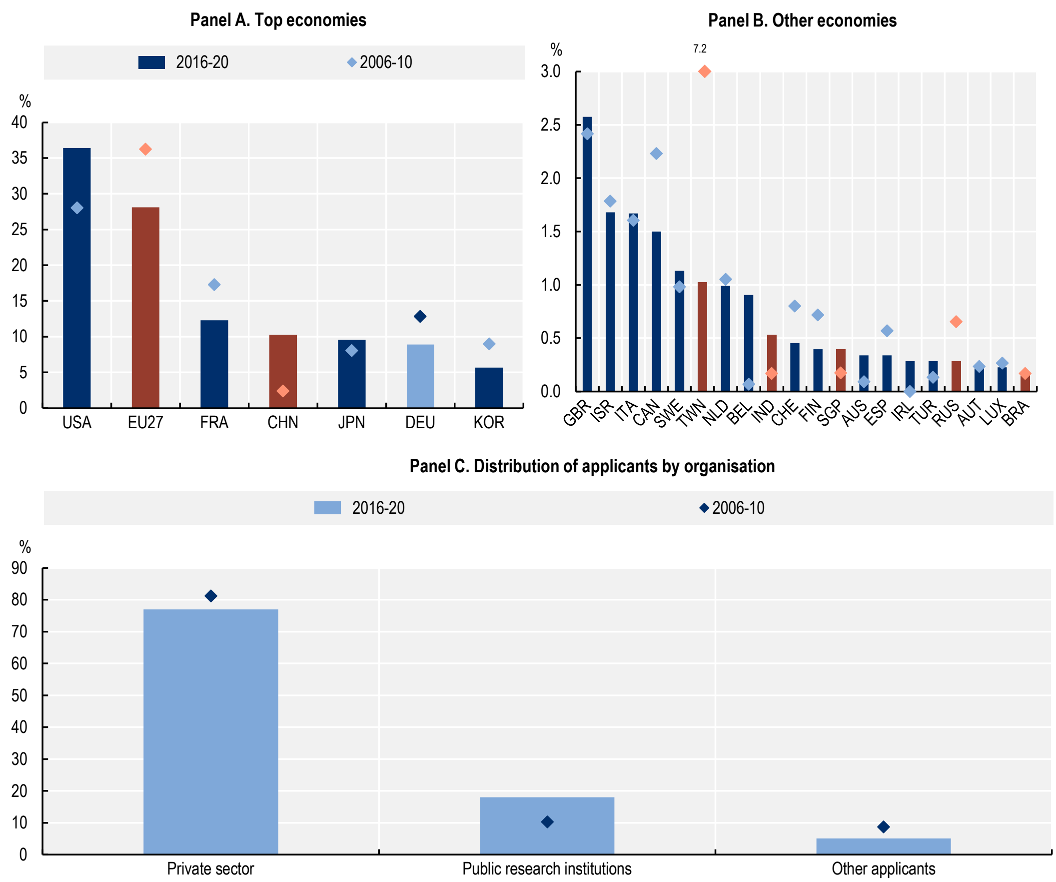
Note: Data include contributions to the European Space Agency and Eumetsat.
Source: OECD analysis based on institutional sources.

In 2022, Germany's institutional space budget reached USD 1 839.5 million (EUR 1 749.2 million), having grown 0.8% yearly since 2015 in real terms. Fifty-eight percent of the funding was allocated to the European Space Agency (most of which returns to Germany as contracts to academia and industry), as part of the Organisation's rule for geographic return), with another 5% dedicated to Eumetsat. The rest was reserved for national activities or smaller international programmes. Key programmes include launchers; human spaceflight and exploration; and earth observation (Figure 8.1). Overall, the institutional space budget accounted for 0.045% of the German gross domestic product in 2022.

A new national strategy was introduced in 2023 after an extensive consultation process involving stakeholders in research, industry and civil society as well as other government ministries. The strategy identifies nine fields of action, notably 1) European and international cooperation; 2) space high-tech and "new space" industry segments as markets of growth; 3) climate change, resources and environmental protection; 4) digitalisation, data and downstream; 5) security, strategic ability to act and global stability; 6) Sustainable use of space; 7) space science; 8) international space exploration; and finally, 9) space activities in "dialogue" with society and talent recruitment. New initiatives include for instance the suggested introduction of competitive launcher development in Europe, and a Space Innovation Hub to match public sector needs with private sector capabilities.

Figure 8.2. Germany: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts



Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

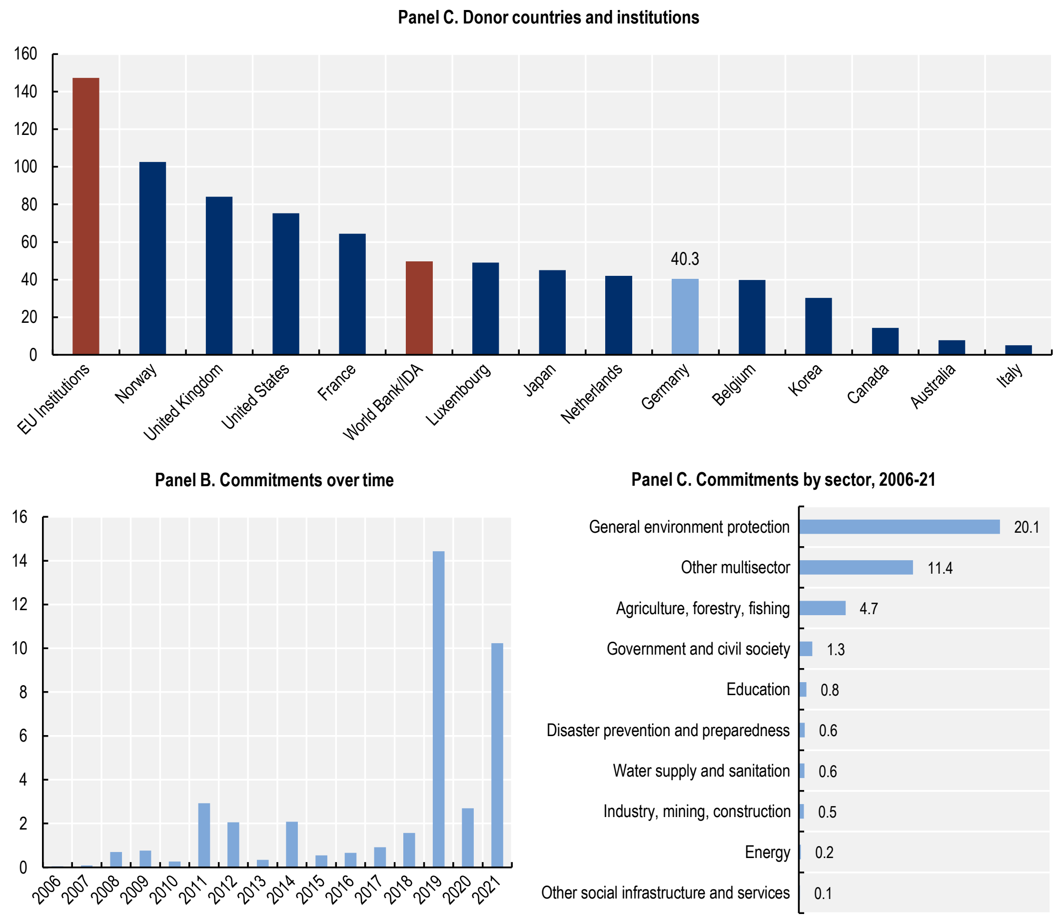
According to data from the German Aerospace Industry Association (BDLI), the German space manufacturing industry generated USD 2.8 billion (EUR 2.4 billion) in revenues in 2021, numbering 9 000 employees. The German Aerospace Centre (DLR) has launched its own survey to complement existing data and comprehensively map the German space sector.

In the 2016-20 period, Germany was the fifth applicant for patents in space-related technologies worldwide, accounting for 8% of applications, as shown in Figure 8.2. A majority of applications were filed by private firms (76.9%).

Based on the data in the OECD Development Assistance Committee Creditor Reporting System database, Germany was among the OECD top-ten country donors in space-related official development assistance over the 2002-21 period, with a total of 40.3 million constant US dollars committed (Figure 8.3). Commitments mainly focused on environmental protection (biodiversity) and rural capacity building, generally within the framework of the Group on Earth Observations. The biggest beneficiary region was Oceania, followed by "developing countries unspecified" and sub-Saharan Africa.

Figure 8.3. Germany: Trends in space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In terms of scientific output and excellence (Table 8.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at Germany-affiliated institutions performed above the OECD average for top-cited publications and publication outputs in the journal categories “Astronomy” and “Space and planetary science”, and ranking high on international co-authorships overall.

Table 8.2. Germany: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	Germany	OECD	**Germany**	OECD	**Germany**	OECD	**Germany**	OECD
Percentage of scientific publications among the world's 10% top-cited publications	**12.0**	12.8	**15.6**	12.7	**9.2**	9.8	**15.8**	12.7
Percentage of scientific publications involving international collaboration	**24.7**	18.0	**71.3**	60.9	**53.0**	42.3	**68.2**	56.1
Publications per 100 000 inhabitants	**0.6**	0.4	**0.7**	0.5	**0.6**	0.4	**0.7**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts. The data are subject to significant fluctuations due to a low yearly number of publications.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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9 Italy

Table 9.1. Italy: At a glance

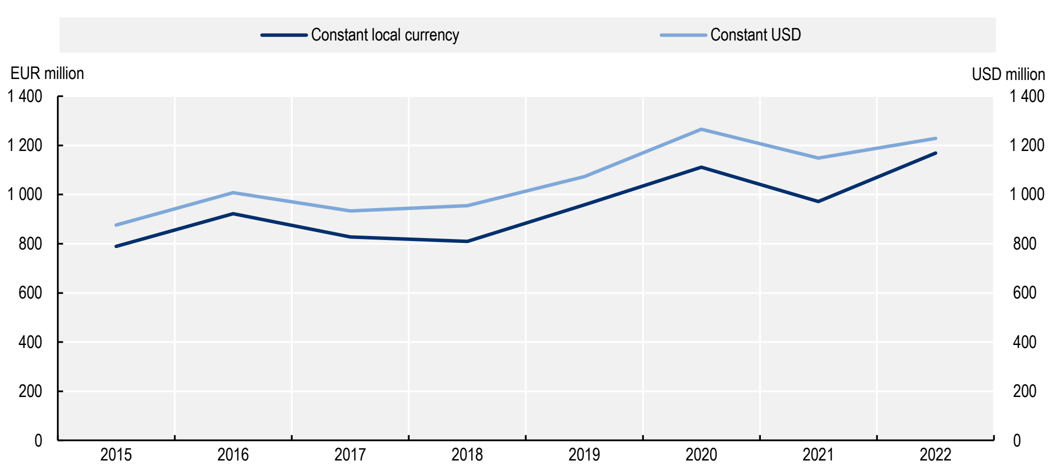
2022 or the latest available year

First satellite in orbit	San Marco 1 (1964)
Number of satellites in orbit	22
Number of spaceports	1 (under development)
Space-related workforce (2020)	7 000
Space-related commercial revenues (2020)	USD 2.3 billion
Institutional space budget as a share of gross domestic product	0.069%
Institutional space budget per capita	23.6

Italy has a long history of spaceflight and is the third-biggest contributor to the European Space Agency after France and Germany, with strong industry capabilities in space transportation and earth observation and dynamic research communities. The European Space Agency Centre for Earth Observation (ESRIN) is located in Italy, as is the European Centre for Medium-Range Weather Forecasts (ECMWF) data centre. The Space Geodesy Centre "Giuseppe Colombo", operated by the Italian Space Agency, is one of the most important geodetic observatories in the international network.

Figure 9.1. Italy: Space budget trends

In constant USD and national currency (base year = 2015)



Note: Data include contributions to the European Space Agency and Eumetsat.
Source: OECD analysis based on institutional sources.

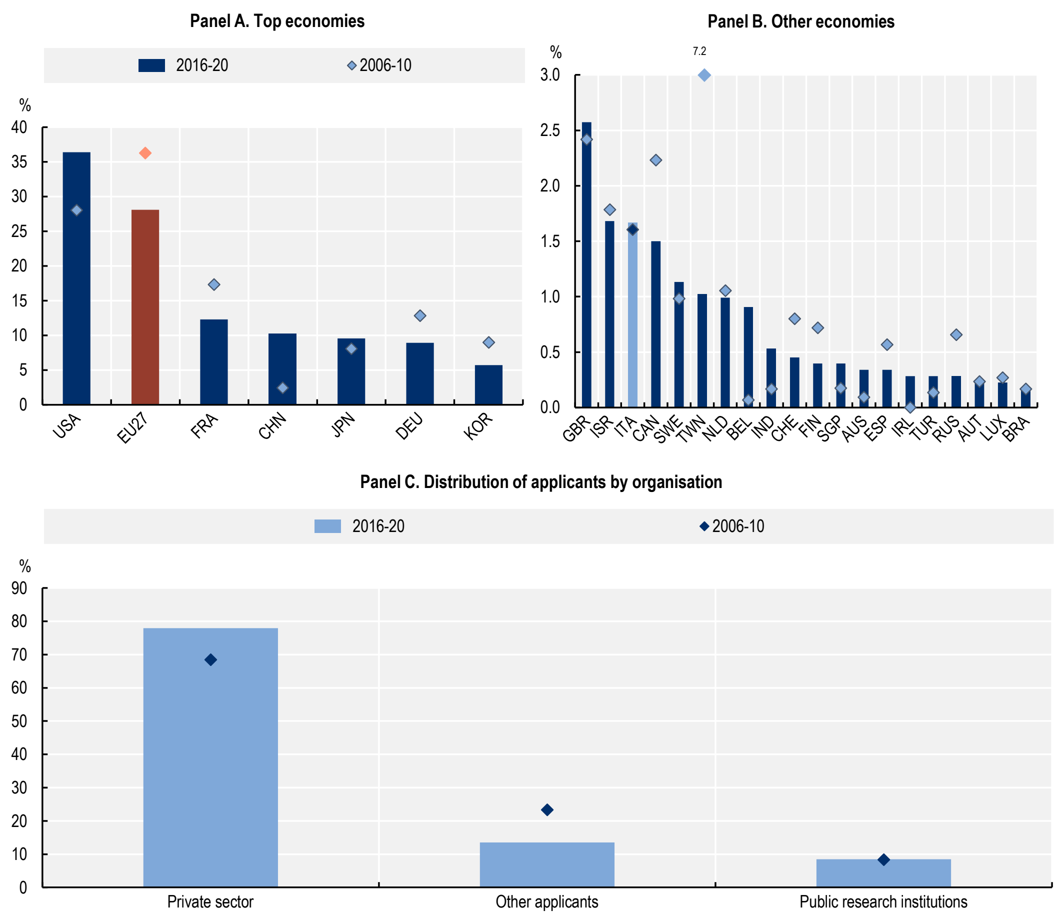
In 2022, Italy's institutional space budget reached USD 1 391 million (not accounting for National Recovery Funds not managed by the Italian Space Agency). The budget has grown significantly since 2015, with a

5.8% yearly growth rate in real terms (Figure 9.1). This includes contributions to the European Space Agency (accounting for 51% of the budget) and Eumetsat (5%), with the rest dedicated to national activities and smaller international projects/programmes. Overall, the institutional space budget accounted for 0.069% of Italy's gross domestic product in 2022. Space is increasingly appreciated at the government level, reflected by recent budget increases and the creation of an inter-ministerial management council in 2018, placing space at the centre of government policy. Another budget hike was expected in 2023, as part of the National Recovery and Resilience Plan partly funded by the European Union.

The Italian space manufacturing industry has strong links to the defence and automotive industries and produces fully assembled space systems (e.g. launchers) as well as subsystems and instruments. In 2020, the Italian space industry generated revenues of about USD 2.3 billion (EUR 2 billion), employing some 7 000 full-time equivalents across main clusters in the centre of the country (in Lazio, Toscana, and Abruzzo).

Figure 9.2. Italy: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts



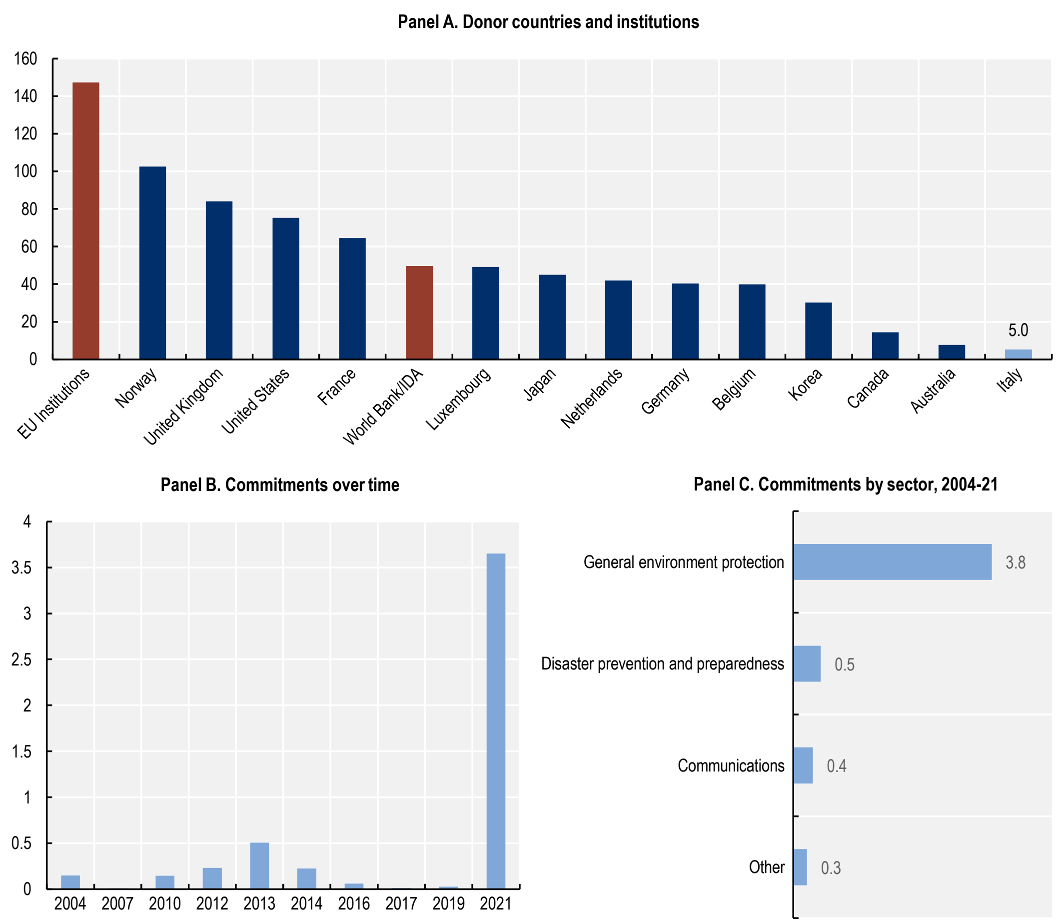
Notes: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Italy was among the top ten patent applicants in space-related technologies worldwide in the 2016-20 period, as shown in Figure 9.2, accounting for some 1.7% of applications. Private firms filed a majority of applications (77%). The share of private sector applicants increased between 2006-10 and 2016-20.

Based on data in the OECD Development Assistance Committee Creditor Reporting System database, Italy committed 5 million inflation-adjusted US dollars to space-related official development assistance over the 2002-21 period (Figure 9.3), with projects focused on environmental protection and disaster prevention and management. Italy also provides assistance indirectly, via European Union institutions, the European Space Agency and the World Bank.

Figure 9.3. Italy: Trends in space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In terms of scientific output and excellence (Table 9.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at Italian-affiliated institutions performed above OECD average in 2021, for all indicators and across all three journal categories, especially for atmospheric science.

Table 9.2. Italy: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	Italy	OECD	**Italy**	OECD	**Italy**	OECD	**Italy**	OECD
Percentage of scientific publications among the world's 10% top-cited publications	**13.5**	12.8	**13.8**	12.7	**17.0**	9.8	**13.2**	12.7
Percentage of scientific publications involving international collaboration	**26.2**	18.0	**58.9**	60.9	**50.6**	42.3	**61.7**	56.1
Publications per 100 000 inhabitants	**0.6**	0.4	**1.0**	0.5	**0.3**	0.4	**0.8**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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Union of Concerned Scientists (2023), *UCS Satellite Database*, 1 January 2023 version, data extracted 27 July 2023, https://www.ucsusa.org/resources/satellite-database.

10 Korea

Table 10.1. Korea: At a glance

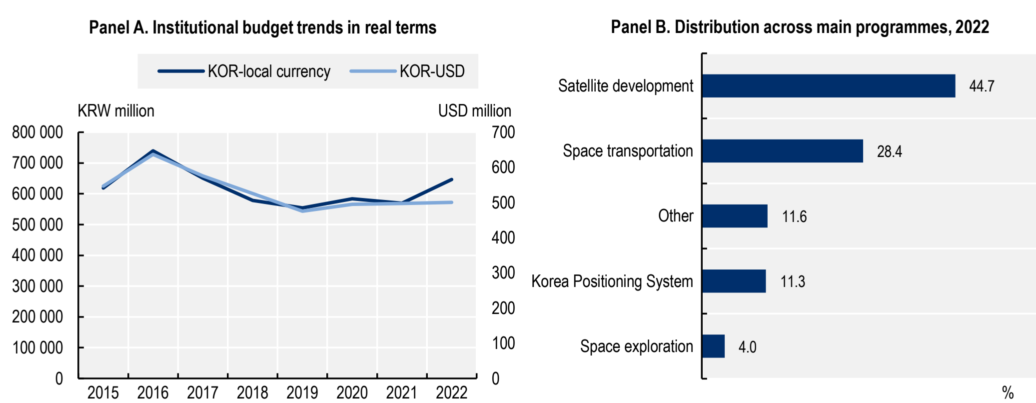
2022 or latest available year

First satellite in orbit	KITSAT-1 (1992)
First successful orbital launch	2013
Number of satellites in orbit	21
Number of spaceports	1 (Naro Space Centre)
Space-related workforce (2021)	9 797 persons
Space-related commercial revenues (2021)	USD 2.8 billion
Institutional space budget as a share of gross domestic product	0.034%
Institutional space budget per capita	10.1

Korea has an ambitious space programme, with domestic capabilities in satellite manufacturing and launch, as well as independent space access. In 2022, the country's first lunar orbiter Danuri successfully entered into orbit around the Moon. Korea is furthermore working to enhance its satellite navigation infrastructure by creating the Korea Augmentation Satellite System, to be followed by a regional satellite navigation system by the 2030s, the Korea Positioning System (KPS).

Figure 10.1. Korea: Space budget trends

In constant USD and national currency (base year: 2015)



Source: OECD analysis based on institutional sources.

In 2022, Korea's institutional space budget reached USD 568.4 million (KRW 734 billion), following a yearly 0.6% increase since 2015. The lion's share of the budget is devoted to satellite development (e.g. for earth observation and the KPS satellite navigation system), to foster commercial growth (Figure 10.1). Other budget priorities included launcher development (space transportation), the development of the

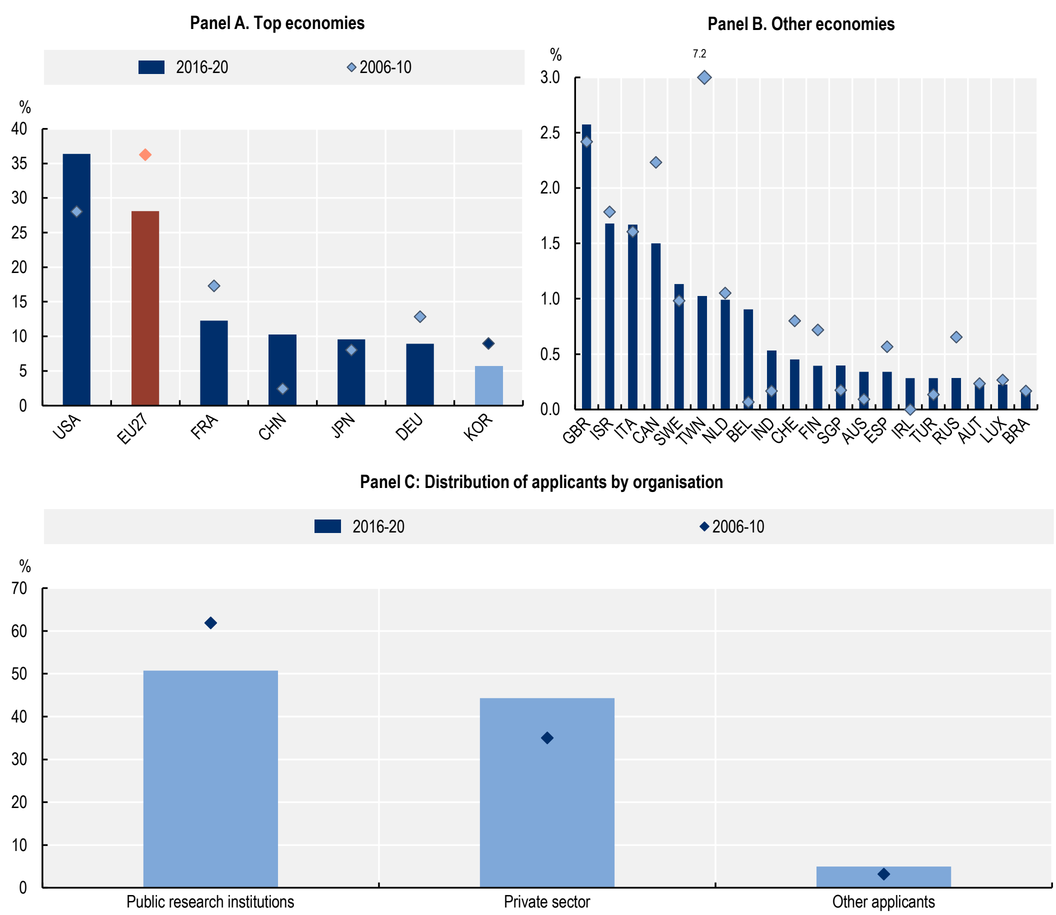
Korea Positioning System and space exploration. Satellite manufacturing responsibilities are being transferred from the country's government research institutions to the private sector. Overall, the institutional space budget accounted for 0.034% of Korea's gross domestic product in 2022.

According to Korea's pace industry survey, the space sector (comprising private firms, government research institutes and universities) employed 9 797 persons in 2021 and generated some USD 2.8 billion (KRW 3 189.3 billion) in revenues, mainly from the manufacturing of equipment related to satellite television and satellite navigation (e.g. set-top boxes).

Korea was among the top-ten patent applicants in space-related technologies worldwide in 2016-20 period, accounting for 6% of applications, as shown in Figure 10.2. A majority of applications (51%) were filed by public research institutions. The share of private sector applicants has increased between 2006-10 and 2016-20, from 35% to 44%.

Figure 10.2. Korea: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts

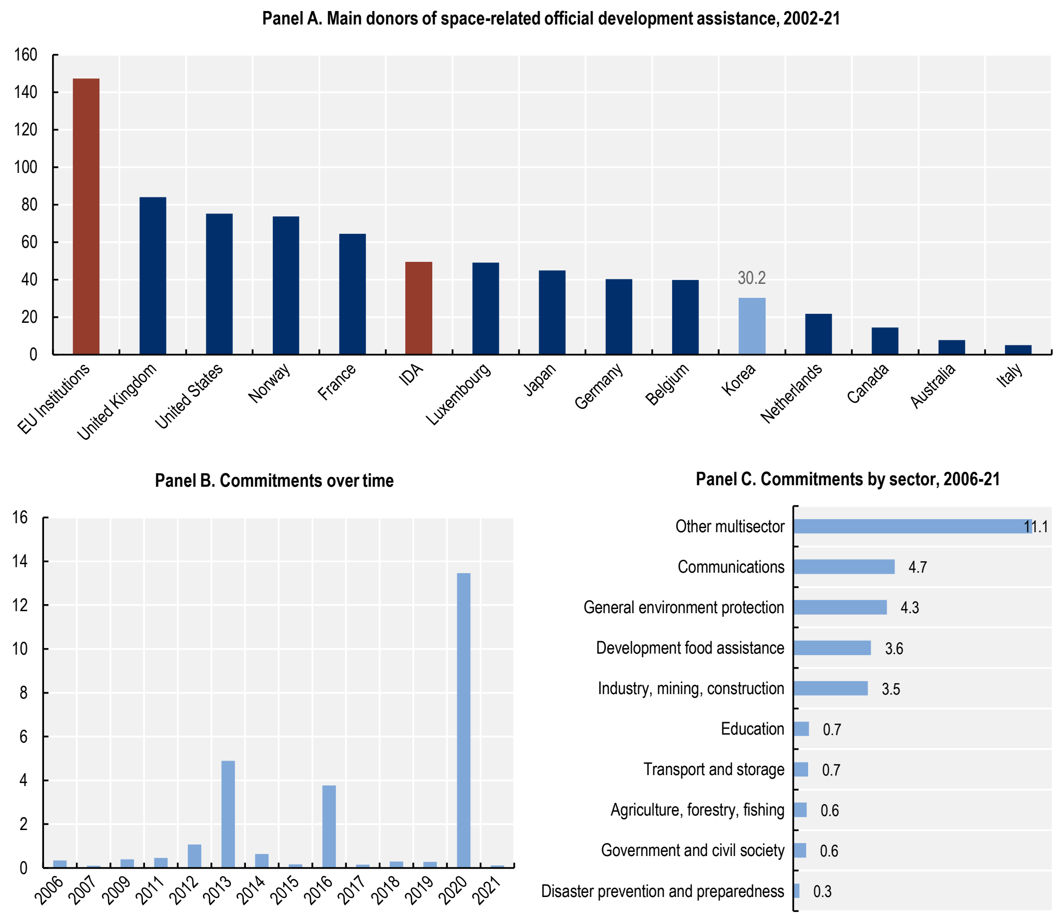


Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Based on data in the OECD Development Assistance Committee Creditor Reporting System database, Korea is among the OECD top-ten country donors in space-related official development assistance over the 2002-21 period, with a total of 30 million constant USD committed (Figure 10.3). Commitments mainly focused on the provision of satellite data for disaster risk reduction (under "multisector aid") and the utilisation of Korean weather satellites (under "telecommunications"), predominantly to Asian recipients. There were also projects using satellite imagery for mineral/mining prospection and exploration or training sessions for the use of global satellite navigation systems (GNSS) in air transport.

Figure 10.3. Korea: Trends in space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In terms of scientific output and excellence (Table 10.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at Korean-affiliated institutions performed at or slightly below the OECD average in 2021.

Table 10.2. Korea: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	Korea	OECD	**Korea**	OECD	**Korea**	OECD	**Korea**	OECD
Percentage of scientific publications among the world's 10% top-cited publications	**10.2**	12.8	**5.9**	12.7	**8.2**	9.8	**5.8**	12.7
Percentage of scientific publications involving international collaboration	**17.4**	18.0	**55.6**	60.9	**38.4**	42.3	**50.0**	56.1
Publications per 100 000 inhabitants	**0.4**	0.4	**0.2**	0.5	**0.3**	0.4	**0.3**	0.5

Notes: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts. Journal categories may be overlapping (e.g. "astronomy" and "space and planetary science").
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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Scopus Custom Data, Elsevier, Version 1.2023.

Union of Concerned Scientists (2023), *UCS Satellite Database*, 1 January 2023 version, data extracted 27 July 2023, https://www.ucsusa.org/resources/satellite-database.

11 The Netherlands

Table 11.1 The Netherlands: At a glance

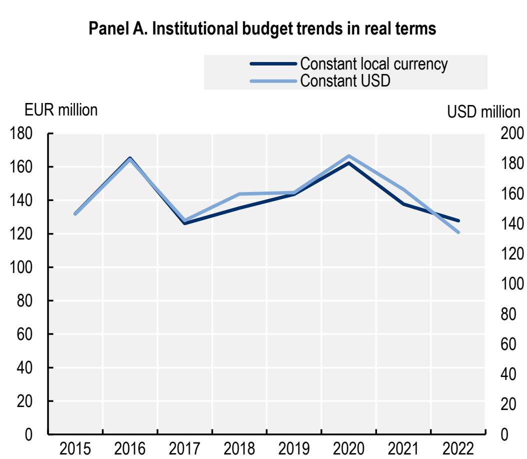
2022 or latest available year

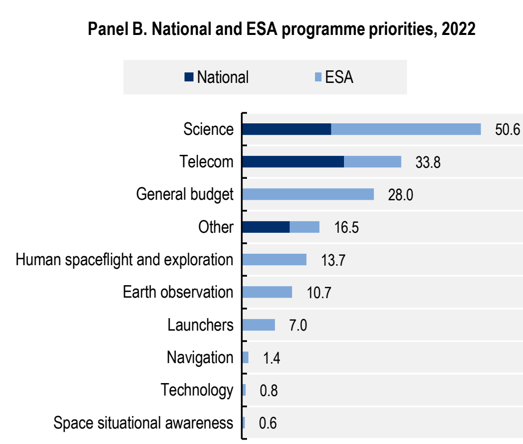
First satellite in orbit	Astronomical Netherlands Satellite (ANS), 1974
Number of satellites in orbit (as of 31 December 2022)	15
Space-related workforce (2018)	6 000[1] full-time equivalents
Space-related commercial revenues (2018)	USD 966 million
Institutional space budget as a share of gross domestic product	0.016
Institutional space budget per capita	9.2

1. 2 500 of this total are employees based at the European Space Research and Technology Centre (ESTEC).

The Netherlands is a founding member of the European Space Agency (ESA) and hosts the European Space Research and Technology Centre (ESTEC). The country has strong research communities and capabilities in space-related science and engineering and has provided instruments to international missions such as TROPOMI, measuring air quality, and contributed to the Mid InfraRed Instrument (MIRI) on the US James Webb Telescope. The country further hosts the Galileo Reference Centre, which monitors and assesses the accuracy and availability of European Union programme Galileo services for positioning, navigation and timing.

Figure 11.1. The Netherlands: Space budget trends and main programmes





Note: Space budgets include national activities and allocations to the European Space Agency and Eumetsat.
Source: OECD analysis based on institutional sources.

In 2022, the institutional budget for space activities of The Netherlands amounted to some USD 163.1 million (EUR 155 million), indicating a 0.5% yearly decline since 2015. The majority of funding

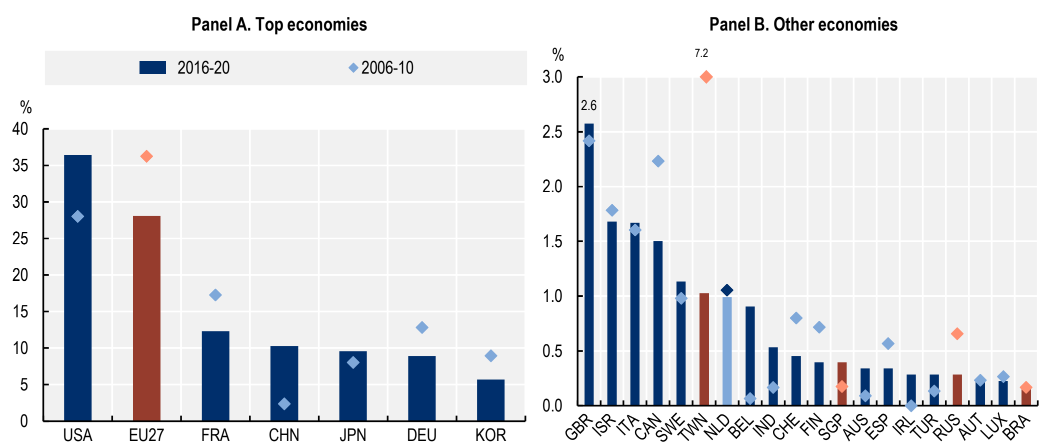
(87%) was channelled through the European Space Agency and returned to the country as contracts, through the Organisation's rule of geographical return, or allocated to other international organisations, such as Eumetsat (13.6%). Key programme priorities in 2022 included science and telecommunications (Figure 11.1). Overall, the institutional space budget accounted for 0.016% of the country's gross domestic product in 2022. The Netherlands has launched several nanosatellites (smaller than 10kg) in the last years, including its first military satellite in 2021 in partnership with a domestic manufacturer and Delft University of Technology; and two nanosatellites in 2023 in partnership with Norway, as part of the MilSpace2 project to remotely detect, classify and geolocate radio frequency signals (e.g. navigation radars on ships).

The Netherlands conducts industry surveys at regular intervals. In 2018, the space sector generated revenues of USD 966 million (EUR 820 million) and employed 6 000 full-time equivalents (some 40% of which were employed at ESTEC). Downstream activities focus on products and services for precision farming; infrastructure modelling; flood and water management; and navigation. Furthermore, several satellite operators are headquartered in the country. The space manufacturing sector produces subsystems (e.g., instruments and solar panels) and essential components (e.g. sensors, igniters) for satellites and launchers.

The Netherlands' maintained its share of patent applications in space-related technologies worldwide between 2006-10 and 2016-20, accounting for about 1% of applications, which is about the same as in the 2006-10 period (Figure 11.2).

Figure 11.2. The Netherlands: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts

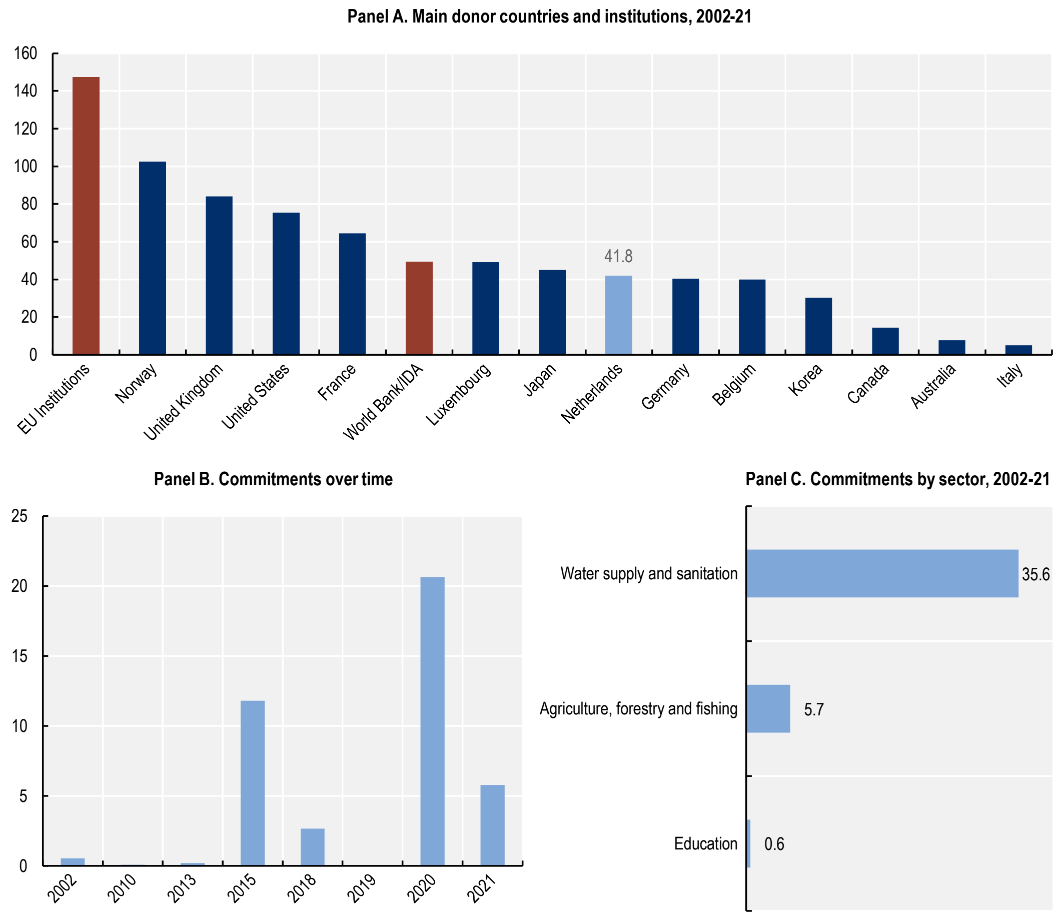


Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Based on data in the OECD Development Assistance Committee Creditor Reporting System database, the Netherlands committed some 41.8 million constant US dollars in space-related official development assistance over the 2002-21 period, (Figure 11.3), mainly as part of the Geodata for Agriculture and Water (G4AW) programme. The first project calls of G4AW were launched in 2013-14 with the aim to promote and support private investments for satellite-based information services for food producers in low-income countries.

Figure 11.3. The Netherlands: Space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[8]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In terms of scientific output and excellence (Table 11.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at Netherlands-affiliated institutions performed above OECD average in 2021, for all indicators and across all three journal categories, especially in astronomy and astrophysics and atmospheric science. In atmospheric science, some 15.7% of Netherlands-affiliated publications were among the world's 10% top-cited, compared to the 9.8% OECD average.

Table 11.2. The Netherlands: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy and astrophysics		Atmospheric science		Space and planetary science	
	The Netherlands	OECD average	**The Netherlands**	OECD average	**The Netherlands**	OECD average	**The Netherlands**	OECD average
Percentage of scientific publications among the world's	**12.1**	12.8	**17.0**	12.7	**15.7**	9.8	**16.7**	12.7

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy and astrophysics		Atmospheric science		Space and planetary science	
	The Netherlands	OECD average	**The Netherlands**	OECD average	**The Netherlands**	OECD average	**The Netherlands**	OECD average
10% top-cited publications								
Percentage of scientific publications involving international collaboration	**34.2**	18.0	**79.4**	60.9	**61.7**	42.3	**75.7**	56.1
Scientific publications per 100 000 inhabitants	**0.8**	0.4	**0.9**	0.5	**0.5**	0.4	**0.9**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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12 Norway

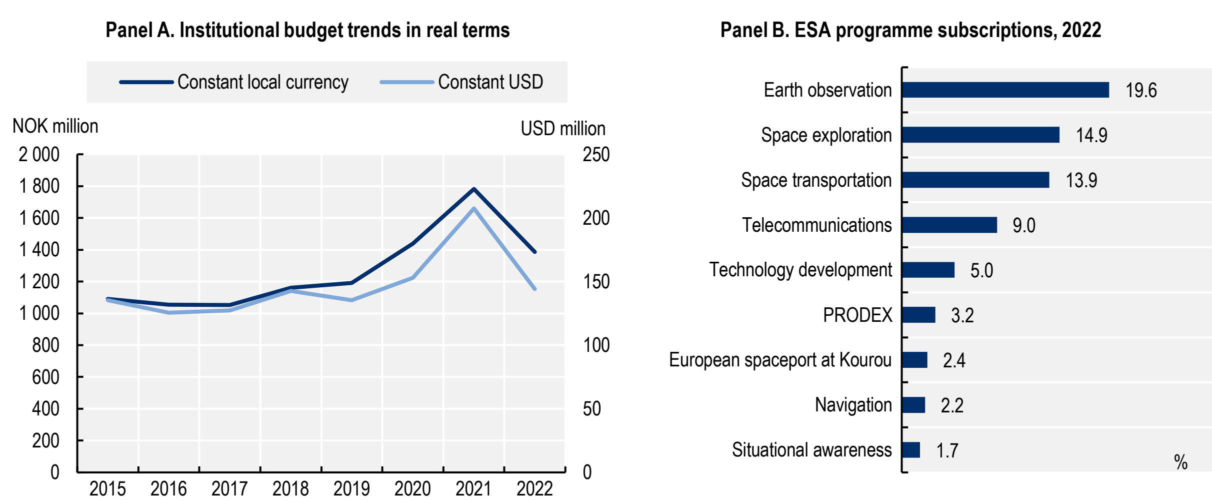
Table 12.1. Norway: At a glance

2022 or the latest available year

First satellite in orbit	Thor 1 (1992, acquired while on orbit)
Number of satellites in orbit (as of 31 December 2022)	9
Number of spaceports	1 (officially opened in 2023)
Space-related workforce (2021)	2 700
Space-related commercial revenues (2021)	USD 1.3 billion
Institutional space budget as a share of gross domestic product	0.031
Institutional space budget per capita	32.5

Norway has been involved in space operations for more than sixty years, starting in 1962 with the launch of a suborbital atmospheric sounding rocket in the northern part of the country. Norway is home to important ground stations for polar-orbiting satellites and the European Galileo navigation satellites, thanks to its position close to the north pole. In recent years, the country has invested in both space- and ground-based infrastructure to exploit space technologies for both societal and economic purposes.

Figure 12.1. Norway: Space budget trends and main programmes



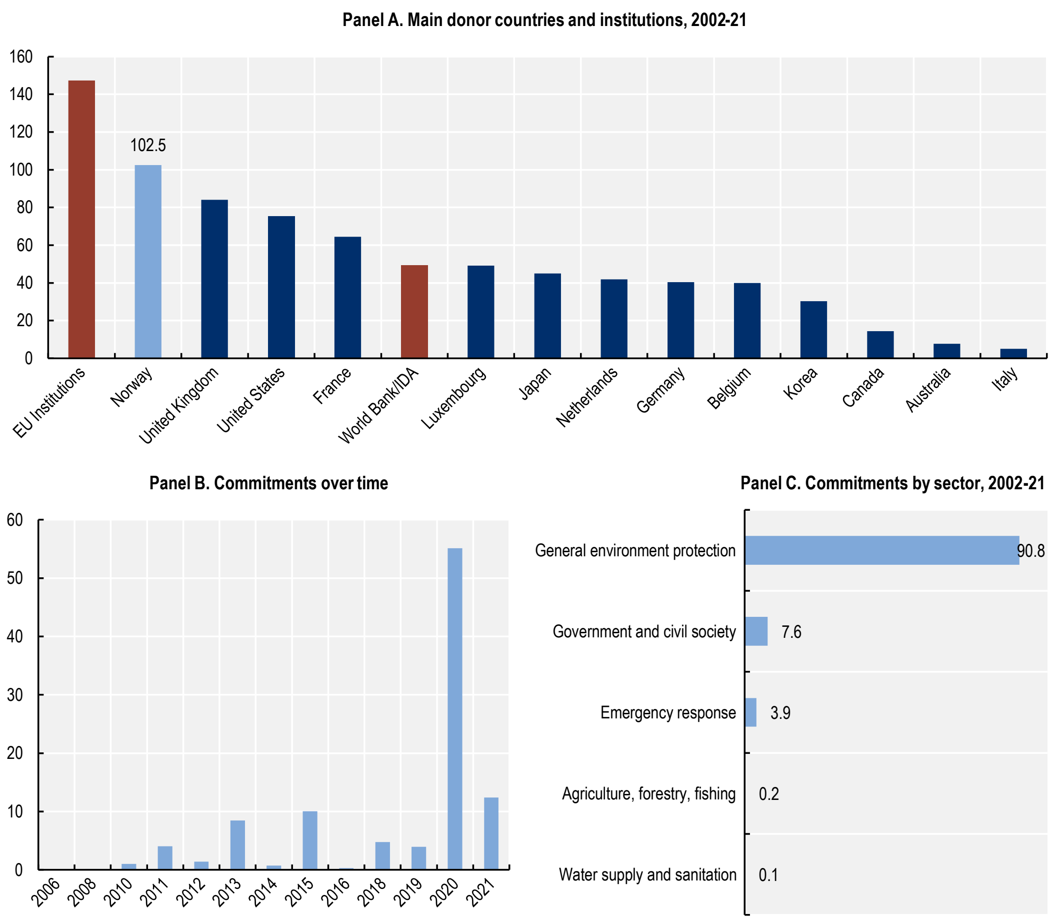
Note: Space budgets include national activities and allocations to the European Space Agency, European programmes Copernicus and EGNOS/Galileo and Eumetsat.
Source: OECD analysis based on institutional sources.

Government allocations to space activities have been rising steadily since 2015, with a yearly growth rate of 3.5%, reflecting the growing importance of space both for domestic and foreign policy objectives (Figure 12.1). Norway's institutional budget for space activities reached USD 177 million (NOK 1.7 billion) in 2022, the majority of which (76%) is subscriptions to the European Space Agency and European Union programmes for earth observation and navigation. Still, national activities play a growing role and the country has considerably expanded its space infrastructure in the last decade, for both government and commercial operations, including the development of satellites for maritime monitoring and Arctic broadband connectivity and the development of a commercial spaceport. Overall, the government institutional budget for space activities accounted for about 0.031% of the Norwegian gross domestic product in 2022. This is a conservative estimate, including only the most prominent space-related budget items in the Ministry of Trade, Industry and Fisheries and in the Ministry of Climate and the Environment.

Norwegian space industry has links to the defence, maritime and offshore sectors and has delivered subsystems to US and European launchers and missions, Industry revenues are dominated by telecommunications, maritime communications and satellite operations, reaching USD 1.3 billion (NOK 11 billion) in 2021. Employment in the Norwegian space sector was estimated to be 2 700 full-time equivalents.

Figure 12.2. Norway: Space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In 2020, Norway established the International Climate and Forest Initiative (NICFI) satellite data programme, which makes high-resolution and monthly updated imagery from private providers freely available for non-commercial use, to improve rainforest monitoring. Based on data in the OECD Development Assistance Committee Creditor Reporting System database, Norway was the top OECD country donor in space-related official development assistance over the 2002-21 period, with a total of 102 million constant US dollars committed (Figure 12.2). Commitments mainly focused on environmental policy and research purposes (general environmental protection); public sector policy and administrative management ("government and civil society"); and relief co-ordination and support services ("emergency response").

In terms of scientific output and excellence (Table 12.1), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science) show that authors at Norway-affiliated institutions performed above the OECD average in aerospace engineering in 2021 for the share of top-cited publications (excellence), and had a strong output in atmospheric science.

Table 12.2. Norway: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy and astrophysics		Atmospheric science		Space and planetary science	
	Norway	OECD average	**Norway**	OECD average	**Norway**	OECD average	**Norway**	OECD average
Percentage of scientific publications among the world's 10% top-cited publications	**18.0**	12.8	**5.2**	12.7	**6.8**	9.8	**7.1**	12.7
Percentage of scientific publications involving international collaboration	**29.2**	18.0	**68.0**	60.9	**60.6**	42.3	**69.9**	56.1
Scientific publications per 100 000 inhabitants	**0.3**	0.4	**0.4**	0.5	**1.4**	0.4	**0.6**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts. The data are subject to significant fluctuations due to a low yearly number of publications.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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13 Switzerland

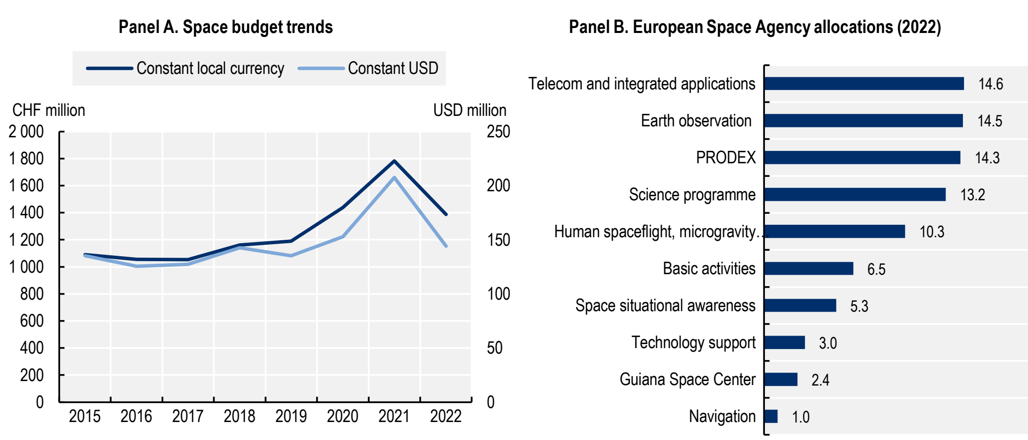
Table 13.1. Switzerland: At a glance

2022 or latest available year

First satellite in orbit	SwissCube-1 (2009)
Number of satellites in orbit (as of 31 December 2022)	15
Space-related workforce (2021)	1 500
Institutional space budget as a share of gross domestic product	0.036
Institutional space budget per capita	32.9

Switzerland has been involved in European space activities since the 1960s. As a founding member of the European Space Agency (ESA) and a participating state in the European Space Council, the country has a strong position in research and innovation in several domains, e.g. space science and scientific instruments. The country further hosts the Group on Earth Observations and signed an agreement in 2022 to host ESA's European Space Deep-Tech Innovation Centre.

Figure 13.1. Switzerland: Space budget trends and main programmes



Note: Space budgets include national activities and allocations to the European Space Agency, European programme EGNOS/Galileo and Eumetsat.
Source: OECD analysis based on institutional sources.

In 2022, the institutional space budget in Switzerland amounted to USD 288 million (CHF 276 million), following a 1.5% yearly increase since 2015 in real terms (Figure 13.1). This growth mainly reflects increasing contributions to the European Union programme for satellite navigation (EGNOS/Galileo). The budget is otherwise mainly centred on allocations to European Space Agency, which accounted for 68% of the overall budget in 2022. Key ESA programme posts in 2022 were telecommunications, earth observation, and the development of science experiments (PRODEX). Overall, the institutional space budget accounted for 0.036% of the Swiss gross domestic product in 2022.

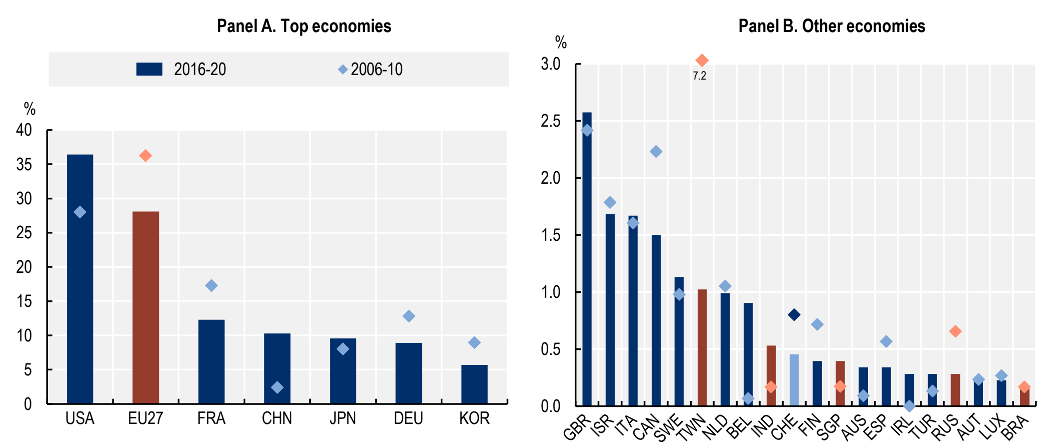
Switzerland published a new space policy in 2023, defining three strategic priorities: securing access to Europe's space infrastructure; ensuring competitiveness and relevance of the Swiss space industry; and promoting partnership and reliability in international co-operation. Switzerland is furthermore working on its first Space Act, with the aim to adopt practical and sustainable measures for space sector players and promote the responsible, peaceful, and sustainable use of outer space.

The Swiss space sector, which employs around 1 500 workers, has links to the aerospace and mechanics industries and produces subsystems for satellites and launchers (e.g. atomic clocks and fairings). Business firms are mainly located near universities or economic centres, such as Bern, Zürich, and French-speaking cantons (Geneva, Lausanne). A Swiss firm was awarded ESA's first service contract to remove debris from the low-earth orbit, with the launch planned in 2026. Another notable initiative includes the Space Sustainable Rating project, initiated in 2016 by the World Economic Forum and currently hosted by the Swiss Federal Institute of Technology in Lausanne, which assesses the sustainable conduct of space operators (e.g. data sharing, choice of orbit, etc.).

In terms of patent applications, a proxy for innovation activity and capabilities, Switzerland accounted for 0.4% of space-related applications worldwide in the period 2016-20, a notable decrease compared with 2006-10, as shown in Figure 13.2.

Figure 13.2. Switzerland: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts



Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

OECD indicators for scientific output and excellence (Table 13.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at Switzerland-affiliated institutions performed above OECD average in 2021, for all indicators and across all journal categories, especially in astronomy and astrophysics and atmospheric science. In space and planetary science, some 17.5% of the country's publications were among the world's 10% top-cited, compared to the 12.7% OECD average. Switzerland is home to several renowned universities and space-related observatories, including Swiss Federal Institutes of Technology (ETH) in Zürich and Lausanne, the Universities of Bern, Geneva, and Zürich, the Technical Universities of Windisch and Luzern, as well as the Observatory of Davos (which is linked to ETH Zürich).

Table 13.2. Switzerland: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	Switzerland	OECD	**Switzerland**	OECD	**Switzerland**	OECD	**Switzerland**	OECD
Percentage of scientific publications among the world's 10% top-cited publications	**16.9**	12.8	**16.2**	12.7	**11.0**	9.8	**17.5**	12.7
Percentage of scientific publications involving international collaboration	**38.0**	18.0	**71.0**	60.9	**61.8**	42.3	**76.9**	56.1
Publications per 100 000 inhabitants	**0.4**	0.4	**1.4**	0.5	**1.2**	0.4	**1.2**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts. The data are subject to significant fluctuations due to a low yearly number of publications.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

References

OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

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Union of Concerned Scientists (2023), *UCS Satellite Database*, 1 January 2023 version, data extracted 27 July 2023, https://www.ucsusa.org/resources/satellite-database.

14 United Kingdom

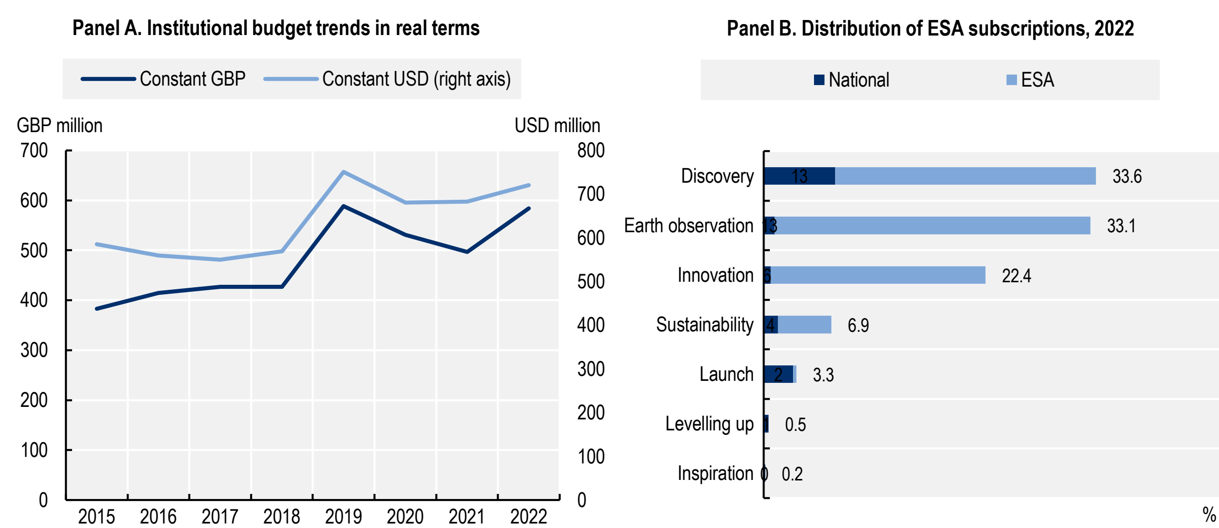
Table 14.1. United Kingdom: At a glance

2022 or the latest available year

First satellite in orbit	Ariel (1962)
First successful orbital launch	1971 (Black Arrow)
Number of satellites in orbit (as of 31 December 2022)	565
Number of spaceports	6 (under development)
Space-related workforce (2020)	48 800
Space-related commercial revenues (2020)	USD 21.6 billion (GBP 17.5 billion)
Institutional space budget as a share of gross domestic product	0.022%
Institutional space budget per capita	9.8

The United Kingdom has actively participated in space activities for more than 60 years and is one of the major contributors to the European Space Agency. It is home to the headquarters of the European Centre for Medium-Range Weather Forecasts and the European Space Agency Centre for Space Applications and Telecommunications. Major commercial satellite operators are based in the United Kingdom, making it one of the countries with the highest number of registered satellites.

Figure 14.1. United Kingdom: Space budget trends and main programmes



Source: OECD analysis based on institutional sources.

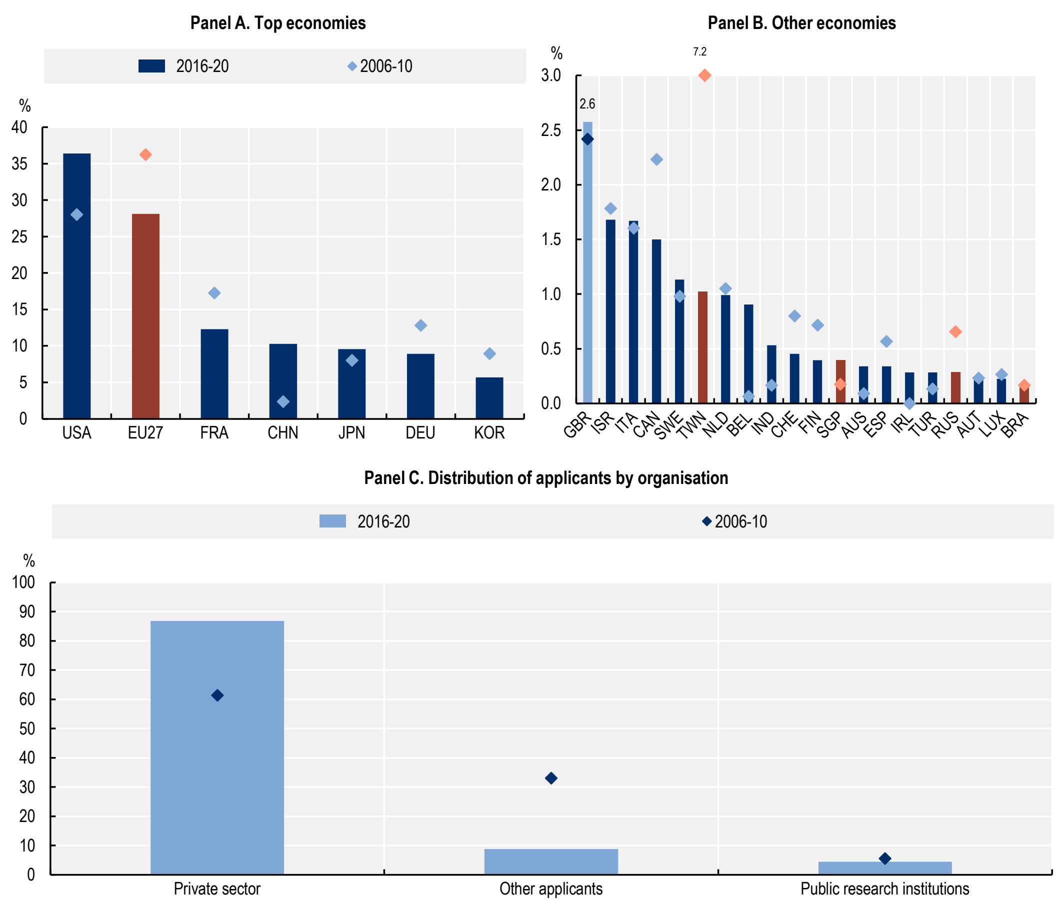
In 2022, the UK institutional space budget amounted to USD 867.9 million (GBP 704 million), comprising national activities, contributions to European Union programmes, the European Space Agency and Eumetsat. The budget has notably increased since 2015, with a 6.2% yearly growth in real terms (Figure 14.1). Contributions to the European Space Agency accounted for some 85% of the total in 2022. UK institutional space priorities include discovery (science and exploration); earth observation, innovation (high risk/high reward investments) and sustainability (to improve object tracking in orbit; and reduce and remove debris). A key national priority is space transportation with the support of several spaceports on UK soil – a first (failed) orbital launch attempt was made from Spaceport Cornwall in 2023. Overall, the UK institutional space budget accounted for some 0.022% of the gross domestic product in 2022.

According to the United Kingdom's survey on the size and health of the space industry, the UK space economy employed some 48 800 direct employees in 2020 and generated USD 21.6 billion (GBP 17.5 billion) in revenues, mainly from the exploitation of satellite data and signals. The provision of direct-to-home television accounted for almost half of total revenues (46%), followed by space manufacturing (12%). Employment is concentrated in the northern and southern parts of the country.

The United Kingdom was among the top ten patent applicants in space-related technologies worldwide in the 2016-20 period, accounting for 2.6% of applications, as shown in Figure 14.2. A majority of applications (87%) were filed by private firms.

Figure 14.2. United Kingdom: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts



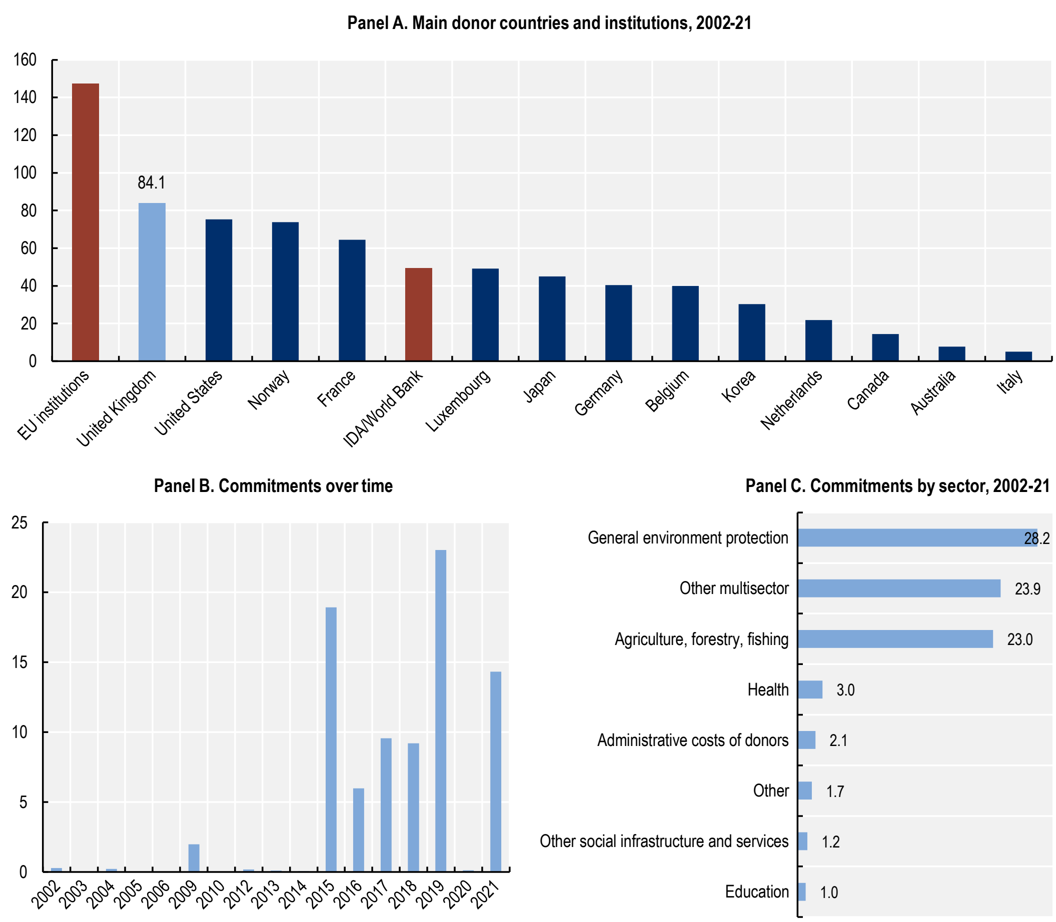
Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Based on data in the OECD Development Assistance Committee Creditor Reporting System database, the United Kingdom was among the OECD top donors in space-related official development assistance over the 2002-21 period, with a total of 84 million constant USD committed (Figure 14.3). Commitments mainly focused on the use of space technologies for environmental protection (e.g. for research and biodiversity purposes) and multisector activities (notably disaster risk reduction, rural development and food security policy).

The United Kingdom has been actively promoting space-based solutions in development assistance in its International Partnerships Programme, which was launched in 2016 as a five-year programme and completed its latest phase of work in 2022.

Figure 14.3. United Kingdom: Space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), "Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

In terms of scientific output and excellence (Table 14.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at UK-affiliated institutions performed above OECD average in 2021, for all indicators and across all three journal categories, especially in atmospheric science where some 14% of UK-affiliated publications were among the world's 10% top-cited, compared to the 9.8% OECD average.

Table 14.2. United Kingdom: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	United Kingdom	OECD	**United Kingdom**	OECD	**United Kingdom**	OECD	**United Kingdom**	OECD
Percentage of scientific publications among the world's 10% top-cited publications	**15.8**	12.8	**15.8**	12.7	**14.0**	9.8	**16.5**	12.7
Percentage of scientific publications involving international collaboration	**33.6**	18.0	**67.2**	60.9	**50.2**	42.3	**66.2**	56.1
Publications per 100 000 inhabitants	**0.6**	0.4	**0.9**	0.5	**0.7**	0.4	**0.9**	0.5

Notes: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts. Journal categories may be overlapping (e.g. “astronomy” and “space and planetary science”).
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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15 United States

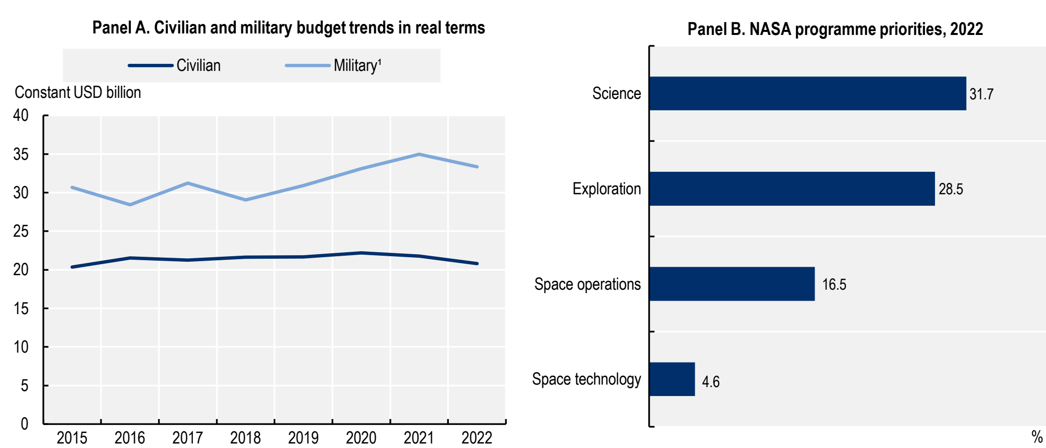
Table 15.1. United States: At a glance

2022 or the latest available year

First satellite in orbit	Explorer 1 (1958)
First successful orbital launch	1958 (Juno 1)
Number of satellites in orbit (as of 31 December 2022)	4 529
Number of spaceports	3 federal, 13 commercially-licensed (two of which are co-located on a federal range), 3 exclusive-use
Space-related workforce (2021)	360 000
Space-related commercial revenues (2021)	USD 211.6 billion (gross output)
Institutional space budget as a share of gross domestic product	0.243%
Institutional space budget per capita	186.1

The United States has been at the forefront of spaceflight for more than 60 years. It launched its first satellite (Explorer 1) into orbit in 1958 and has the world's largest government space programme. US-registered satellites accounted for more than half of all operational satellites in 2022, and the country is home to more than a dozen launch sites. The US government policy to support commercial industry through product and service procurement, as well as a dynamic venture capital landscape, have contributed to the current growth and vitality of the US space sector.

Figure 15.1. United States: Space budget trends and main programmes

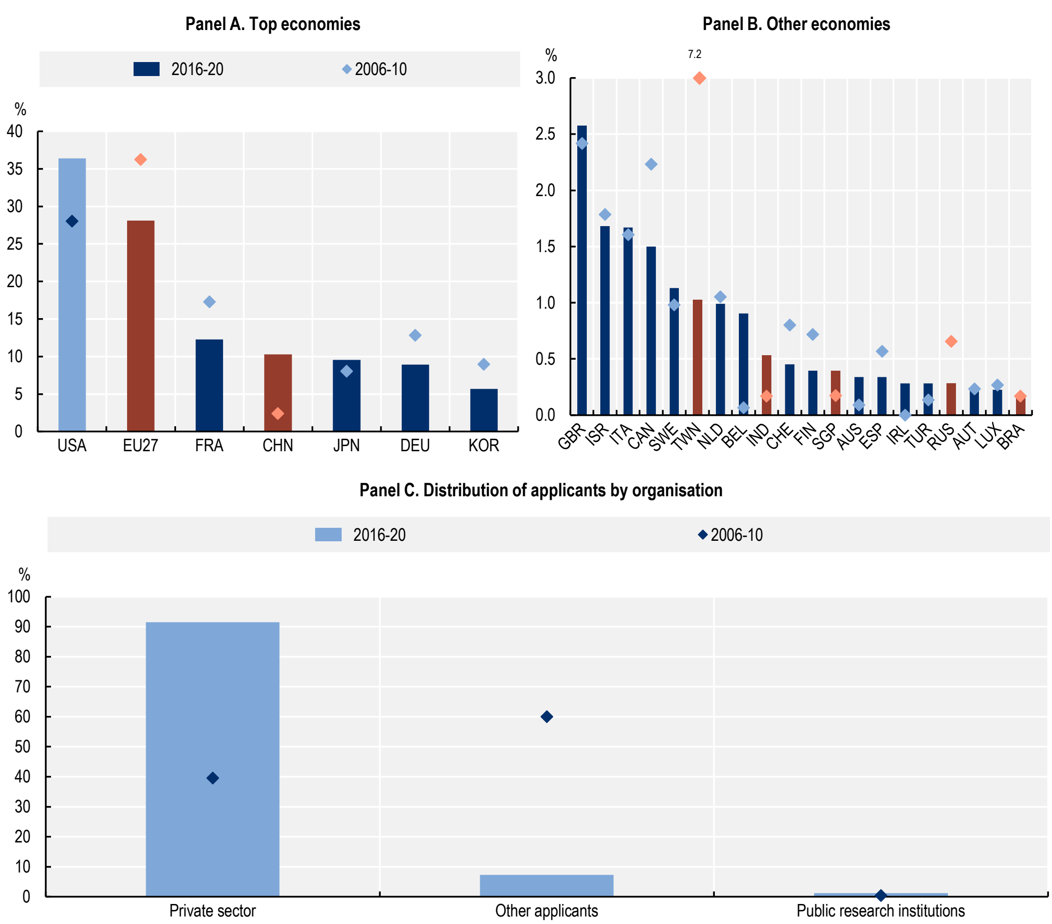


1. Does not include classified budget provisions.
Source: OECD analysis based on institutional sources.

The US institutional space budget for civilian activities amounted to USD 25.7 billion in 2022, comprising the activities of the National Aeronautics and Space Administration; the National Environmental Satellite, Data, and Information Service of the National Oceanic and Atmospheric Administration; the Landsat programme of the US Geological Survey; the Commercial Space Transportation Office in the Federal Aviation Administration; as well as activities in the Department of Energy (e.g. power systems), the Department of Agriculture (e.g. smart agriculture, forest fire management) and in the National Science Foundation. In real terms, this represents a 0.3% yearly growth since 2015 (Figure 15.1). Also in 2022, the US Space Force received USD 17.4 billion in government funding, with considerable additional classified space-related intelligence activities conducted in the National Reconnaissance Office and National Geospatial Agency, in addition to classified technology development and acquisition programmes. The overall space budget of the United States for 2022 was conservatively estimated to USD 60 billion, which represents 0.24% of gross domestic product. Key civilian exploration priorities include the Artemis programme, with the first crewed mission to the Moon since 1972 scheduled for 2024, and the deployment of a space station in lunar orbit (the "Gateway), with assembly starting no sooner than 2025. The science programme mainly comprises planetary and earth science (41% and 27% of the science portfolio, respectively), with smaller budgets allocated to astrophysics, heliophysics and the James Webb Space Telescope.

Figure 15.2. United States: Space-related patent applications

IP5 patent families, by priority date and applicant's location, using fractional counts



Note: Patent families are compiled using the information on patent families within the Five IP offices (IP5). IP5 patent families correspond to patent families filed in at least two offices worldwide, including at least one of the Five IP largest offices (IP5, i.e. the European Patent Office, EPO; the Japan Patent Office, JPO; the Korean Intellectual Property Office, KIPO; The China National Intellectual Property Administration, CNIPA; and the US Patent and Trademark Office, USPTO). Figures are based on incomplete data from the year 2019. "Other applicants" include private individuals, universities and private non-profit organisations.

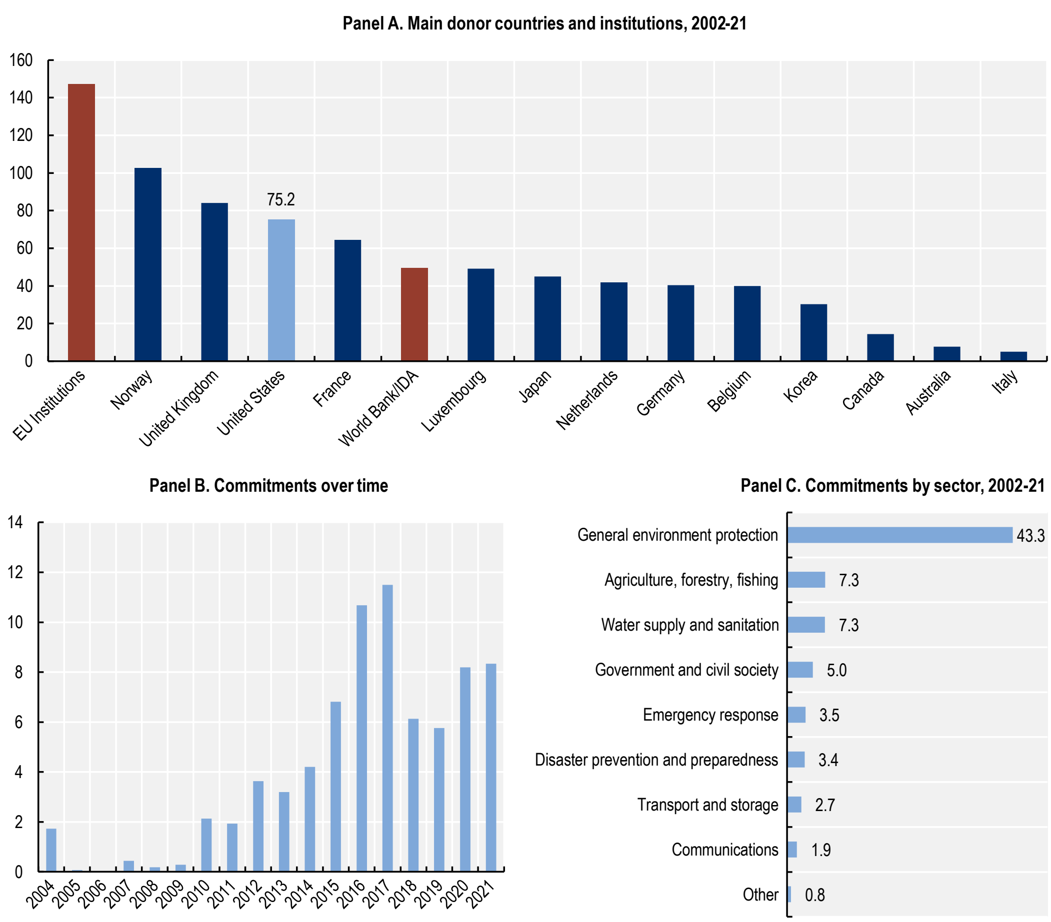
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

In terms of patent applications, a proxy for innovation activity and capabilities, the United States accounted for 36% of space-related applications worldwide in the period 2016-20, a notable increase by eight percentage points compared with the 2006-10 period, mainly driven by private sector applications (Figure 15.2). “Other applicants” refers to higher education institutions and private individuals.

The US is currently the only country with a thematic account for space activities, allowing it to track the space economy in robust and comparative ways with other parts of the US economy, using the statistical framework of national accounts. According to the US Bureau of Economic Analysis, the US space economy employed 360 000 workers and generated USD 211.6 billion in gross output in 2021, including government activities. Downstream information services and associated manufacturing accounted for some 40% of output. US space industry, which covers all segments from R&D to satellite data/signal exploitation and analysis (notably satellite broadband), caters both to a strong domestic government demand (including defence) and international markets. By the end of 2022, seven out of the ten biggest commercial space operators worldwide, in terms of number of satellites, were headquartered in the United States, four of which were founded after 2000 and three after 2010.

Figure 15.3. United States: Space-related official development assistance

In constant USD million (base year=2021)



Source: Calculations based on OECD (2023[1]), “Creditor Reporting System (CRS)", OECD.stat (database), https://stats.oecd.org/Index.aspx?DataSetCode=CRS1 (accessed on 24 April 2023).

Based on data in the OECD Development Assistance Committee Creditor Reporting System database, the United States committed some 75 million constant US dollars in space-related official development assistance over the 2002-21 period, (Figure 15.3), mainly to protect biodiversity and support environmental policy (general environment protection) and promote agricultural policy and forestry education/training (agriculture, forestry, fishing). The main recipient regions were sub-Saharan Africa and Far East Asia. A considerable share of the assistance was not tied to a specific region. Many projects were part of the SERVIR programme, which is a joint initiative of the National Aeronautics and Space Administration and the United States Agency for International Development and partner organisations, launched in 2004. SERVIR uses earth observation information, earth science and technology to increase awareness, improve access to information and support analysis in more than 50 countries.

OECD indicators for scientific output and excellence (Table 15.2), OECD indicators for scientific production, international co-authorships and citations in space-related scientific journal categories (aerospace engineering; astronomy; atmospheric science; and space and planetary science), show that authors at US-affiliated institutions performed above OECD average in 2021 for citations and outputs across all journal categories, except in atmospheric science. International co-authorships were less frequent in the United States than the OECD average in 2021.

Table 15.2. United States: Space-related scientific output and excellence indicators in 2021

Scientific journal categories (Scopus)	Aerospace engineering		Astronomy		Atmospheric science		Space and planetary science	
	United States	OECD	**United States**	OECD	**United States**	OECD	**United States**	OECD
Percentage of scientific publications among the world's 10% top-cited documents	**14.1**	12.8	**13.3**	12.7	**9.1**	9.8	**12.8**	12.7
Percentage of scientific documents involving international collaboration	**7.8**	18.0	**53.2**	60.9	**32.3**	42.3	**43.6**	56.1
Scientific document output per 100 000 inhabitants	**0.9**	0.4	**0.6**	0.5	**0.6**	0.4	**0.8**	0.5

Note: publications are attributed to countries based on the authors' institutional affiliations, using fractional counts. The data are subject to significant fluctuations due to a low yearly number of publications.
Source: OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2023.

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The Space Economy in Figures

RESPONDING TO GLOBAL CHALLENGES

Efforts to respond to global challenges have greatly benefited from space technologies that are more advanced, perform more efficiently and are operating at greater scale than ever before. But as the challenges facing society grow and intensify, questions arise as to whether the space sector can continue to deliver on its promise. Reaping the full benefits of what space activities have to offer will require substantial and targeted government action. Key priorities include maintaining the continuity and quality of government civilian missions, levelling the playing field for private actors entering the market, and securing the orbital environment for future generations. This edition of the Space Economy in Figures delves into these topics, drawing from both established and novel economic and policy data sources.

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