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The arguments employed herein do not necessarily represent the official views of the member countries of the OECD or the G20.

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**Key messages**

- As key components of the world’s growing digitalisation, space technologies will play a role in furthering social well-being and sustainable growth in the post-COVID-19 pandemic recovery. Notably, space technologies can contribute to bridging the digital divide, monitor changing climate, extreme weather and the use of natural resources, and create new economic opportunities.

- However, a number of challenges need to be addressed before G20 economies can make the most of what space technologies have to offer. Skills and gender gaps in the space-related workforce, and a need to improve on-the-ground digital infrastructures, are common issues.

- Moreover, the unprecedented intensified use of Earth’s orbits is threatening the orbital environment and its space infrastructure, with debris accumulating yearly. With a growing societal reliance on space-based infrastructure and systems, debris-related incidents and collisions could have significant negative consequences globally.

- Decision makers need to better understand and map the use of space technologies in government services and society as well as future needs, and identify and address key hurdles to technology uptake and sector development, such as skills gaps and availability of personnel, so as to ensure the cost efficiency and sustainability of critical space infrastructure. This will require concerted efforts across multiple government services and between countries, as well as expanding cooperation with the private sector.

- Several G20 economies have made great progress in the economic measurement of their space activities, contributing to enhance awareness of the contributions of the space economy to the economy and to the accountability of public spending in this area. These activities contribute to better understanding and evaluating the impacts of government investments and will prove useful for underpinning future government investments and policy decisions.
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## Acronyms, abbreviations and units of measure

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<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>BEA</td>
<td>Bureau of Economic Analysis (United States)</td>
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<tr>
<td>CAD</td>
<td>Canadian dollar</td>
</tr>
<tr>
<td>CEOS</td>
<td>Committee on Earth Observation Satellites</td>
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<tr>
<td>CHF</td>
<td>Swiss franc</td>
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<tr>
<td>CNES</td>
<td>Centre national d’études spatiales (France)</td>
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<tr>
<td>CSA</td>
<td>Canadian Space Agency</td>
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<tr>
<td>ECV</td>
<td>Essential climate variable</td>
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<td>ESA</td>
<td>European Space Agency</td>
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<tr>
<td>EUR</td>
<td>euro</td>
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<tr>
<td>GDP</td>
<td>Gross domestic product</td>
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<td>GNI</td>
<td>Gross national income</td>
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<tr>
<td>ICT</td>
<td>Information and communications technology</td>
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<tr>
<td>IPP</td>
<td>International Partnership Programme (United Kingdom)</td>
</tr>
<tr>
<td>ISRO</td>
<td>Indian Space Research Organisation</td>
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<tr>
<td>JAXA</td>
<td>Japan Space Exploration Agency</td>
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<tr>
<td>JPY</td>
<td>Japanese yen</td>
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<tr>
<td>LEO</td>
<td>Low-earth orbit</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration (United States)</td>
</tr>
<tr>
<td>ODA</td>
<td>Official development assistance</td>
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<tr>
<td>R&amp;D</td>
<td>Research and development</td>
</tr>
<tr>
<td>SMEs</td>
<td>Small and medium-sized enterprises</td>
</tr>
<tr>
<td>STEM</td>
<td>Science, technology, engineering and mathematics</td>
</tr>
<tr>
<td>USD</td>
<td>United States dollar</td>
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Introduction

Building on OECD research and indicators, particularly in the framework of the OECD Space Forum, this background paper for the 2021 Space Economy Leaders’ Meeting at the G20 provides new evidence on how space technologies can promote growth and well-being in G20 economies and beyond, identifies some of the key challenges that need to be addressed, and suggests a number of policy options for decision makers.

The central role of government in space activities

The important role of government investments in the development of space activities is a trend likely to continue in the coming decade, despite greater private sector participation. In G20 economies, government actors play a key role in the space economy as investors, developers, owners, operators, regulators, and customers. Governments are also increasingly partners with the private sector, for the joint development of space products and services. Government agencies fund basic and applied science as well as research and development (R&D), and purchase space products and services. National agencies, research centres and laboratories also perform their own space R&D and in some cases have a role in space manufacturing.

Government space budgets account for the lion’s share of investments in many space activities, in particular funding traditional activities, such as space science, space manufacturing and launch (OECD, 2019[1]; Undseth, Jolly and Olivari, 2021[2]). In 2020, the median value of space budgets as a share of gross domestic product (GDP) amounted to 0.05% for G20 economies, as a whole, with the United States and the Russian Federation investing more than 0.2% of GDP and France more than 0.1% (Figure 1). These findings are comparable to those of previous years (space programmes and projects tend to have long lead times), though Saudi Arabia is emerging as a notable new large investor, following a series of programme launches in recent years.

Figure 1. G20 government space budgets (2020)

As a share of GDP

Notes: Budgets include data for civil and defence programmes, when available. The figure does not include the aggregate budget for the European Union.
1. Conservative estimates.
2. Includes contributions to the European Space Agency and Eumetsat.
3. Includes for non-European Union members their specific contributions to EU space programmes (i.e. Copernicus and Galileo/EGNOS).
4. Includes only civil R&D.
Source: OECD calculations based on government budget sources and OECD databases.
It is still too early to estimate the future impacts of the COVID-19 crisis on government space investments and activities as the pandemic is strongly affecting many parts of the world. However, as an illustration, the US National Aeronautics and Space Administration (NASA) estimates that delays caused by the 2020 government lockdown and disrupted deliveries has so far cost the Agency more than USD 1.6 billion (or some 7% of NASA’s 2020 budget) (NASA, 2021). Furthermore, the pandemic caused launch delays in many countries (e.g. it contributed to postponing the European ExoMars mission from 2020 to 2022) (Undseth, Jolly and Olivari, 2021). Lessons learned from the 2001 and 2008 financial crises indicate that business R&D expenditures on the whole could decrease, as could government R&D expenditure in the countries most hit by the crisis (Paunov and Planes-Satorra, 2021). On a more positive note, COVID-19 has contributed to highlighting how space technologies can support society during a crisis, and the role they can play in the recovery. Indeed, some governments have made investments in the wake of the pandemic to improve connectivity (e.g. the Space Infrastructure Hub in South Africa) (SANSA, 2020).

It is expected that COVID-19 will reinforce and accelerate the pre-pandemic trend of public-private co-investments, partnerships and space commercialisation, as private sector capabilities mature and public organisations transfer more responsibilities and risks to non-government actors. This is associated with technological transfers to the private sector, deregulation and more extensive space service buys. India and Korea are both in the process of transferring technologies and know-how on satellite and launcher manufacturing to private actors, NASA is extending service buys to space exploration (e.g. lunar payload service contracts) and the People’s Republic of China (hereafter “China”) is encouraging private financing and initiatives in the sector (Undseth, Jolly and Olivari, 2021).

**Growing evidence on space economy contributions to economic growth and innovation**

With mounting pressures on government budgets, expenditures on space programmes, as any other budget item, need justification. As space budgets have grown and diversified in many countries, decision makers need to better track the implementation and impacts of government investments in the space sector. In the post-COVID-19 recovery efforts, economic growth and societal well-being are key objectives of most government space strategies, and this needs to be better reflected in data and indicators.

**Progress in economic measurement**

Studying the economics of space activities has become increasingly professionalised in recent decades, with many space agencies and administrations in G20 economies employing chief economists (e.g. in Canada, Germany, United Kingdom and United States) and/or investing significant resources in industry surveys and data collection, increasingly with the involvement of national statistical offices.

Regarding economic measurement at the national level, the most comprehensive effort to date is the experimental US Space Economy Satellite Account (SESA), built by the US Bureau of Economic Analysis (BEA). By identifying and isolating space commodities (goods and services) in existing supply-use tables, the BEA has produced a number of economic indicators, such as gross outputs, value added, employment, etc., which are fully comparable with those of other industries. As an illustration, in 2018, the US space economy accounted for 0.5% of national GDP, or some USD 108.9 billion in value added. The biggest contributing industries to GDP are manufacturing as well as information and communications technology (ICT) (mainly direct-to-home – i.e. satellite – television), as described in Figure 2. This measurement effort facilitates comparison of different domains of the US economy. For example, the vast US ocean economy, comprising for instance resource extraction, marine food production and recreation, accounts for 1.8% of GDP.
Figure 2. US Space Economy value added, by industry (2018)
In current USD billion

Notes: The space economy consists of space-related goods and services, both public and private. This includes goods and services that: 1. Are used in space, or directly support those used in space; 2. Require direct input from space to function, or directly support those that do; and 3. Are associated with studying space. This definition includes direct-to-home satellite television services. Government includes spending on personnel, operations, and maintenance. Government spending on private sector investment (structures, equipment, intellectual property) is included within the individual industries.


Many other government agencies are also making significant efforts with economic measurement and data collection, often in co-operation with national statistical offices and/or the private sector:

- The Canadian Space Agency (CSA) has been running its space industry survey since 1997 (Canadian Space Agency, 2020[7]), and the Agency has partnered with other government agencies to improve the economic analysis of space activities (integrating space in national accounts to calculate contributions to GDP, similar to the BEA’s efforts) and patent analysis. Multiple surveys make it possible to identify returns on investments, gender and skills.

- Korea and the United Kingdom have been surveying their space industry since the early 2000s, initially reflecting on revenues and employment, but increasingly focused on innovation and societal impacts, and improving definitions for international comparability. Korea carried out a large-scale socio-economic impact assessment in conjunction with the 30-year anniversary of the Korea Aerospace Research Institute in 2019 (Shin, 2020[8]). The UK Space Agency is currently re-evaluating its space industry survey to better reflect needs in national strategies and results frameworks (UK Space Agency, 2019[9]). The Agency has also launched a number of other surveys to better assess workforce demographics, impacts of R&D investments, etc.

- Many other countries have started collecting data and/or improving their initial measurement processes. France is exploring the opportunities of launching a satellite account for space manufacturing and launch activities, similar to the United States. Germany launched its first national space industry survey in 2019. The Italian Space Agency has supported various studies, such as the analysis of socio-economic impacts of Italian space activities (using different methodologies such as input-output matrix, econometric models, cost-benefit analysis etc.) or the analysis of national space industry spill overs. Australia has published its first “snapshot” of the space sector, following the implementation of its national space strategy (Australian Space Agency, 2021[10]). Belgium and the Netherlands have carried out repeat studies with interesting lessons on the growing diversity of actors involved in space programmes.
• In the same vein, the European Space Agency (ESA) has created a dedicated Space Economy unit, working to improve economic measurement and collect and share best practices in socioeconomic impact assessment in co-operation with the OECD Space Forum, ESA member states and relevant government entities involved in economic analysis and statistics.

**Contributions to innovation and entrepreneurship**

There is growing interest in specific economic benefit domains of government space programmes, such as contributions to innovation or entrepreneurship. Government space R&D programmes, especially in the domains of spaceflight and on-orbit applications (e.g. launch, earth observation, space exploration) have specific characteristics that lead them to be particularly beneficial for participating firms and organisations in terms of knowledge and technology transfers (Olivari, Jolly and Undseth, 2021[11]).

**Figure 3. Top 20 regions in space-related patents**

Patent applications filed under the PCT, by inventor’s residence and priority date (2004-08 and 2014-18)

Notes: PCT = Patent Cooperation Treaty. Data refers to patent applications filed under the PCT, by inventor’s region at Territory Level 2 (TL2) and priority date.


These include the following:

• Space R&D projects are often long-lasting and collaborative: Projects in space science and space exploration involve multiple public and private actors, sometimes from different countries, and may last several years, providing an environment for long-term durable learning, technology transfer within and outside the space sector, and knowledge acquisition across domains and countries.
Testing is an important part of space technology development and a potential source of technology transfer. Government testing facilities, such as wind tunnels, vacuum chambers, cryogenic chambers, etc., are important for prototype development and flight qualification. Bigger firms may have certain in-house capabilities, but small and medium-sized enterprises (SMEs) are big users of government facilities and services, which can further foster SME dynamism and innovation.

New sources of evidence, in particular patent and bibliometric databases, make it possible to better track innovation activities in the space sector in a uniform manner. Figure 3, for instance, combines space patent applications with inventors’ residences to identify specific “innovative”, geographic clusters. The importance of regional high-tech regional clusters within the space economy is shown in Figure 3. Space manufacturing, in particular, is often organised in clusters close to government centres and facilities, as well as to industrial centres (e.g. the Great Southwest in France – Midi-Pyrénées and Aquitaine). California accounts for some 16% of total space-related patent applications, followed by Southern Kanto (Japan) and Guangdong (China). The Guangdong province in China, which has seen a significant rise in space-related patent applications since 2004-08, is home to the cities of Shenzhen and Guangzhou, both important regional centres of aerospace manufacturing and other high-technology activities.

As a proxy for scientific excellence in space research, Figure 4 shows the share of highly cited (upper tenth percentile) scientific papers in the OECD space literature dataset between 2000 and 2020. The share has remained stable for a number of G20 economies (e.g. Australia, France, Germany, Italy, Japan and United Kingdom), but the United States saw its share decline from 39% to 19% over the last two decades, as the globalisation of space research has accelerated. China’s share has increased significantly, from 1% to 8% (although the growth for highly cited papers has been less steep than for the overall production of scientific papers). G20 economies such as Korea, South Africa, Saudi Arabia, Brazil and India have all seen an increase in their share of highly cited papers. Bibliometric indicators need to be treated with care (e.g. researchers’ publication patterns can be influenced by evaluation metrics, etc.), but these trends coincide with the growing globalisation of space activities, characterised by new entrants’ investments and partnerships with incumbents.

Figure 4. Scientific excellence
Share of top 10% most cited publications in space literature

Source: OECD analysis based on Elsevier (2021), Scopus Custom Data.
Government agencies also increasingly support start-ups and entrepreneurship in the space sector, based on the use of government-funded technology development and data. The following examples highlight these supportive efforts:

- Several government initiatives are targeting downstream business and application development, e.g. the UK Satellite Applications Catapult at the Harwell space cluster for UK start-ups, and the French Booster programme which supports four dedicated activities in co-ordination with existing technology clusters.

- ESA is supporting some 22 business incubation centres (BIC) in its member states, having resulted in more than 500 company creations since the launch of the first centres in 2003 (ESA, 2017[12]). The UK ESA BIC in Harwell reports a company survival rate of 92% since the creation of the incubation centre in 2011 (O’Hare, 2017[13]). The Bavarian ESA BIC, established in 2009, incubated more than 130 start-ups in its first ten years of operations, generating 1 800 new jobs and EUR 150 million in annual turnover (ESA BIC Bavaria, 2018[14]). Since its start in 2016, ESA BIC Switzerland (CH) has supported 40 start-ups, investing a total of more than EUR 6 million funding from ESA. Since then, ESA BIC CH start-ups have raised more than EUR 170 million in third-party funding and created more than 300 domestic jobs. At least five ESA BIC CH supported start-ups have CHF 1 million annual revenues, and some of these new firms have attracted the interest of well-known organisations like IBM. The best-known alumni of ESA BIC CH is ClearSpace, which has received a contract of EUR 86 million from ESA to demonstrate the first space debris clearance mission (Startupticker ch, 2021[15]). In Italy, ESA BIC Lazio started its activity in 2009 and by 2016 reported that 21 companies of those supported were operating with cumulative revenues of more than EUR 7 million and 200 people involved. With ESA BIC Sud France and ESA BIC Nord, established in 2013 and 2018 respectively, the French space Agency (Centre national d'études spatiales [CNES]) and other partners have incubated more than 110 start-ups that have benefitted from expertise and dedicated support, as well as access to funding from the French public investment bank BPI France via the “Space Ticket” accreditation scheme.

- To better support entrepreneurship and R&D commercialisation, ESA is creating a new Commercialisation department, which will be responsible for existing and new programmes identifying and incubating new space start-ups and businesses with a commercial and competitive potential; enabling an appropriate environment for these businesses to commercialise their products outside of ESA programmes; and providing training, access to finance and also other opportunities. Finally, the Department will work with other ESA programmes on the creation of new markets (e.g. in-orbit servicing) by developing from the outset a commercialisation strategy, bringing together public and private investors as well as anchor customers.

- Space agencies furthermore regularly organise hackathons, prizes and challenges to reach out to non-space users, in particular those in the ICT sector, to identify new ideas and business models. This may be regular annual events, e.g. NASA’s International Space App Challenge and ActInSpace organised by the ESA and the CNES; or ad-hoc challenges, such as the Earth Observation Dashboard Hackathon, organised in mid-2021 by ESA, NASA and the Japan Space Exploration Agency (JAXA) to explore environmental effects of COVID-19.

- While highly publicised in the last years, venture capital funding remains relatively rare in the space sector, compared to other types of financing (e.g. debt financing). This is not unique to the space sector, as firms backed by venture capital in other sectors represented less than 1% of enterprise births in 2016 in most OECD countries (OECD, 2017[16]). To complement private funds, a number of space agencies and countries have announced their support for dedicated space venture capital funds. In 2018, the Japanese government announced the creation of a fund with a pool of JPY 100 billion (USD 940 million) to be offered over five years to space sector firms, provided by the Development Bank of Japan, the Industrial Innovation Organisation, and other organisations (Foust, 2018[17]). The same year, the CNES created CosmiCapital in France (fund size EUR 70 million), managed
Two other European funds were announced in 2020: Primo Space, with the European Investment Fund and CDP Venture Capital SGR as cornerstone investors and backed by Italian Space Agency (EUR 80 million) and Orbital Ventures, supported by the Luxembourg government (EUR 70 million) (European Commission, 2020[19]; Luxembourg Space Agency, 2020[20]).

Furthermore, space agencies do considerable work to identify and stimulate additional socio-economic benefits of government missions, such as space exploration. Increasingly, missions are designed with multiple applications and technology transfers to other sectors in mind. As an illustration, technology from the ROLIS camera on the European Philae lander in the Rosetta mission, which captured images of Comet 67P/Churyumov-Gerasimenko, is now used in early warning systems for forest fires. Other technologies from the Rosetta mission have also been commercialised, notably the UK Ptolemy sensor technology that is now being used to develop air monitoring systems for military submarines (Sadlier, Farooq and Romain, 2018[21]). NASA has recorded more than 2 000 successfully developed US commercial products between 1976 and 2018, with a majority of transfers to manufacturing and consumer products; computer technology; and environment and resource management (Figure 5).

![Figure 5. NASA technology transfers to different economic sectors](image)

The COVID-19 pandemic is contributing to highlighting how space technologies can support society during a crisis, and more importantly, the role they can play in the socio-economic recovery afterwards (OECD, 2020[22]). Space infrastructure can in particular help meet long-term societal needs, notably in addressing challenges related to the climate and the environment, bridging the digital divide and in supporting development assistance.

**Monitoring the climate and the environment**

The last seven years, 2013-20, have been the warmest years ever recorded on Earth, according to NASA analysis of land and space-based observations (July 2021 has also been described as the hottest month on record by the US National Oceanic and Atmospheric Administration). For its estimates, NASA used the Atmospheric Infrared Sounder instrument flying on NASA’s Aqua satellite in low-earth orbit at some 700 kilometres altitude, a mission that was launched in 2002 and is in its nineteenth year of operation. Other satellites that measure surface temperature include the US Landsats 7 and 8, and the European Sentinels 2 and 3. Indeed, space-based observations play a crucial role in the study and monitoring of the...
climate. They provide invaluable contributions to more than half of the 54 “essential climate variables” currently used by the international research community to characterise Earth’s climate (Table 1). Some of these observations are unique.

Table 1. Satellites’ contribution to measurements of essential climate variables

<table>
<thead>
<tr>
<th>Sphere</th>
<th>Essential climate variables</th>
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<tbody>
<tr>
<td>Atmospheric (over land, sea and ice)</td>
<td>Surface: air temperature, wind speed and direction, water vapour, pressure, precipitation, surface radiation budget</td>
</tr>
<tr>
<td></td>
<td>Upper-air: temperature, wind speed and direction, water vapour, cloud properties, Earth radiation budget (including solar irradiance)</td>
</tr>
<tr>
<td></td>
<td>Composition: carbon dioxide, methane and other long-lived greenhouse gases, ozone and aerosol</td>
</tr>
<tr>
<td>Oceanic</td>
<td>Surface: sea-surface temperature, sea-surface salinity, sea level, sea state, sea ice, surface current, ocean colour, carbon dioxide partial pressure, ocean acidity, phytoplankton</td>
</tr>
<tr>
<td></td>
<td>Sub-surface: temperature, salinity, current, nutrients, carbon dioxide partial pressure, ocean acidity, oxygen, tracers</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>River discharge, water use, groundwater, lakes, snow cover, glaciers and ice caps, ice sheets, permafrost, albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation, leaf area index, above-ground biomass, soil carbon, fire disturbance, soil moisture</td>
</tr>
</tbody>
</table>

Notes: The Global Climate Observation System has specified 54 essential climate variables (ECVs) that critically contribute to the characterisation of Earth’s climate. ECVs to which satellites make a significant contribution are in **bold italic**. Source: OECD (2016[23]), Space and Innovation, http://dx.doi.org/10.1787/9789264264014-en.

Space infrastructure furthermore contributes to monitoring the emission of greenhouse gases. Better exploitation of existing data (e.g. ESA’s Greenhouse Gases Climate Change Initiative) and new missions provide better temporal and spatial coverage in addition to higher resolution, making it now possible to identify sources of emissions at a regional scale. A number of G20 economies and the European Union are planning greenhouse gases monitoring missions. Some nine missions supported by China, France, Germany, Japan, the United States and the European Union are planned in the next decade (Werner, 2021[24]).

**Bridging the digital divide**

COVID-19 has highlighted the importance of digital connectivity for both economic development and social well-being. 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. Satellite-based broadband is one of the technologies that could bring connectivity to areas where other terrestrial alternatives are not available or too expensive to deploy, and new services are underway.

Although the digital divide is closing for mobile connectivity – as mobile broadband may be reaching 93% of the world’s population – access to Internet at home is much more limited (Figure 6), in particular in rural areas (ITU, 2020[25]). Despite great improvements in the last years, some 17% of rural Americans still do not have access to high-speed Internet (defined as at least 25/3 megabits per second) (FCC, 2020[26]). And while 89% of rural Europeans have access to fixed broadband, a much lower share of them (59.3%) have access to higher-speed next-generation-access technologies, such as Very-high-bit-rate Digital Subscriber Line (VDSL), almost 30 percentage points below the regional average (European Commission, 2020[27]).

In this context, satellite systems have a role to play, despite their technical limitations. The most performant low-earth orbit “mega-constellations”, currently 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[28]). Satellite systems will be most usefully deployed as a complement to terrestrial networks, by:

- filling the coverage gap to deliver broadband service to residential and business users in remote and isolated geographic areas by offering ubiquitous and easy-to-deploy solutions (“last mile” solution)
- providing backhaul or backbone network interconnection to the global Internet for terrestrial fixed or mobile telecommunication network service providers (the “middle mile” solution); and potentially
• expanding the market for satellite broadband through the use of satellites in low-earth orbit to deliver broadband to lower density areas closely adjoining urban areas (OECD, 2019\[1\]; 2017\[29\]).

**Figure 6. Internet access at home**

Percentage of households with Internet access at home (2019)

Satellite broadband is still much less used than other technologies (less than 0.05 subscriptions per 100 inhabitants) in most parts of the world (Figure 7), as documented in the OECD Broadband Portal. This is expected to change in the near future, following the rollout of new consumer services and several recent government initiatives. More than ten broadband satellite constellations are in different stages of development, with three companies (SpaceX, OneWeb and Telesat) having already launched satellites. The Starlink constellation currently numbers more than 1 000 operational satellites and could reach global coverage by the end of 2021, pending regulatory approvals. Other operators in North America and China in particular, are following suit.

Several of these and other initiatives are receiving significant public backing. In Australia, two geostationary Sky Muster satellites have been providing broadband to rural and remote areas since 2016, as part of the National Broadband Network initiative. The scheme now covers more than 100 000 connections (Australian Department for Infrastructure, Transport, Regional Development and Communications,, 2020\[30\]). The Government of Canada has entered into an agreement with the satellite operator Telesat to secure high-speed Internet capacity over Canada through the company’s low-earth orbit satellite constellation. Up to CAD 600 million has been committed to secure capacity that will be made available to Internet service providers at a reduced rate (Government of Canada, 2020\[31\]). This will provide high-speed and reliable Internet access to the most challenging rural and remote areas. In 2021, the Chinese government announced that it would develop a 13 000-satellite Guo Wang (“national network”) broadband constellation, under the auspices of the newly created China Satellite Network Group (Jones, 2021\[32\]). The Norwegian government, in partnership with the commercial operator Inmarsat, is also bringing broadband connectivity to the Arctic region (65 degrees north and above) to support civil and military government operations in the area (Undseth, Jolly and Olivari, 2021\[2\]).
Figure 7. Deployment of satellite broadband in perspective

A. Worldwide satellite broadband subscriptions over time

B. Satellite broadband subscriptions by selected regions

Notes: Latest available years have been used for some countries instead of 2013 and/or 2019. The developing countries aggregate includes all low-income (gross national income [GNI] per capita of USD 1,045 or less), lower-middle-income (GNI per capita between USD 1,046 and USD 4,095) and upper-middle-income countries (GNI per capita between USD 4,096 and USD 12,695). The world aggregate includes data for all countries available (94 over 237 for both 2013 and 2019).

Providing development assistance

Space technologies are increasingly used also for development assistance purposes. Space-related official development assistance (ODA) includes technical assistance in telemedicine, geographic information systems, etc. G20 economies have committed some USD 650 million to space-related ODA over the 2000-18 period, mainly benefitting economies in Far-East Asia and Sub-Saharan Africa (Figure 8). Space-related ODA projects support a range of different objectives, such as monitoring the environment and natural resources, improving food safety, supporting government services or developing economic infrastructures.
Figure 8. Commitments for space-related ODA projects (2000-19)

A. Commitments by recipient region, in constant 2017 USD

B. Commitments by declared socio-economic purpose, in constant 2017 USD

Note: The regions mentioned in the graphs are those used by the OECD Development Assistance Committee (DAC).
Source: Calculations based on OECD (2021), Development Assistance Committee Database.

Space-related technologies and services contribute to aid programmes. A selection of prominent initiatives include:

- The SERVIR initiative is a partnership between NASA and the US Agency for International Development (USAID) using earth observation for environmental management purposes in more than 30 developing countries. The goal is to help local governments improve their response to natural disasters, tackle food security, safeguard human health, and manage water and natural resources. Projects have been carried out in the Hindu-Kush region (Himalayas), in the Lower Mekong River basin and in Eastern and Southern Africa to address challenges associated with forestry, agriculture and region-wide issues such as land cover change, air quality, and adaptation to climate change.

- The CNES has launched several projects using earth observation in the area of tele-epidemiology to prevent the diffusion of contagious diseases. Combining environmental variables with satellite
imagery, it is possible to draw predictive risk maps able to track the exposure to disease-bearing insects and ideally create widely applicable early warning systems. Projects have been conducted in Africa, the Caribbean and South America.

- The **UK International Partnership Programme (IPP)** develops space-based solutions in partnership with developing countries to tackle specific challenges. The programme is delivered through a series of calls run by the UK Space Agency. Several projects are registered under the IPP umbrella in many regions and countries in the world, in Asia-Pacific, Africa and Latin America.

- In the **Geodata for Agriculture and Water (G4AW)** food security programme, the Netherlands Space Office uses earth observation data and satellite broadband to provide low-income countries with information on climate, weather and hazards and help food producers and other stakeholders. The goals are to improve the output of the agricultural, pastoral and fishing sector; increase sustainable food production and to achieve more effective use of inputs.

As a final example of how space technologies contribute to socio-economic development, the **Indian Space Research Organisation (ISRO)** uses satellite communications in the provision of telehealth services to people living in remote areas, linking more than 300 hospitals daily. The goal of the project is to connect remote college hospitals and mobile telemedicine units to major specialty hospitals in cities and towns through Indian satellites. Thanks to satellite links it is possible to provide medical diagnosis and consultation by specialist doctors to patients located in remote and rural areas.

### Remaining challenges to realise the benefits of public space investments

The space sector has evolved and spread with astonishing speed in the last two decades, but challenges remain to realise the full benefits of public space investments. While some of these challenges can be addressed by space organisations themselves, more often they rely on close co-ordination and co-operation with other government services.

#### Addressing skills and gender gaps in the workforce

The competition for talent across diverse sectors of the economy is growing, as mentioned in the latest G20 Ministers of Research’s **Joint Declaration on Leveraging Research, Higher Education and Digitalisation for a Strong, Sustainable, Resilient and Inclusive Recovery** (August 2021) (G20 Group, 2021[33]). The longer-term effects of the next production revolution and digitalisation (see, for instance, OECD (2017[34])) on space sector employment are yet to be fully understood, but demand for talent and skills increases with the needs of a growing number of space-faring nations and the ever-growing supply of satellite data and signals.

New opportunities are opening up across G20 economies, as baby boomers retire in higher-income countries, while emerging economies with newly launched space programmes are employing not only international experts, but also staff that is trained locally. Dozens of countries, including lower-income countries, have registered a satellite in orbit and/or created a space agency in the last two decades. The supply chain for space products and services is also increasingly diverse and international (OECD, 2014[35]; 2019[1]).

At the same time, the supply of skilled workers is a concern in many G20 economies, as the space sector faces strong competition from other high-technology sectors.

- Industry actors in several G20 economies (e.g. Canada, United Kingdom, United States) report problems in finding qualified staff. The UK Space Agency’s space sector skills survey identifies a number of challenges, notably recruitment problems, skills gaps (particularly in scientific, engineering and/or technical functions) and difficulties retaining staff (Sant et al., 2021[36]). In Canada, 58% of space organisations reported difficulties hiring personnel in the latest annual industry survey carried out by the Canadian Space Agency (Canadian Space Agency, 2020[7]).
Similar issues are to be expected in other G20 economies, both high and lower-income. Government agencies in Brazil, which are experienced in the utilisation of satellite data, struggle with finding qualified staff for cutting-edge technologies, such as radar imagery (Cerbaro et al., 2020[37]).

The ageing of the space-related workforce is an issue in a number of G20 economies, but not all. In the United States, the 2013 space industrial base deep dive assessment by the Department of Commerce found that some 36% of the space-related workforce was 50 years or older (US Department of Commerce, 2014[38]). The European space manufacturing workforce has a similar age structure, according to the 2020 Eurospace space industry survey (Eurospace, 2020[39]). 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 (Korean Ministry of Science and ICT, 2020[40]). Similarly, in the United Kingdom, those aged 55 and over only accounts for some 17% of the space workforce, according to the 2020 UK space census (Thiemann and Dudley, 2021[41]).

Space agencies are raising awareness about these issues (e.g. recent ESA Future of Work workshops) and consulting with different types of industry actors to better identify problem areas. But 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 science, technology, engineering and mathematics (STEM)-related constraints and a notable gender gap in scientific and management occupations.

University enrolment in a number of space-related scientific disciplines (e.g. aerospace engineering), and in STEM disciplines more generally, is low and falling in a number of countries.

There is a persistent gender gap in both space-related employment and in space-related fields of education. Overall, women are under-represented in all segments of the space sector, from government sector administration (Table 2) and research to private sector manufacturing and services provision, irrespective of fields (OECD, 2019[42]).

Table 2. Share of women in scientific and/or management occupations in space organisations in selected G20 economies

<table>
<thead>
<tr>
<th>Organisation (year)</th>
<th>Canada</th>
<th>South Africa</th>
<th>France</th>
<th>United States</th>
<th>Germany</th>
<th>Europe</th>
<th>Japan</th>
<th>India</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share of total staff</td>
<td>47%</td>
<td>39%</td>
<td>37%</td>
<td>34%</td>
<td>32%</td>
<td>26%</td>
<td>22%</td>
<td>20%</td>
</tr>
<tr>
<td>Share of “non-administrative” and/or “non-clerical” staff</td>
<td>23% (scientific and professional positions)</td>
<td>37% (engineers and scientists/researchers)</td>
<td>26% (engineers)</td>
<td>23% (science and engineering occupations)</td>
<td>20% (scientific staff)</td>
<td>21% (executive staff, translators and “off-scale”, e.g. directors, staff)</td>
<td>12% (researchers)</td>
<td>16% (science and technology occupations)</td>
</tr>
</tbody>
</table>

Notes: SANSA = South African National Space Agency; DLR = Deutsches Zentrum für Luft- und Raumfahrt.
1. This category typically refers to women in science and engineering occupations, but definitions and data availability vary across organisations.

Thanks to the inspirational effects of space activities – human and robotic space exploration missions in particular – space agencies can play a significant role in attracting students and women to STEM-related disciplines. Public and private space organisations tend to concentrate their efforts in the following broad areas of action with respect to their mandates to inspire future generations and cultivate STEM workforces:
• increasing awareness and engaging decision makers at a high political level (conferences, workshops), e.g. UN’s Space for Women conference
• activities targeting primary and secondary education (e.g. science camps; facility tours, teachers’ programmes; educational material and dedicated websites)
• dedicated scholarships and grants for tertiary education; guidance and mentoring programmes
• promoting women and under-represented minorities in a professional setting (e.g. recruitment objectives at entry level and for management positions; mentoring schemes and networks; work-life balance schemes).

Space organisations’ education-related activities would benefit from more research, as there is a general lack of data and knowledge at all levels of policy implementation. This spans from data on enrolment and graduation in space-related scientific disciplines to the outcomes of government initiatives.

Addressing limitations to accessing and utilising satellite data

The volume and variety of satellite data and signals have exploded in recent years, as have the digital tools and technologies to exploit them for both public and commercial purposes. As has been illustrated in the previous sections, this is making a tangible impact on the quality of government services, human well-being and economic growth. Access has been greatly facilitated by dedicated platforms and government data are now generally available for free. Space agencies and related organisations have made notable efforts in this area.

• Several countries have taken extra steps to make data available for societal and commercial applications, by creating national data portals, for example Digital Earth in Australia, satellitdata.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.
• Data from government missions (e.g. from NASA, the CSA, JAXA, the ESA) are also available on popular commercial platforms, such as Earth on AWS or Google Earth Engine. The Committee on Earth Observation Satellites (CEOS) and other partners supported the 2018 launch of the Africa Regional Data Cube. Finally, the global initiative Open Data Cube, supported by government organisations in Australia, the United Kingdom and the United States, as well as commercial partners and CEOS, provides an open and freely accessible tool to access satellite data.
• There is furthermore a 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 the Radiant Foundation’s ML Hub, an open library of training data, models and standards for applications of machine learning on earth observation.

Still, there is a general view that some space technologies, e.g. earth observation, are under-exploited, in cases where space-based approaches could provide equal or better results than terrestrial alternatives. The reasons for this are multiple and often outside the reach of space agencies, including for instance poor quality terrestrial infrastructure such as roads and electricity needed to access on the ground certain areas to ground-truth the data collected via satellites, lack of reliable socio-economic data, such as household surveys, to train and validate satellite-based models (Burke et al., 2021[43]), and insufficient institutional resources (e.g. cuts in manpower due to economic downturns) (Cerbaro et al., 2020[37]), or lack of awareness or scepticism among specific user groups about the relative benefits of space technologies over terrestrial alternatives.

For these reasons, there is a strong need for more knowledge and better communication between academic and user communities as well as between different government services about the utility of space technologies in specific user contexts, as well in overcoming administrative obstacles to adopting them.
Addressing the threats of space debris to ensure the sustainability of space activities

The challenge of space debris is becoming more critical (Undseth, Jolly and Olivari, 2020[44]). The use of Earth’s orbits, in particular the low-Earth orbits, has intensified, while at the same time, the orbital debris population has increased, mainly due to two debris fragmentation events (including a collision between two satellites) in 2007 and 2009 (Figure 9).

Figure 9. Monthly number of objects in Earth orbit, by object type

Notes: Data as of 5 January 2021. 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.

With the full deployment of mega-constellations of satellites under development (e.g. Starlink, OneWeb, as well as others mentioned in the “Bridging the digital divide” section), the number of operational satellites in orbit could triple in the next five years. When taking into account all existing satellite filings, there could be several tens of thousands of operational objects in orbit by 2030. With this level of orbital density, it is only a matter of time before a defunct satellite collides with debris, according to international modelling efforts, e.g. by the Inter-Agency Space Debris Coordination Committee (see IADC (2013[46])).

The impacts of accumulating space debris could be disastrous. If debris density reaches critical levels, it could trigger an irreversible chain reaction of orbital collisions, creating ever-more small and dangerous debris. This so-called Kessler Syndrome (Kessler and Cour-Palais, 1978[47]) could ultimately render certain orbits of high socio-economic value unusable and hinder much of humanity’s further potential activity in space. The loss of these orbits could bring significant, wide-reaching social and economic consequences, including:

- Loss of unique commercial applications and functionalities: The damage or destruction of crucial observation, navigation and telecommunications satellites on orbits most vulnerable to space debris could disrupt the best or only sources of data and signals for multiple areas of human activities, ranging from weather forecasting, sea navigation to banking and stock markets using satellite networks to operate securely.
- Interrupted time series for earth science and climate research: Uninterrupted time series are crucial for the accuracy and reliability of weather prediction and climate models. The loss of several polar-
orbiting weather satellite observations would, in particular, heavily affect the Southern hemisphere, where there are fewer terrestrial observations.

- **Distributional effects:** The loss or perturbation of certain low-Earth orbits would affect certain groups and geographic regions more heavily than others, broadening the gaps between urban and rural populations and between high- and lower-income countries (e.g. in some low-income countries, satellite systems provide more reliable and accurate data and signals than terrestrial infrastructure).

- **Disruption of current and future economic potential:** The Kessler Syndrome would not only destroy a significant part of existing space infrastructure, but also create a significant obstacle to further space development and its vast potential social, economic and scientific benefits.

The most important implication of this worst-case scenario for policy-makers is the need to avoid the Kessler Syndrome, by making sure their public and commercial satellite operators realise the need to abide by the rules.

- Comprehensive national and international mitigation measures exist already and have been gaining force since the late 1990s. Existing national and international guidelines entail no intentional generation of debris (including anti-satellite tests); no accidental explosions in orbit; a 25-year deorbit rule in low earth orbits (LEOs) and geostationary orbits (GEOs); and collision avoidance when feasible. However, compliance with these measures is still insufficient. While most GEO operators comply with guidelines, compliance rates are lower in LEO (some 70% in all LEO orbits in 2019, but less than 20% if excluding naturally compliant objects).

- A number of countries have introduced new complementary or compulsory measures. France and the United Kingdom require satellite operators to have in-orbit third-party liability insurance. And New Zealand, a relative newcomer to space activities, has launched the pilot “Space Regulatory and Sustainability Platform” to track space objects launched from the country and monitor compliance with permit conditions.

- Some studies recommend the active removal of several large pieces of debris per year when this becomes economically and technologically feasible. Active debris removal could be one of the responses to the problem and several technology demonstration missions for active debris removal are underway. This includes for instance ESA’s ClearSpace-1 mission, purchasing services provided by a Swiss company and scheduled for launch in 2025, and JAXA’s CRD-1 mission, targeting a Japanese rocket body. It is worth noting that active debris removal faces significant technological and legal challenges that would need to be addressed by the international community.

### Policy options

This note has illustrated some of the ways in which space can support decision makers in reshaping economies and improving lives in the coming decades. It has further identified a number of challenges that need to be addressed in order to reap the full benefits of space technologies and ensure a sustainable space infrastructure. This is in particular linked to human capital and skills as well as technical barriers for the uptake of space technologies.

In order to guide and facilitate the implementation of space policies nationally and internationally, G20 governments are encouraged to consider the following:

- **Improve the monitoring of human resources and skills’ needs in the sector:** More data are needed to track tertiary education enrolment in space-related scientific disciplines and space sector demographics (age, diversity), as well as evolving skills’ needs, etc., in order to ensure enough qualified personnel to support the long-term development of the sector.

- **Identify key hurdles to space technology adoption and develop strategies to address them:** This refers for instance to the availability of skilled personnel, as well as high-quality ground data
to validate satellite data and models, which could significantly increase the applicability and value of space-based observations particularly in developing countries.

• **Reinforce efforts in the collection of space-related economic statistics**: Several G20 economies have made great progress in economic measurement, notably by estimating contributions of the space economy to national GDP or supporting collecting industry data. These activities contribute to better understanding and evaluating the impacts of government investments and will prove useful for underpinning future government investments and policy decisions.

Furthermore, medium- and long-term solutions to the growth of space debris need to be considered by governments:

• **Addressing debris mitigation guidelines compliance, particularly at national levels**: Improving compliance among satellite operators is an indispensable step to long-term sustainability of orbits. For this, a range of policy solutions and lessons learned from other domains and sectors may serve as inspiration, particularly common pollution abatement measures, with instruments that include taxes, tradable permits, financial security mechanisms, and voluntary agreements.

• **Further relevant avenues for action could include the strengthening of space situational awareness systems, data reporting structures, and engaging in further R&D in debris removal in particular**: This will imply close co-operation with public and private actors. In order to support and improve decision making, the development of new indicators should also be explored, as to monitor debris mitigation performance and environmental instability.
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Notes

1 It should be noted that direct-to-home television is facing growing competition, e.g. from online streaming
platforms, resulting in declining revenues. Nevertheless, it continues to represent a significant share of the
space economy.

2 The “space literature” dataset has been built by the OECD Space Forum and is based on data from the
Scopus Custom Data bibliometric database. It comprises papers from all journals in the space and planetary
science classification as well as selected journals in aerospace engineering and journals dedicated to
specific space applications (e.g. GPS, GNSS, satellite remote sensing and navigation).

3 With the support of the OECD, G20 members discussed in March 2021 in the framework of the G20
Infrastructure Working Group (IWG), the importance of extending high-quality connectivity and identifying
policies to further strengthen networks resilience and performance, while eliminating connectivity divides.
http://www.oecd.org/innovation/inno/space-forum/

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