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April 2022

Impact evaluation of UK investments in ESA

PART B: Programme level reports

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Impact evaluation of UK investments in ESA

PART B: Programme level reports

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Table of Contents

Tables

Figures

1 Science

1.1 ESA's Science programme

The Science Programme dates from the creation of ESA in 1975 and is the only programme of the eight covered by the evaluation that comes under ESA's mandatory activities. All ESA member states contribute to the mandatory activities in line with Gross National Income (GNI) and as a result the UK contributes around 16% of the total budget. Within the UK contribution Space Science programme accounts for the majority (63%) of the total.[1]

1.1.1 Purpose of the programme

The ESA Science Programme is science-driven, with two key objectives:

- Providing the scientific community with the best tools possible to maintain Europe's competence in space
- Contributing to the sustainability of European space capabilities and associated infrastructures by fostering technological innovation in industry and science communities and maintaining launch services and spacecraft operations

Activities within the CMIN19 investment period continue to deliver ESA's current long-term plan for the Science Programme: 'Cosmic Vision 2015-2025'. Published in 2005, it targets the most fundamental scientific questions concerning the universe and our place in it, addressing research questions in astronomy, solar system and planetary science and fundamental physics:

- What are the conditions for planet formation and the emergence of life?
- How does the Solar System work?
- What are the fundamental physical laws of the Universe?
- How did the Universe originate and what is it made of?

From the UK's perspective , it seeks to achieve the following through its participation in the ESA programme:

- Participate with lead roles in world-class research and discoveries in the fields of astronomy and space through synergetic investments with other ESA member states. Indeed, missions of the calibre of the ones undertaken under the Space Science programme would be unaffordable if the UK were to undertake them autonomously, both financially and in terms of infrastructure
- Secure the opportunity for UK companies to bid for high-value mission contracts
- Shape and lead ESA missions to pursue national objectives

1.1.2 Programme design

While Cosmic Vision sets out the themes to be addressed and the range of small, medium and large-scale missions (known as S-class, M-class and L-class mission), specific missions are selected via 'bottom-up' processes. The European scientific community drives this – it develops,

[1] The remainder supports UK's contributions to ESA's 'basic activities' (including laboratories, ground stations and control facilities to European-wide early-stage technology development efforts, actions to support innovation and standardisation, highly secure networks and IT infrastructure and cybersecurity) and UK's (relatively small) contribution to ESA's launch capability at the Giana Space Centre

and proposes the missions (recently the UK has led the proposals for the Ariel, Comet Interceptor and EnVision missions, which have subsequently been selected in ESA's competitive peer review process). The research community and also peer reviewsproposals, providing advice to decision-makers within ESA on the selection of missions for each S-, M-, L-class mission 'slot'. Advice is provided via a Space Science Advisory Committee (SSAC) and two working groups: Astronomy Working Group (AWG) and Solar System and Exploration Working Group (SSEWG).decisions on the Science Programme content are made by the Science Programme Committee (SPC) – with the former made up of scientific experts and the latter by national delegations (i.e. formal representatives of member states funding agencies including UKSA).

The ESA Science programme funds the manufacture of spacecraft, launch, and mission operations. It also supports the development of identified needs for new or enhanced key technologies for future missions. Spacecraft instrumentation is developed by the scientific community and funded by member states' national funding mechanisms, with each mission led and supported by a Mission Consortium that design the research and work in partnership with ESA to design, plan and build the instrumentation. Therefore, the ESA Science Programme sits at the centre of a complex internationally collaborative activity, providing a critical role and focal point for the coordination of member state scientific activity and funding. Missions may also involve collaborations between ESA and other space agencies including NASA, JAXA, CNSA, Roscosmos and ISRO, with ESA taking a key negotiation and collaboration role on behalf of member states.[2] The recently launched James Webb Space Telescope is the product of such a collaboration between ESA, NASA and the Canadian Space Agency; the UK through its membership of ESA led the European Consortium that designed built and tested the Mid InfraRed Instrument for JWST.

1.2 Inputs and activities

As described above, ESA Science Programme missions are complex activities that coordinate and integrate activities funded by the ESA subscription and by member states directly through their national programmes. In the UK this takes the form of:

- ESA funds spacecraft design and build, integration of the science instruments with the spacecraft, test and validation including provision of major facilities, technical and management expertise, and critical gate review infrastructure, as well as the launch and operations – this is funded through the UK subscription to ESA along with the subscriptions of other Member States.
- Member states fund the design of scientific research programmes and the design and build of the required instrumentation and, ultimately, the research undertaken using the data generated by missions. In the UK:
  - UKSA funds the design, build and testing of the science instruments that will fly in space and the data processing centres that will convert the raw data from the mission into science ready data. I
  - Science and Technology Facilities Council (STFC) within UK Research and Innovation (UKRI) funds the UK research community to develop, propose and design missions at the start and to conduct scientific research using ESA mission infrastructure and the science ready data post launch. STFC/UKSA also fund some early-stage development work (at low TRLs) for instrumentation which may be used on future science missions; most

[2] The space agencies in the USA, Japan, China, Russia and India respectively

recently this has included a jointly funded call administered by UKSA National Space Technology Programme.

1.2.1 Inputs

UK commitments to ESA Science Programme

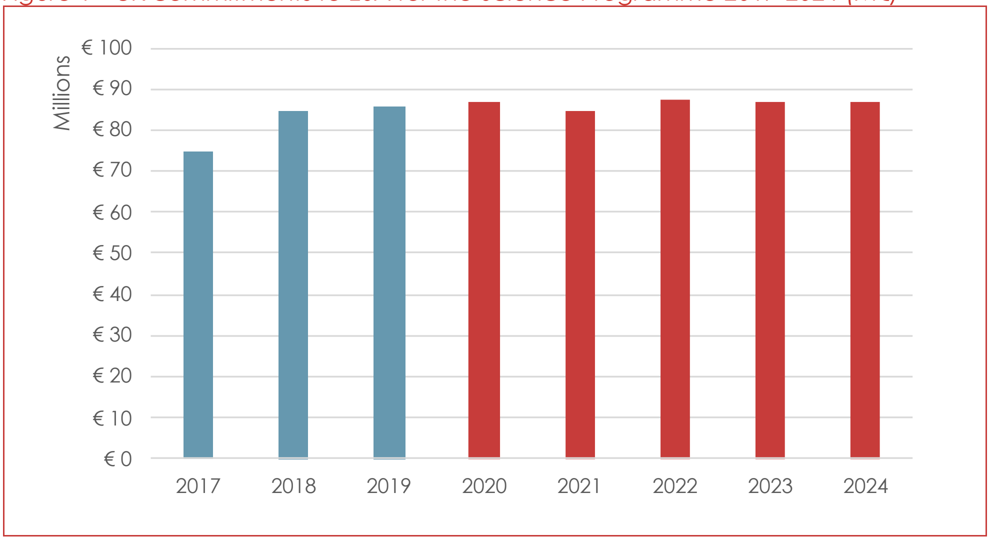
As a mandatory programme, the UK commitment has been relatively stable over time, though an uplift was agreed at CMIN19 (Table 1, Figure 1) – of the order of **€85-87M per year**. The UK national programme to support instrumentation development is of the order of **£23m per year**. As instrumentation has become ever more complex and costly, ESA is increasing its involvement with member states, aiming to work in a collaborative partnership mode rather than a customer-supplier relationship. The STFC annual budget for research grants is of the order of £30m a year, though only a portion of this will be assigned to research using space-based infrastructure created via the ESA Science Programme. [3] Grant proposals for astronomy research using ESA infrastructure, ground-based infrastructure (e.g. European Southern Observatory) or theoretical research are all funded from the same budget and allocated via competitive processes.

Table 1 UK commitments to ESA for the Science programme 2017-2024(M€)

	CMIN16 Period (M€)			CMIN19 Period (M€)				
	2017	2018	2019	2020	2021	2022	2023	2024
Science Programme	€74.46	€84.76	€85.61	€86.77	€84.38	€87.16	€86.71	€86.71

ESA datasheet on national obligations

Figure 1 UK commitments to ESA for the Science Programme 2017-2024 (M€)



ESA datasheet on national obligations

Science missions take many years to develop, some taking decades, and span several CMIN investment periods. Therefore, the investments in any CMIN period in any specific mission will

[3] STFC Astronomy Programme Evaluation Report, June 2019. (£29.7m a year is provided as the level of budget available for 'exploitation grants') https://stfc.ukri.org/files/astronomy-programme-evaluation/

not reflect the entirety of the investment required. Even the new fast-missions are unlikely the fall within a single five-year investment period – the first fast-mission, Comet Interceptor, was selected in 2019 and is due to launch in 2029.

UK contracts within the CMIN19 investment period

31 ESA contracts were signed with UK organisations between Jan 2020 and Jun 2012, i.e. within the CMIN19 investment period, with a total €15.3m.

- Nearly half of contracts (46%) are with businesses and the reminder with universities and research organisations
- The top 10 contractors account for 89% of contracts (by value) with the top five accounting for just over half (51%)
- A half of contracts by value (50%) are supporting the development of missions formally adopted as ESA missions (Comet Interceptor, ARIEL, SMILE). 34% support potential future missions (Theseus, SPICA)[4], 12% support existing operational missions (Solar Orbiter, Bepi-Colombo, Rosetta)

Comparing the value of contracts let to date to the annual UK commitments to ESA does not allow us to readily to determine if the contracts under CMIN19 are in line with expectations (at least in value terms) for three reasons. Firstly, the contracts data includes the full value of the contract in the year it was signed even though many contracts signed in 2020 and 2021 will expend costs over several years[5]. Secondly, some of UK's commitments to ESA in 2020 and 2021 will relate to contracts signed before Jan 2020 and therefore relate to financial commitments agreed at CMIN16. Thirdly, a single large contract to a UK company to lead (prime) a spacecraft build will appear in the data in a single year (i.e. the year the contract is signed) and therefore one contract will make a significant difference to the total value of contracts signed. Nevertheless, despite these difficulties, looking back at the average for values of contracts signed each year over a longer time period (when the effects of contract length and single large contracts are reduced) against the annual commitments, gives an average annual figure of contracts let of £39m since 2013 (this includes a large contract to a UK prime in 2015 to build the Solar Orbiter). This suggests the UK has been under-returned in the Science Programme for a number of years. The UK is expecting to prime or be a leading subcontractor for further contracts to build spacecraft under CMIN19. ESA signed a contract with Airbus for ARIEL in December 2021 (so will appear in 2021 Q4 geo-return datasheet) led by Airbus France with a significant role for Airbus UK. Thales Alenia Space UK (TSA UK) are expected to have a key sub-contractor role in the development of PLATO after the project successfully reached a critical design milestone in January 2022. TAS UK is also one of two companies bidding to lead the build of Comet Interceptor having been involved in contracts during the early stages of development. These contracts, the one for Comet Interceptor in particular, would make a difference to the value of ESA Science contracts in the UK and UK's geo-return rate.

[4] SPICA was removed as an M-class mission in October 2020

[5] The ESA geo-return datasheet does not record contract duration or end dates so the expected duration of contracts is not known

Table 2 Science contracts within CMIN19 investment period

	Total
Number of contracts*	31
Total value of Contracts	€15.33m

ESA geo-return datasheet *this includes contracts and sub-contracts to UK organisations

Table 3 Science contracts by entity type Jan 2020-Jun 2021

Entity Type	Value of contracts (M€)	% of total	No. of Contracts	% of total
Company	€7.12	46%	11	35%
Research organisations and universities	€8.22	54%	20	64%

ESA geo-return datasheet

Table 4 Top 10 Science contract recipients 2020-Q2 2021[6]

Entity name	Total Contract Value (M€)	% of total value of Science contracts to date	No. of contracts
University College London / MSSL	€2.12	14%	3
ABSL Space Products	€2.00	13%	1
University of Leicester	€1.95	13%	4
TAS (GB)	€1.67	11%	1
Teledyne UK Limited	€1.25	8%	1
Mars Space Limited	€1.20	8%	1
University of Cardiff	€1.16	8%	3
University of Cambridge	€0.72	5%	1
ADS (GB)	€0.70	5%	3
National Physical Laboratory	€0.63	4%	1

ESA geo-return datasheet

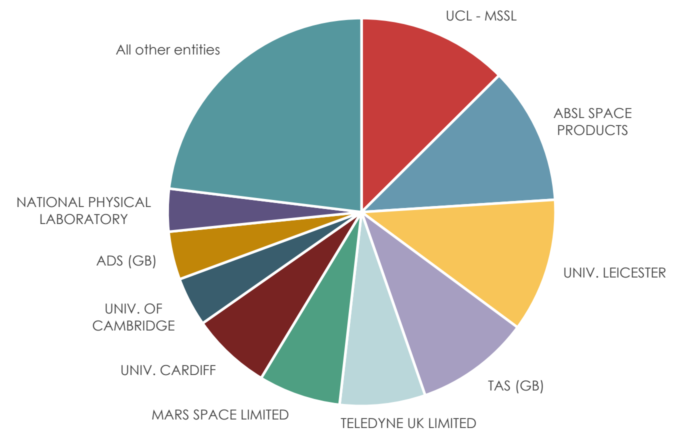
Table 5 Science contracts by mission stage 2020 – Jun 2021

	% of total contract value
Supporting operational missions	12%
Current selected missions in development	50%
Potential future missions	34%
Other	3%

ESA geo-return datasheet

[6] The contract to ADS (Airbus) to build ARIEL, signed in Dec 2021, some of which will come to the UK, does not appear in geo-return dataset

Figure 2 Science contracts by value per contractor Jan 2020 – Jun 2021



ESA geo-return datasheet

1.2.2 Activities

Table 6 illustrates the UK's role in the key mission under development by ESA within CMIN19, presenting a description of roles in terms of spacecraft build, instrumentation development and build and scientific research design (while noting that instrument and research design are highly inter-connected). The UK has a role in some shape or form in all eight ESA missions under development during the CMIN19 investment period (three L-class and five M-class) plus the joint missions with NASA (James Webb Space Telescope)[7] and the China National Space Administration (SMILE). It has leading roles in Solar Orbiter, ARIEL, PLATO, Comet and SMILE and is contributing instrumentation to all other missions. Regarding footnote 7 – the UK-led instrument for JWST was delivered to NASA in 2012 so it is to be expected that there would be no contracts within the CMIN 19 timeframe

This breadth and depth of activity is testament to the UK's very strong track record and reputation in space science and instrumentation and, as such, it plays a leading role in the ESA Science Programme. However, when it to comes to the building of spacecraft for space science, and where the ESA Science funding is spent, the UK does not appear to have fared so well in recent years. While Airbus UK is the prime contractor for Solar Orbiter, prior to that the UK has tended to be sub-contractor to primes in other member states. This may explain the relatively the low level of past contracts in Science. However, as noted above, the UK is expecting to prime or be a leading subcontractor for further contracts to build spacecraft under CMIN19 – for Comet Interceptor and ARIEL in particular and, in the longer-term, possibly for LISA where UK led the spacecraft build for the precursor mission (LISA Pathfinder).

Investment in most of these missions will continue beyond CMIN19 with only Euclid and SMILE due to be launched during the CMIN19 period. PLATO is expected to be launched during the CMIN22 five-year investment period (in 2026), ARIEL and Comet Interceptor will be launched together in 2029 and all others in the 2030s.

UK's choice of scientific missions to support requires both alignment of UK scientific interests and instrumentation capabilities (and relevant UKSA national funding for these) with ESA mission selection and there is a level of risk to be taken as not all missions proposed can be supported

[7] We note there are no ESA contracts in the UK in the CMIN19 period that relate to the JWST

by ESA. UKSA governance processes develop the UK position and then UK delegates and UK scientific advisors to ESA play a role in influencing and negotiating which missions are selected by the ESA Science Programme Committee. Ultimately ESA missions require substantial member state support and cannot be undertaken without their support. As a scientific leader and a large contributor to ESA, the UK's position is influential.

Table 6 UK involvement in ESA Science Programme under CMIN19 (chronological order based on launch date)

ESA mission	Description	Stage of development during CMIN19	UK role: Spacecraft manufacture (ESA funded)*	UK role: Payload / instrumentation (UKSA funded)	UK role: Scientific research (design & use of ESA space infrastructure) (STFC funded)
Solar Orbiter M-class (M1)	To perform a close-up study of our Sun and inner heliosphere to better understand, and even predict, the behaviour of the star ESA-led mission - in partnership with NASA	Initially selected by ESA in 2000 Launched at the start of CMIN19 (Feb 2020) First images released in July 2020 and already creating new knowledge (using instrument with key UK input) Routine science operations started in Nov 2021	**UK is prime contractor -** Airbus UK as prime and high levels of UK content	**UK is lead for three instruments** RAL Space (SPICE: Spectral Imaging of the Coronal Environment in the ultra-violet) MSSL, UCL (SWA: solar wind analyser) Imperial (MAG: magnetometer) And co-investigator on one instrument: UCL, MSSL (EUI)	**UK members of science team from:** Imperial college, UCL, Universities of Glasgow, Reading, Warwick, Central Lancashire
James Webb Space Telescope (JWST)	NASA led mission with ESA and Canadian Space Agency ESA contributing two instruments plus launch from ESA's launch facility in Guiana	Formal ESA-NASA agreement for the mid-Infrared instrument (MIRI) signed in 2004 Launched at end of 2021		**Instruments** Ten European space agencies are involved via ESA and contributing to MIRI instrument – including UK MIRI consortium is led by UK academic at the UK Astronomy Technology Centre in Edinburgh (UKATC) Other UK participants: University of Leicester, RAL Space,	**Science team includes Leicester, UKATC. UK MIRI Consortium PI provides science leadership on the instrument**
JUICE L-class (L1)	JUpiter ICy moons Explorer: will make detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa and explore the conditions for planet formation and emergence of life	Selected as a mission by ESA in 2012 Now in final stages of development (Phase D) Planned launch in 2022 was delayed due to covid. Launch now planned for early 2023.	Spacecraft prime is Airbus FR. **Some subcontracts to UK businesses** *and ground segment contracts*	**UK is lead on one instrument** Imperial (J-MAG - JUICE Magnetometer) **UK involved in other instruments:** UCL MSSL (providing the Solid-State Detectors for the (Swedish-led) Particle Environment Package (PEP))	**Science team includes** Imperial, University of Leicester, UCL

				Aberystwyth University is contributing to the radiation design of PEP instrument suite In addition, UKSA is funding the Open University to characterise, test and calibrate the CMOS imaging sensors for the Italian-led optical camera system, JANUS	
Euclid M-class (M2)	Near infrared telescope to map the geometry of the Universe and better understand dark matter and dark energy	Selected as a mission by ESA in 2011 Now in final stages (Phase D) Spacecraft integrated and launch planned for 2023.	*ESA contract to Teledyne e2v in UK to provide the CCD detectors for the UK-led VIS instrument. Some contracts to UK for final testing and ground segment*	**UK is lead on one instrument** (of two on spacecraft) MSSL, UCL and Uni of Portsmouth (VIS instrument) UK company Teledyne e2v providing imaging detector and electronics	UK has two members on the Euclid Consortium Board and leads one of the Science Data Centres (Shear Measurements)
SMILE	Solar wind Magnetosphere Ionosphere Link Explorer aims to build a more complete understanding of the Sun-Earth connection by measuring the solar wind and its dynamic interaction with the magnetosphere A joint mission between ESA and Chinese Space Agency (CAS), it is the first time that ESA and China have jointly selected, designed, implemented, launched, and operated a space mission together	Selected as a mission by ESA in 2019 Selected from 13 proposals put forward as joint missions to ESA and CAS in 2015 Launch planned for 2024	*Some contracts to support UCL and University of Leicester for instruments* *UK company (Photex Ltd) has also been contracted to assemble the camera for the UVI instrument*	**Instruments** UK leading on one of three instruments: University of Leicester's Soft X-ray Imager (SXI) by University of Leicester MSSL, UCL is in a joint venture with CAS LPP/CNRS/Ecole Polytechnique to build the Light Ion Analyser (LIA) UK company Teledyne e2V is providing the CCDs (calibrated by the Open University) for SXI	**Science** UCL, MSSL academic is the European lead (Co-PI with lead for China) Two of three SMILE working groups chaired by UK (Ground-Based and Additional Science (GBAS) chaired by University of Leicester and Outreach chaired by MSSL, UCL)
PLATO M-class (M3)	PLAnetary Transits and Oscillations of stars (PLATO) aims to detect and characterise terrestrial exoplanets around bright solar-type stars, with emphasis on planets that might support life	Selected as a mission by ESA in 2014 In construction phase (Phase D) Passed a critical milestone review in Jan 2022 Launch planned for 2026	**Spacecraft manufacture:** UK has a key role as sub-contractor to the spacecraft manufacturer (TAS UK under sub-contract to TAS FR and then to Prime OHB in Germany). TAS UK is providing assembly, integration and test of a structural model and	**Instruments / detectors** UCL's MSSL is leading the design and build of the electronics for the cameras Teledyne e2v has already delivered set of imaging detectors (CCDs) *(funded directly by ESA)*	**Science** UK academic from University of Warwick leads the Science Management Team and sits is on the Consortium Board along with an academic from UCL, MSSL 17 UK universities are in the PLATO consortium

			flight mode platform and the AOCS (Attitude and Orbit Control Electronics). ESA contract to Teledyne e2v UK to provide the CCD detectors for PLATO		Cambridge University is leading a UK consortium to develop the UK PLATO Data Centre. Birmingham, Open University, Oxford and St Andrews are contributing to the Data Processing Centre
ARIEL M-class (M4)	Atmospheric Remote-sensing Infrared Exoplanet Large-survey will explore what exoplanets are made of, how they formed and how they evolve, by surveying a diverse sample of about 1000 extrasolar planets in visible and infrared to determine their chemical composition and thermal structures	Selected as a mission by ESA in 2018 Phase B2/C Launch planned for 2029	**Spacecraft manufacture:** Prime contract for spacecraft manufacture is Airbus FR and UK. Airbus FR is main site for designing, manufacturing & integrating the spacecraft. **Airbus UK** - lead engineering of the avionics, radio frequency comms & electrical design of platform	**Payload** **STFC RAL Space** will lead and manage the overall European consortium building the payload, which will be assembled and tested in Harwell, Oxfordshire. Other UK involvement will come from Cardiff University (working with UCL on the ground segment), Oxford University (leading on testing the telescope and optical elements) and the UK Astronomy Technology Centre	**Science** UK-led mission from scientific point of view – lled by a UK PI is from UCL UK is also deputy lead of the Ariel Science Ground Segment, ensuring close involvement in data processing and calibration
Comet Interceptor Fast-mission (F1)	Made up of three spacecraft, Comet Interceptor will be the first to visit a pristine, and as yet undiscovered, comet. It will make a flyby and the three spacecraft will perform simultaneous observations from multiple points creating a 3D profile of the comet A partnership with JAXA	ESA's first 'fast-mission' (identified as new approach in CMIN16) Selected as a mission by ESA in 2019 In Phase 1 (for fast-missions this includes both Phase A & B) To be launched with ARIEL in 2029	**Spacecraft manufacture:** TAS UK leading one of two consortia groups contracted by ESA to contract parallel studies on spacecraft design and preparation for the development phase. One of the two consortia will be selected to manufacture the spacecraft	**Instruments** UK is lead for one of 10 instruments (one of 7 that are ESA led) – University of Oxford for the MIRMIS: Multispectral InfraRed Molecular and Ices Sensor	**Science** UK-led mission from scientific point of view – science lead is from UCL and deputy lead from University of Edinburgh
ATHENA L-class (L2)	Advanced Telescope for High Energy Astrophysics - combining a large X-ray telescope with state-of-the-art scientific instruments, Athena will address key questions in astrophysics	Selected by ESA in 2014 Phase B1 Launch expected in 2037	**Spacecraft** Airbus UK currently subcontracted to Airbus DE for phase A study	**instruments** Open University and University of Leicester are in the team developing the wide-field imager (WFI)	**Science** The UK has three members (out of 26) on the Athena Community

LISA L-class (L3)	Laser Interferometer Space Antenna (LISA) will be the first space-based gravitational wave observatory. It will consist of three spacecraft separated by 2.5 million km in a triangular formation, following Earth in its orbit around the Sun.	Selected by ESA in 2017 (first proposed and considered since in 2007) Phase A, moving into B1 in 2022 Launch expected in 2037	**Spacecraft** UK played key role in precursor mission LISA Pathfinder - Airbus UK was prime contractor for the spacecraft for LISA Pathfinder, launching a demonstrator of both spacecraft and instruments. This was critical to demonstrate that the spacecraft could be accurately enough to fulfil the requirements of LISA experiments. Airbus UK currently subcontracted to Airbus DE for phase A study	**Instruments** A team from Glasgow University developed the optical bench for Pathfinder and they are now working STFC's Astronomy Technology Centre in Edinburgh to design the optical benches for LISA Universities of Edinburgh and Birmingham Universities are developing (supported by UKSA) a LISA Data Centre in the UK	**Science** The UK has two members (out of 22) on the LISA Consortium Board 12 members (out of 125) from 12 universities involved in LISA consortium: Birmingham, Durham, Imperial College, Glasgow, Kings College, Nottingham, Portsmouth, Queen Mary, Southampton, Sheffield, Sussex, UKATC
EnVision M-class (M5)	Venus orbiter to investigate Venus from its inner core to its upper atmosphere. An ESA-led mission in partnership with NASA, with NASA providing the Synthetic Aperture Radar (VenSAR) and Deep Space Network support for critical mission phases	Selected in 2021 Launch expected in early 2030s	*Too early*		**Science** Mission was originally proposed by UK scientists. Scientists from Imperial College and University of Oxford on ESA science study team; scientist from RHUL potentially on NASA Study Team
Icy Moons mission (ESA-NASA) Potential future L-class mission	A mission proposed during development of new ESA Science Programme strategy Voyage 2050, and recent mandate from ESA to take further as a sample return mission - It would aim to bring back a core of ice	Very early phase of development	*Too early*		**Science** A UK (UCL) scientist is on the Working Group to identify the optimum mission scenario to maximise science return

Technopolis 2022 *pink shading denotes where the UK has a key role in the spacecraft build either a prime or as key sub-contractor, blue shading denotes where the UK is leading on the science

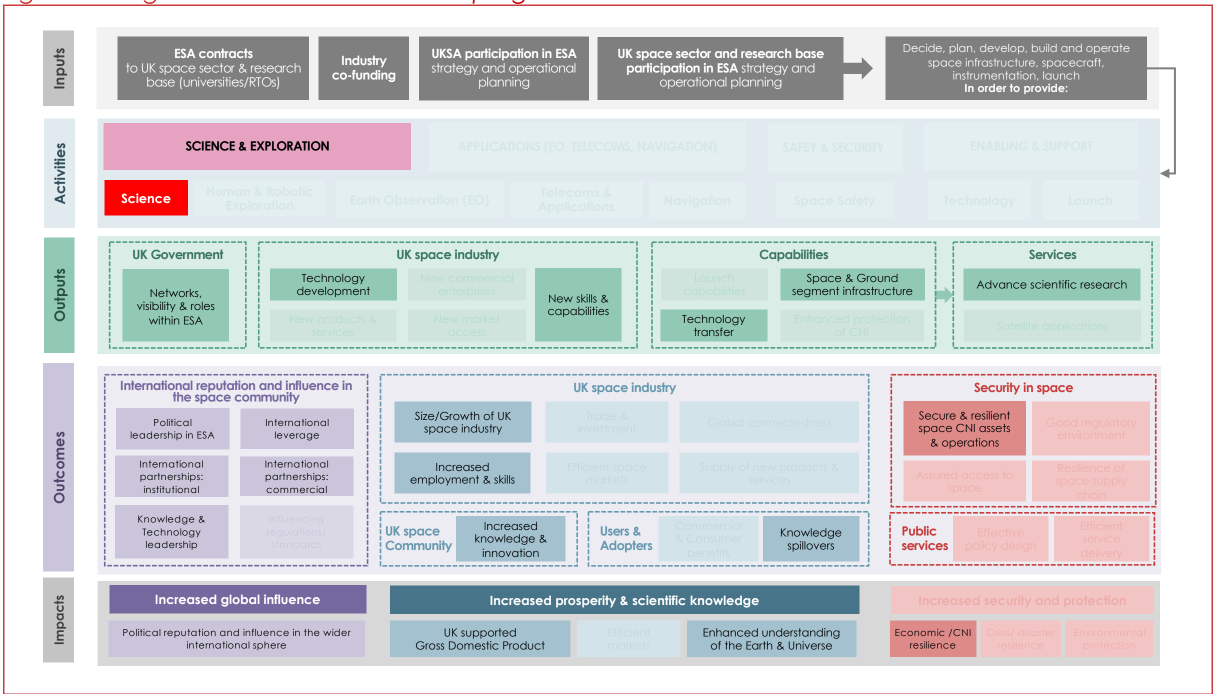
1.2.3 The logic model for the UK's investment in ESA's Science programme

Figure 22 presents an overview of the various outputs, outcomes and impacts achieved and anticipated from the UK's CMIN19 investments in ESA's Science programme (logic model).

The primary role of the inputs and activities within the Science programme is to advance scientific research and contribute to new knowledge about the Solar System and Universe. This knowledge is of value in its own right, but also, as for all public support for scientific research, it is expected to lead to skills and knowledge spillovers of benefit to the wider economy.

In developing the space infrastructure to do this, the programme supports the UK space sector, directly though the support of revenue and jobs in the short-term, but also in developing new skills and capabilities in leading-edge technologies and management of highly complex engineering projects within the space sector for future public and commercial requirements.

Figure 3 Logic model for ESA's Science programme



Technopolis (2021)

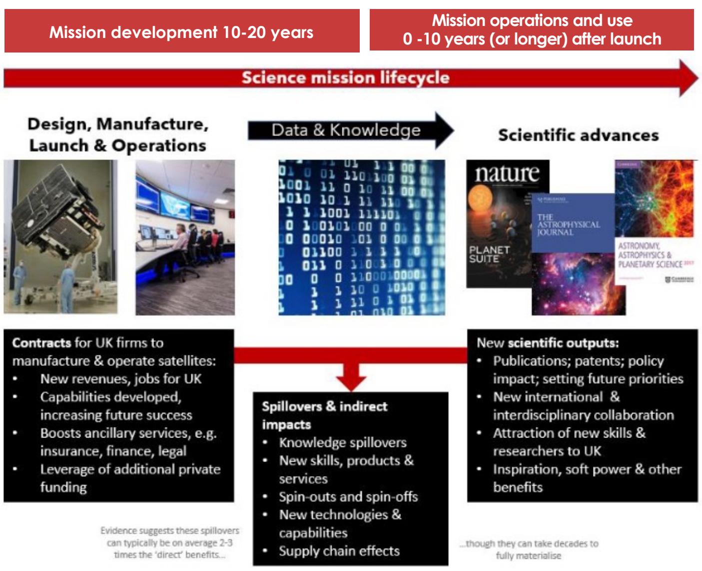
1.2.4 Timescales to Science programme effects

The timescales are different for the different levels of effects (Figure 4) and, for investments made within a specific CMIN period, are dependent on the stage of development of each ESA mission:

- **Outputs occur during the lifetime of ESA contracts: e.g.** ESA contracts develop new and enhanced technologies to support ESA missions with the aim of increasing the technology readiness level by the end of each contract. Depending on the stage if the mission this may result in new space infrastructure. The direct effects for ESA contractors (outputs) occur during the contracts and include the direct economic in terms of jobs and skills enhancement and may also involve the creation of new partnerships and collaborations.
- **Outcomes and impacts occur on a range of timescales after contracts have been completed:**

- economic outcomes for ESA contractors are likely to occur in the near-term (0-3 years) – deploying technologies and intellectual property developed and new skills and capabilities acquired as products and services for other public or commercial space contracts. Some technologies and skills may also be transferred to other sectors either by the contractors themselves or by other via formal (patents, spin-outs, etc) or informal technology transfer and wider knowledge spillovers.
- The impact in terms of GDP occurs on range of timescales – immediately for the direct effects on ESA contractors (outputs), over 0-3 years for the follow-on effects for ESA contractors and over several years for spillover effects (these are dealt with in more detail in the Impact Evaluation Report Part A)
- Scientific outcome and impacts occur once missions are launched and, depending on the stage of mission development during a CMIN period, may commence during the period for mission launched or 10-20 years for missions in the early stages of development. In any CMIN period ESA supports missions at all stages of development. During CMIN19, for example, two missions have been launched already (Solar Orbiter and JWST), (with most of their development funded under prior CMIN periods), three are expected to launch JUICE, Euclid, SMILE) and others will launch at various points from 2026 to the 2030s. This means that each mission will be generating scientific impact on different timescales. The scientific knowledge will not only deepen our understanding of the Solar System and Universe over many decades but will also provide further opportunities for knowledge spillovers.
- Due to the continuous nature of ESA investments over many years, the outcomes and impacts in terms of international influence and reputation within the space and wider global communities, are like the scientific impacts, occurring on an on-going basis. The very fact of being a financially significant contributor to ESA and an active member in governance and advisory processes, leads to influence and reputation effects. Particular enhancements (or otherwise) may occur at particular points in time as a result of key roles in the leadership of specific missions and specific contract wins (or losses) or new leadership roles in the governance and advisory structure.

Figure 4 The space science mission lifecycle



Source: know.space analysis

Know.space

1.3 Outputs

1.3.1 Technology development and new space infrastructure

The direct outputs of ESA contracts in Science are, in most cases, directed primarily at the technological development of the technology and engineering required to develop spacecraft for operational missions

The majority of survey respondents an uplift in TRL during their CMIN19 contracts to date and a further expected uplift by the end of the contract.[8] While the range of TRLs being addressed varied across contracts, reflecting the different stages of missions being decelopped, there was an uplift of the order of 1 level between the start of the contract and the time of the survey and another uplift of 1 expected by the end of the contract (Table 7). Although survey response numbers were low (n=14) these represent nearly two-thirds of the target organisations with Science programme contracts[9] and these findings were reflected in the interviews. This uplift is expected as the purpose of the ESA contracts in this programme and interviewees see the contracts as developing and advancing technologies that are likely to lead to new operational space infrastructure, albeit that in some cases this will be dependent on contractors winning contracts to build mission spacecraft.

Table 7 TRL progression: mean / median progression (n=12)

	From start of contract to Q4 2021	From start of contract until contract end (expected)
TRL progression (mean)	1.2	1.9
TRL progression (median)	10	2

ESA contractor survey

In terms of new space infrastructure established since Jan 2020, Solar Orbiter was launched early in the CMIN19 period. Other new infrastructure will become available later in the period when Euclid and PLATO are launched. All other contracts related to missions to be launched in the CMIN22 period or later. The JWSC has also been launched since Jan 2020 but there were no JWST ESA contracts with UK organisations in the CMIN19 period.

1.3.2 Employment – direct effect of ESA contracts

These contracts have immediate effects for contractors in terms of providing revenue and supporting employment with much of it high-skilled employment. Interviewees reported ESA contracts as playing a role in attracting and recruiting highly-skilled engineers and scientists who are demand in other sectors particularly young people engineers coming out of university with Masters degrees and PhDs in spacecraft engineering and relates fields. Contracts to conduct studies for ESA in the early stages of mission development provide a good training ground for young engineers. One company has a dedicated department for study phases where younger staff gain skills by working with more experienced staff (who are brought in as needed) who have worked on previous missions and with experts in universities who they collaborate with on studies. The ESA work is viewed as exciting and motivating and helps the

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[8] Contracts signed from Jan 2020

[9] N.B. This is a higher proportion than reported in the Impact Evaluation Report, PART A, as the values reported there include both the Science and Basic activities under the mandatory programme
Survey respondents for the Science programme included two large multinationals active in the space sector, SMEs, micro businesses and academic and research organisations

encourages the young engineers to develop a career in the space sector. Some may well leave company but many remain in the space sector moving between businesses, between civil and defence work and between, in some cases, businesses and space agencies and academia.

1.3.3 Skills and capabilities

Over two-thirds of survey respondents in Science reported new or improved skills and knowledge. The advanced systems being developed for space require solving complex technical and engineering challenges. Interviewees reported that ESA contracts reinforce and update key skills and capabilities for space as well as developing skills in specific technical domains such as optical payloads and developing skills within the UK arm of a business in electronic design and software, in attitude and orbit control systems (AOCS) and in the assembly, integration and testing of systems and sub-systems.

Developing skills in the early stages of mission development (phase A, B1) are essential to winning later contracts to build spacecrafts for Science but they can also have wider applicability. An interviewee from a large space company also spoke of skills gained in the Science programme being transferable toother more application-oriented domains such as EO, meteorology and defence. Though as yet it is too soon within the CMIN19 period to identify specific examples. Interviewees noted that skills acquired are not only technical but also relate to administrative and operational skills for undertaking complex engineering projects such as skills in procurement and managing sub-contractors.

Many projects involved collaborations (50% of survey respondents reported collaborations with industry in the UK and in ESA member states and around a third reported collaborations with academia in the UK and in ESA member states), with one interviewee from a large space company notes the transfer of important space skills from their sister-companies in other ESA member states to the UK, helping to build capability to lead large ESA spacecraft build contracts in the UK. Industry-academic collaborations can help to build relationships between spacecraft manufacturers and instrumentation builders, with interviewees reporting that this typically brings a two-way transfer of skills and knowledge. Interviewees from large space companies reported specific new and/or deepened relationships with RAL Space and with specific academic groups including those who are leading science mission development. This aligns with Table 6 which indicates that the UK is well-positioned to be the industrial lead on ESA contracts to build spacecraft where the UK is also leading the scientific consortia (e.g. PLATO, AREIL, Comet Interceptor)

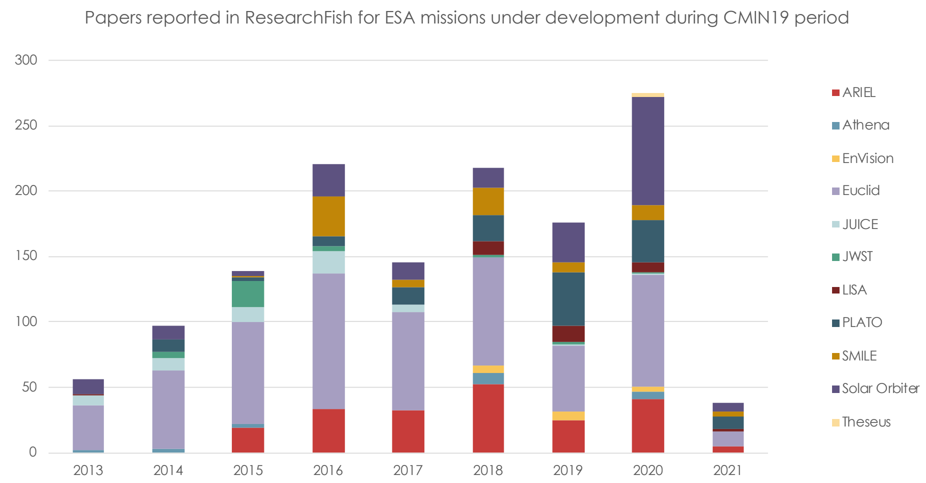
A contract related to Bepi-Colombo and electric propulsion was specifically focused on transferring skills between companies (one company was seeking to divest from this area) both ensuring the skills remained available for ESA but also retaining the skills in the UK.

1.3.4 Advancing scientific research

While the purpose of the Science programme is to advance scientific research and create knowledge this is not the intended direct output of ESA contracts. The ESA funded activity creates the space infrastructure that will enable scientific research to take place (reported in the Outcomes section below). This is not to say that scientific knowledge is not created during the mission development stage - survey respondent reported a small number of papers (nine) published since Jan 2020 arising from contracts let since Jan 2020. Similarly, the design and development of instrumentation for ESA missions creates scientific knowledge and papers are published. The data captured by UKSA via ResearchFish indicates an active level of publication of in this regard (Figure 5). This work is not a direct output of the ESA contracts themselves as it is funded by UKSA, but one cannot happen without the other – the spacecraft and the instrumentation are both critical to a mission. The issue here is about assigning attribution; the papers published as a result of ESA contacts are wholly attributable to ESA funding, while the publications from the work funded by UKSA could be considered to be partially attributable to UK's investments made via ESA due to the mutual dependence of the two funding streams.

Data from Solar Orbiter is already providing scientific insights, a few months after launch, and a healthy stream of papers is expected from UK researchers.

Figure 5 UK papers published in the development of instrumentation for ESA missions (2013-2021)*



Technopolis (2022): based on ResearchFIsh data provided by UKSA *data for 2021 is not yet complete

1.3.5 Networks, visibility, and roles within ESA

The UK is represented as a delegate within all ESA's governance bodies and processes and is particularly well-represented within the advisory bodies for the Science programmes. Interviewees report that the UK's scientific reputation is well-recognised and valued. The issue of reputation and influence is dealt with further in section 0.

1.3.6 Inspiration

The ESA Science Programme is one of three programmes (along with Human and Robotic Exploration and Earth Observation) that provide important content for education and outreach activities, with the ultimate aim of increasing the scientific awareness and literacy of the British population and fulfilling their curiosity and stimulating interest in STEM careers among young people. Understanding the Solar System, Universe and Earth and exploration on the moon and Mars are topics of particular interest to the public and can be expected to form a large portion of the content used – though data on the content of UKSA's and ESERO's material is not systematically captured. Material is based on missions under-development as people are interested in the concepts to be explored and the advanced technology involved as well as on the results of the later findings of the research undertaken.

1.4 Outcomes

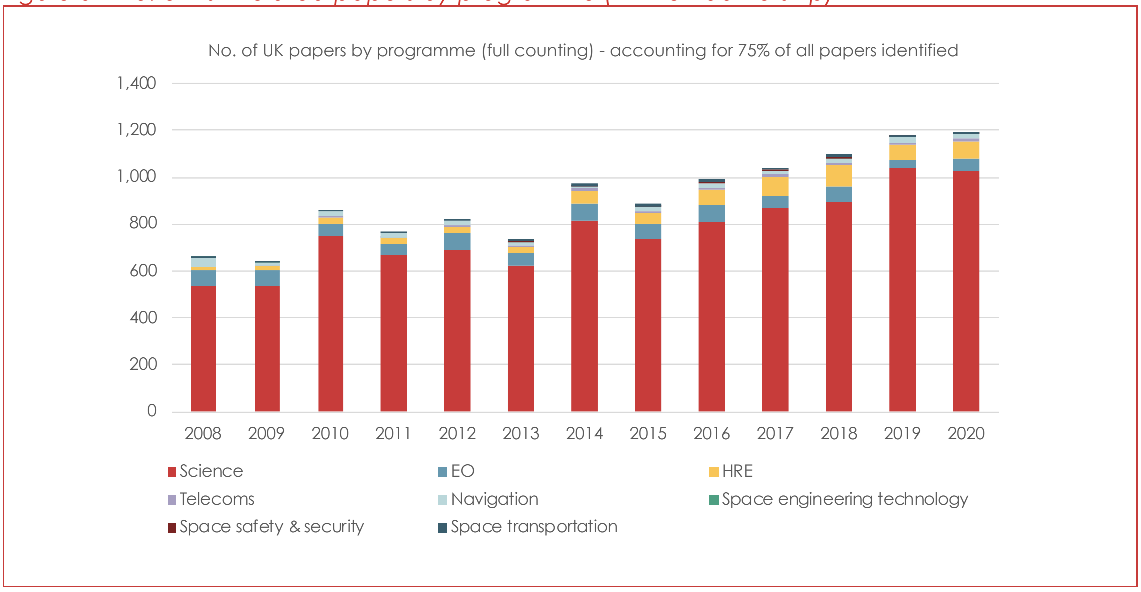
1.4.1 Increased knowledge

As reported in the section on timescales to outcomes and impact (section 1.2.4) most of the scientific research will take place in the future once missions have been launched. Even for

Solar Orbiter, which is just starting to provide data and insights, publication of the first research findings is at least 12-18 months away and research will continue for around 10 years and possibly longer. The UK is at the heart of the Solar Orbiter scientific consortium and is expected to contribute to the scientific outputs and new knowledge.

The *Impact Evaluation REPORT A* provides long-run baseline data for scientific publications from all programmes for 2008 to 2020. The majority of the ESA-related papers presented are from the Science Programme – it accounted for between 82% to 88% of all papers each year and 84% across the 13-year period (Figure 6). Section 1.6 provides a bibliometric analysis for the Science programme, this provides a long-run baseline for the quantity and quality of scientific outputs for the Science programme.

Figure 6 No. of ESA-related papers by programme (with UK authorship)



Science-Metrix (2021) / Scopus

*25% of papers identified as ESA-related could not be assigned to a specific ESA programme

1.4.2 Prosperity: innovation – in space sector

Innovation among ESA contractors – be that new or enhanced technologies and intellectual property developed and /or w new or enhanced skills and capabilities – is expected to lead, in the first instance for ESA contractors. to improved economic performance. At this point in the CMIN period, it is rather soon to be expecting to see substantial effects in this outcome domain, however there are some indications of effects and expected effects.

- **Follow-on sales:** four out of eight survey respondents from industry report some follow-on income related to the outputs of ESA contracts since Jan 2020, with three of them expecting further follow-on sales in the future. The majority of these sales are reported as exports (though we note from interviews that for some contractors ESA contracts are considered as exports). The new capabilities are expected to enable them to continue to bid for ESA contracts but also contract from the UK and other space agencies – both in the Science and programmes and other programmes – as, as described above, the skills and capabilities for Science are transferrable to other space domains.
- Two industry respondents report **new products/services commercialised** as a result of ESA contracts and four companies and one university expect them in the future

- One respondent reported accessing a **new market** and another the expectation that they would do so in future
- **No new patents** are reported by contractors in the Science programme

Interviewees described how current ESA contract are enabling them to build capabilities in new areas with future potential. One described how ESA contracts over a number of years have enabled to position the company as new UK prime for ESA contracts in future, with expectation of the first such contract within the CMIN19 period. Similarly, ESA contracts, and the ESA 'badge of approval', have led to contracts with commercial space companies and contracts for space activities for customers in defence.

1.4.3 Prosperity: innovation – technology transfer and knowledge spillovers

There is very little evidence to date of the transfer of technologies developed within CMIN19 contracts to non-space applications, though again it is rather soon to see these effects. One interviewee noted how technology developed in HRE (so not Science) might have applications in healthcare.[10]

1.4.4 Knowledge and technology leadership

The citation analysis in space science indicates that the UK has strong leadership in space science. Based on past performance, over the 10-year period from 2008 to 2018 the UK has improved its research impact in space science; the UK performs above word-average for ESA-related papers, and above many of our key competitors in the citation indicators FWI, HCP10 and HCP5[11] (Figure 11, Figure 12, Figure 13), only performing lower than the USA and France for most of the 13-year period.

The UK also has, historically, a high international collaboration rate in Science (Figure 15) – with partners worldwide – indicating a level of knowledge and technology leadership, as others wish to collaborate with us.

An interviewee from ESA noted that the UK is one of a very small number of ESA member states that has the knowledge, skills and technology to be able to participate in ESA's partnerships with NASA and with CNSA in China.

1.4.5 International reputation and influence

Collaborations within ESA contracts can build new relationships, though not all collaborations will be new. Interviewees note the role of ESA in making valuable introductions to new potential partners. Also noted was the fact that some collaborations were a result of the need to achieve geo-return, some of which may end up being more effective and valuable than others.

The UK is particularly well-represented in the bodies (committees, working groups, etc) that provide scientific advice to the decision-makers in Science Programme Committee in ESA (Table 8). With, typically, two members (or more) out of 12 on the programme working groups, the UK is represented at a level slightly higher than our proportion contribution to the Science Programme and considerably higher than the one-member-one-vote decision making processes. The UK was even more well-represented on the groups selected to develop ESA's

[10] A highly controlled and insulated processing environment for robotic manipulation and investigation of materials returned from Mars, to protect them from contamination, might have applications in handling viruses and other potentially dangerous biomaterials. Discussion are on-going with potential users / partners for this technology.

[11] Field-weighted citation impact (FWCI) and Highly cited papers at the 10% (HCP10) and 5% levels (HCP5)

new long-term plan for Space Science during 2019 and 2020. Not only with the position of Co-Chair of the Science Strategy Senior Committee but also selected, via an open call, to be members of the Topical Teams. The resulting new Science Strategy 'Voyage 2050', was published in 2021 and covers the period 2035-2050, replacing the current Cosmic Vision (published in 2005) and shaping scientific missions into the 2030s and 2040s.

The fact that the UK is involved in all ESA missions is testament to both the UK's scientific and technology leadership and our reputation and influence – with the two strongly inter-related.

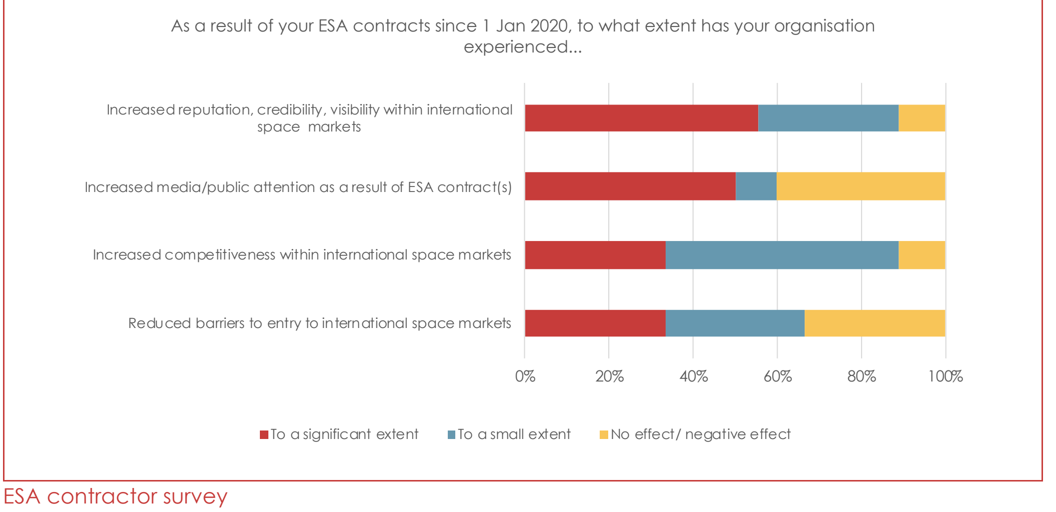
Table 8 ESA advisory bodies and UK roles for the Science Programme

ESA Science Programme Advisory body	UKSA delegate (by role /job title)
Space Science Advisory Committee (SSAC)	Two UK academics are members (out of 12 on the committee) Plus two ex officio membership for two UK academics (via the ESA PSWG and as Chair of the European Space Sciences Committee (ESSC))
Astronomy Working Group (AWG)	One UK academic member (out of 12 on the committee)
Solar System and Exploration Working Group (SSEWG)	Two UK academics are members (out of 12 on the committee)
Voyage 2050 Science Strategy Senior Committee – established in 2020 to develop the new long-term ESA science strategy	Two UK academics were members (out of 13), one as co-chair There were four Topical Teams (TT): • 3 x UK academics (out of 12) on TT1: Solar and Space Plasma Physics • 3 x UK academics (out of 15) on TT2: Planetary Science • 1 x UK academics (out of 10) on TT4: Extreme Universe, including Gravitational Waves, black holes, and compact object

Technopolis (2021): based on ESA and UKSA documentation

From the perspective of ESA contractors; they hold the view that ESA contracts confer positive reputational effects. Survey respondents (Figure 7) and interviewees Winning an ESA contract is a demonstration of technological competence but also operational competence and contractors value the ESA 'badge of approval'. Across all ESA programmes this is particularly the case for SMEs and new entrants, although, to date under CMIN19 the Science programme tends to have less of these.

Figure 7 Reputational effects of ESA (n=9)



ESA contractor survey

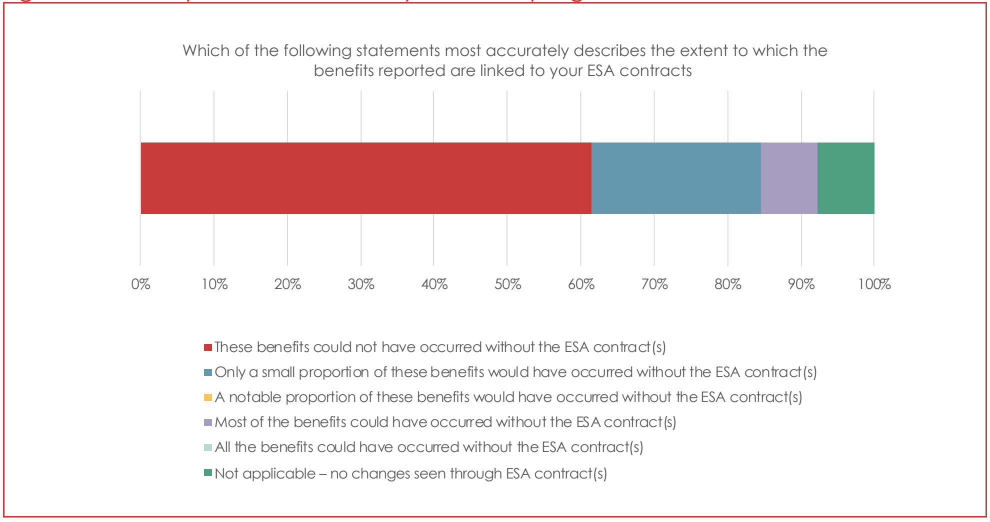
1.5 Attribution and additionality

As scientific missions principal aim is to develop a deeper understanding of the Solar System and Universe with no immediate commercial applicability there is limited incentives for private sector investment. There are limited alternative sources or methods to ESA to support space science missions at the scale and breadth achievable through pooling and coordinating resources across member states. If the UK were to undertake unilateral missions, at current investment levels it would only be able to support a very small fraction of the missions achievable via ESA. Even then UK would not have ready access to all the required technical capabilities nor the expertise in project managing complex missions that it currently accesses via ESA. Survey respondents reported a high-level of additionality of benefits gains to ESA support – with the most reporting that benefits achieved to date from CMIN19 contracts would not have happened without the ESA contracts. Interviewees noted that not only would it be costly to develop the skills and capabilities required, but it may take up 10 years or so to do so. Most interviewees did not take the view that bilateral missions, with NASA for example, are a viable alternative. They noted that our current participation in missions with NASA and CNAS are a result of bilateral partnerships between these agencies and ESA and are based on ESA's reputation and relationships as much as they are based on access to specific UK capabilities. Therefore, the ESA Science programme quite clearly plays a central role in the UK's ability to conduct high-quality space science from space. It has also played an important role in the development, over several decades, of UK's expertise in designing and building complex space instrumentation as, without the ESA missions, the instrumentation would not be developed, or without UK membership of ESA, the UK would not have a role in the instrumentation.

ESA membership and participation in the Science programme also provides the UK with secure access to launch capabilities for missions beyond Earth's orbit. This type of launch capability will not be provided by the current capability being developed in the UK and therefore the UK will continue to need to secure this type of access to space particularly where space science is concerned. If the UK were not in ESA not in ESA the UK would need to negotiate access to this type of launch. Historically, this access has only been provided by space agencies and therefore being in ESA not only provides the UK with access to launch capabilities but also the complete mission 'package' from design to launch. Options for accessing space beyond Earth's orbit are starting to change with commercial launch capability increasing, though as yet only Space X is addressing the type of launch needed for most science missions and the UK acting alone may not have the same the negotiating power of an organisation as large as ESA.

Participation in the ESA Science programme also acts as a signal of the UK's scientific and technological capabilities and skills in space but also more generally. Being a successful space-faring nation is a demonstration and symbol of high-level technological capabilities and most emerging economics seek to achieve the same level of recognition.

Figure 8 Self-reported additionality, Science programme



ESA contractor survey

Assigning attribution of outcomes and impacts to ESA is complex as UK funding to support space science comes from three sources: UK funding allocated via ESA for spacecraft; from UKSA national programmes for instrumentation; UKRI-STFC for space research. They are entirely interdependent. The ESA Science programme is designed around the principle that they only fund the mission spacecraft development, launch and operations and member states pay for the instrumentation and research. ESA also plays an additional, and critical role as the coordination function for member states, coordinating not just mission development and operations but also long-terms planning and mission selection.

One approach is to assign and attribute all outcomes and impacts to investment via ESA, based on the concept that science missions (for UK use) wouldn't happen without ESA. However, the same could be said of UKSA funding for instrumentation, creating the risk of double-counting i.e. assigning all outcomes and impacts to both ESA and UKSA national support. An alternative approach is either to assign outcomes and impacts to ESA and UKSA national support according to size of the investment (for example in the ratio 85:15, representing the typical annual investment for Science via ESA and national programmes) or to assign in ratio 50:50 to reflect high levels of interdependence. Ultimately it is a matter of choice and clarity.

It is also important to note that different effects may have different levels of attribution (and additionality). Scientific outcomes and impact (new knowledge related to high-tech instrumentation and data processing and about the Solar System and Universe) is both highly additional (the majority of the UK ESA-related papers wouldn't happen without ESA) and can be attributed to ESA by any of the methods described above. The economic effects, for the space sector in particular, may need to be considered differently. The effects due to ESA contracts to build and operate spacecraft for Science will have a higher level of attribution to ESA funding and a high additionality – at present there are limited other sources or routes to funding routes for these types of activities. However one concern here, is what seems to be a lower than expected geo-return in the Science programme, meaning that, while additionality and attribution might be reasonably high, value for money may be lower than it could be. It may well be worth the cost of subscribing to the mandatory Science programme to access the scientific benefits (and there are limited alternatives), but a higher geo-return to UK space companies to manufacture mission spacecraft would increase the industrial and economic effects for the UK space industry and increase value for money.

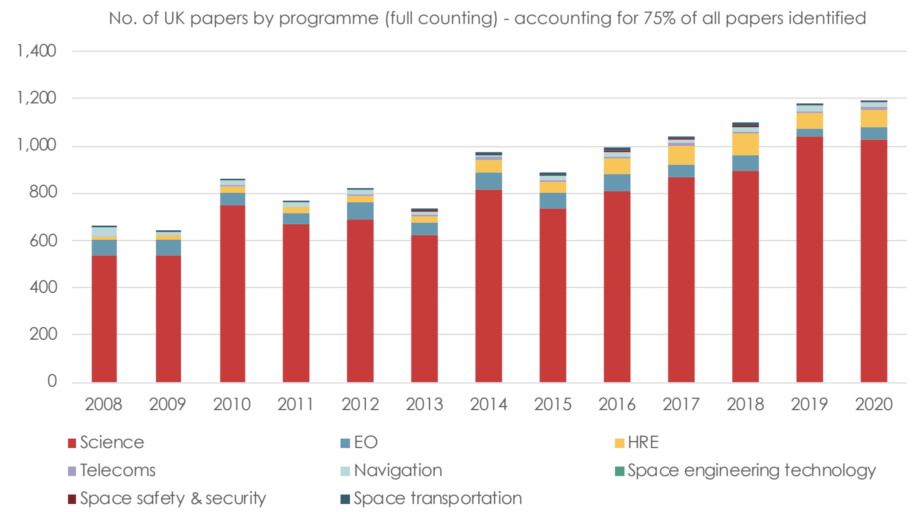
1.6 Appendix: Bibliometrics for the Science programme

The Science programme accounts for the majority of ESA-related papers published – the Science programme accounts for between 82% to 88% each year and 84% across the 13 year period (for all papers that could be assigned to a programme).

The bibliometric data is presented here following the presentation in the Impact Evaluation REPORT A (for all programmes) with key differences noted.

It is important to note that these papers reflect past investments in ESA programmes and not investments made during the CMIN19 period.

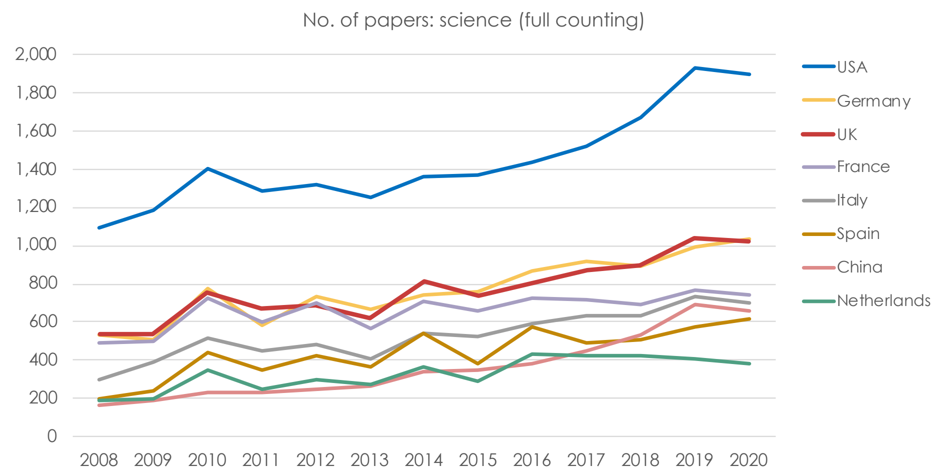
*Figure 9 No. of ESA-related papers: Science programme (UK)**



Science-Metrix (2021) / Scopus

*25% of papers identified as ESA-related could not be assigned to a specific ESA programme

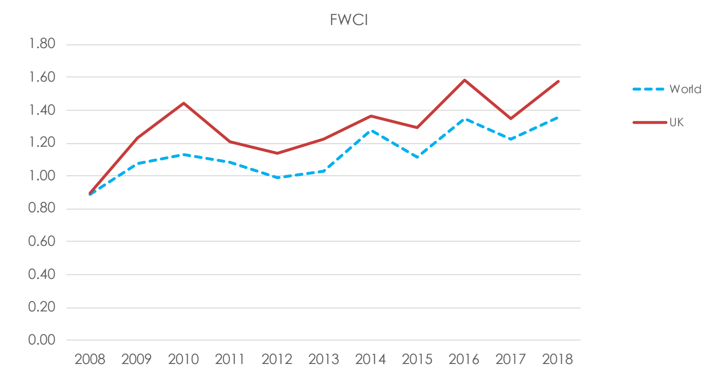
Figure 10 No. of ESA-related papers: Science programme, international comparison



Science-Metrix (2021) / Scopus

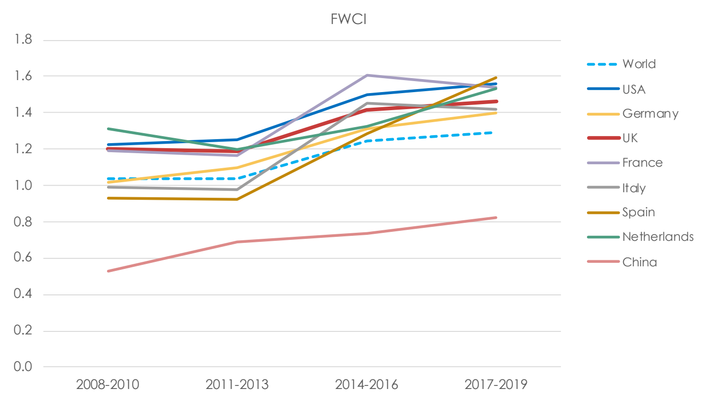
Citations: Citations values are slightly lower for Science than for papers from all programmes (that is Science, EO and HRE – as only these three programmes have sufficient papers to for a citation analysis). The difference appears to be due a small number of highly cited EO papers in 2013 and 2016.

Figure 11 Impact of ESA-related papers: Science programme, FWCI (UK & world average)



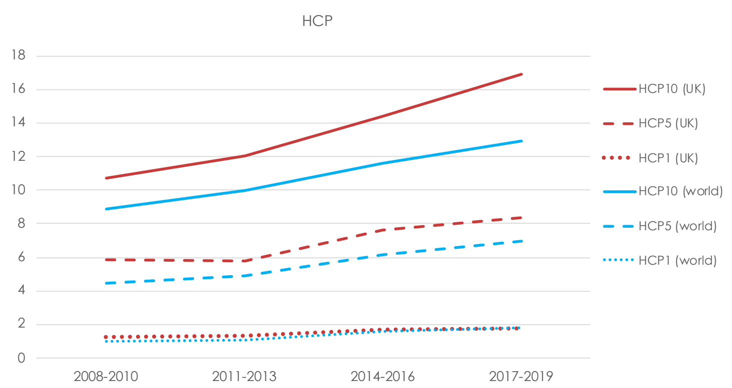
Science-Metrix (2021) / Scopus

Figure 12 Impact of ESA-related papers: FWCI (international comparison): Science programme



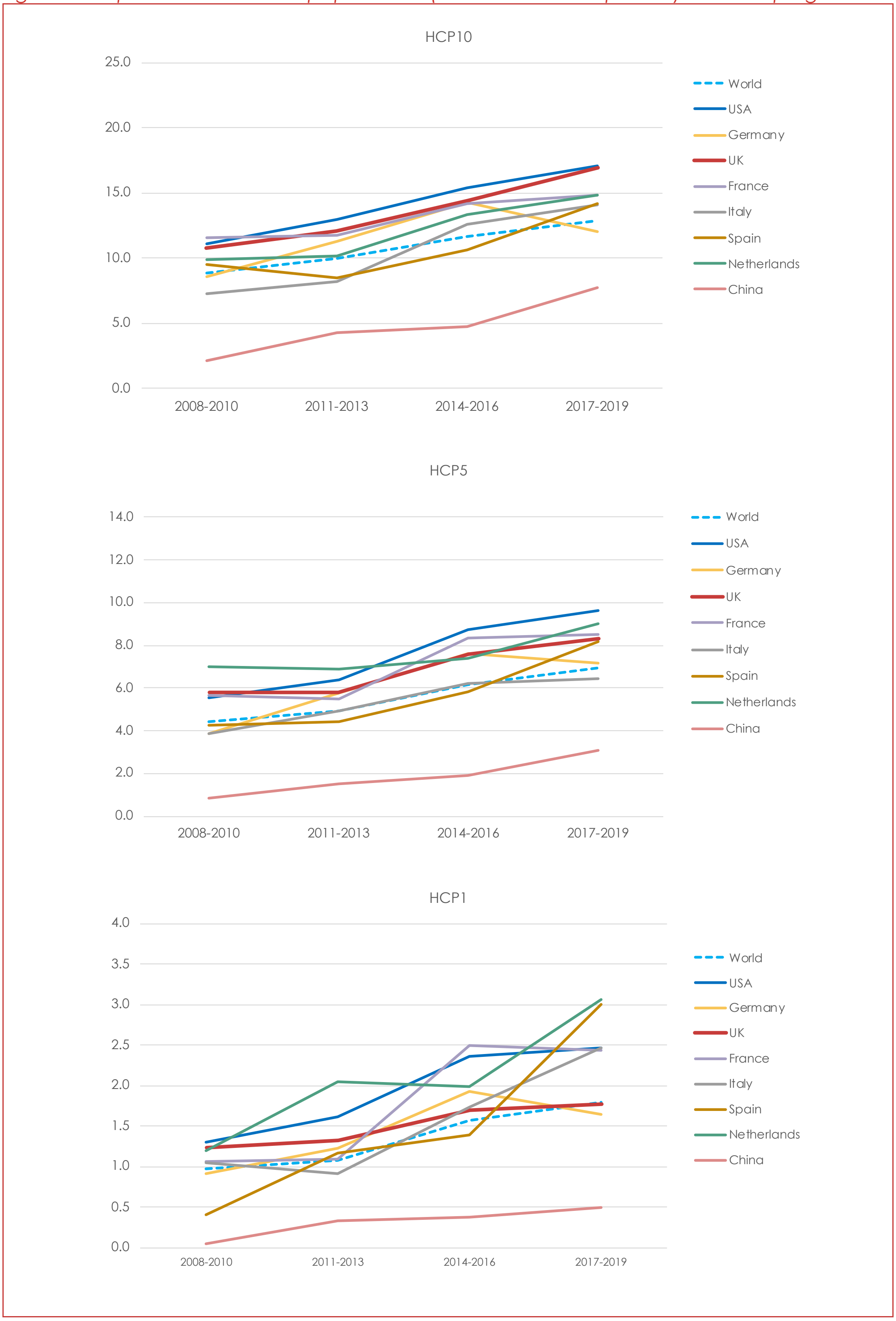
Science-Metrix (2021) / Scopus

Figure 13 Impact of ESA-related papers: Science programme, HCP (UK & world average)



Science-Metrix (2021) / Scopus

Figure 14 Impact of ESA-related papers: HCP (international comparison): Science programme

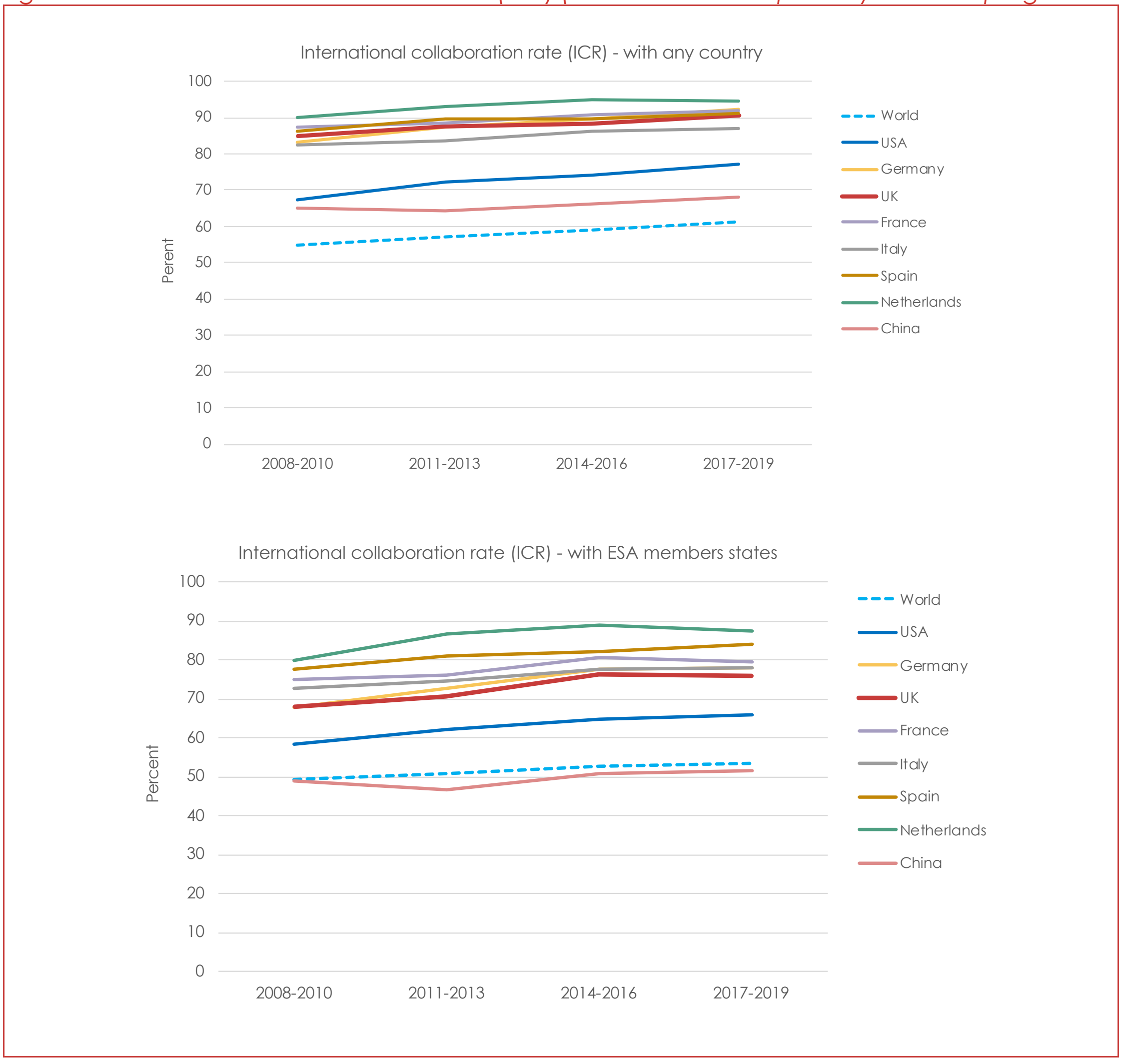


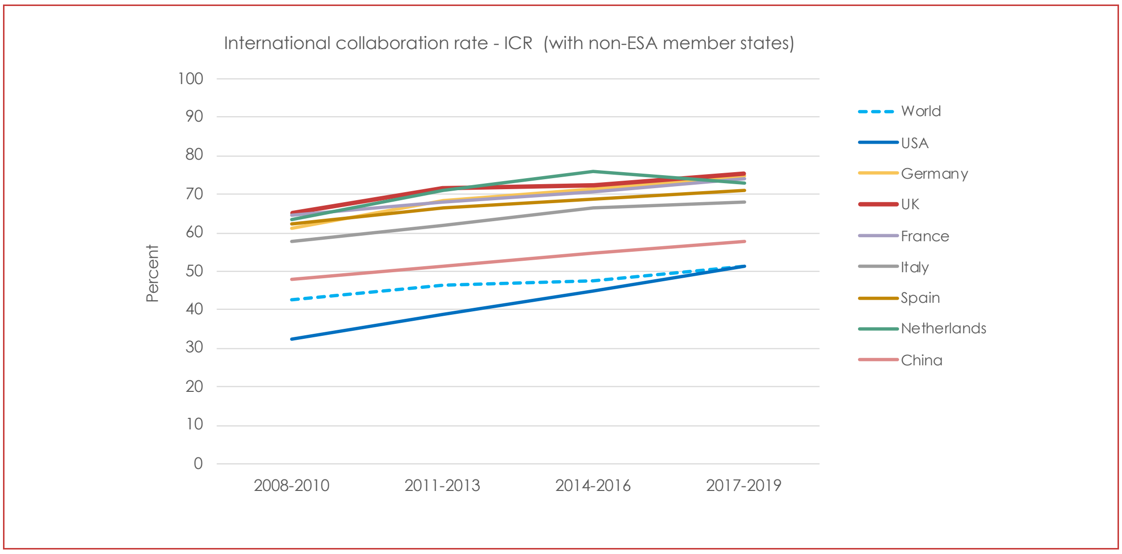
Science-Metrix (2021) / Scopus

International collaboration

- International collaboration with all countries, measured in terms of as co-authorship on publications, is marginally higher for the Science programme than for all papers from all programmes (analysed together)
- International collaboration rates with ESA member states, compared to all programmes, was a little lower in 2008-2010 and a little higher in 2017-2019
- International collaboration rates with non-ESA member states, compared to all programmes, was higher for the Science programme than other programmes

Figure 15 International Collaboration Rate (ICR) (International comparison): Science programme



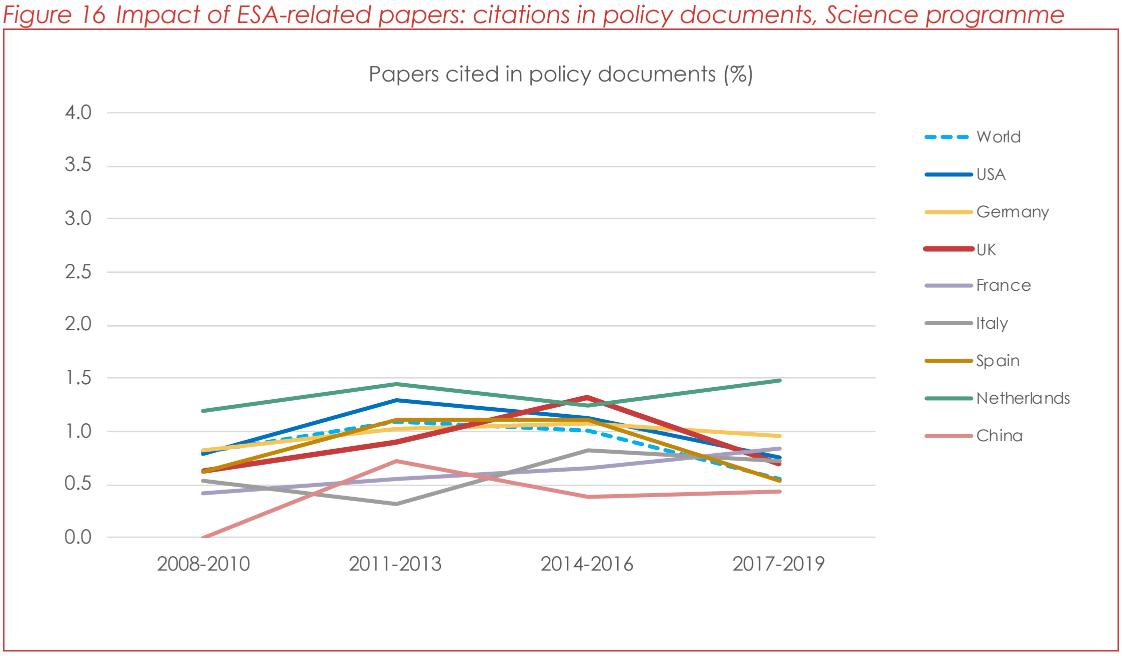


Science-Metrix (2021) / Scopus

Citations in policy documents and on social media

- Science programme papers, compared to all programmes, are cited less in policy documents. As might be expected, with papers in EO accounted for most of the citations in policy documents
- Science programme papers, compared to all programmes, are cited at a higher rate on Facebook, Twitter and Wikipedia

Figure 16 Impact of ESA-related papers: citations in policy documents, Science programme



Science-Metrix (2021) / Scopus

Figure 17 Impact of ESA-related papers: citations in social media, Science programme

Science-Metrix (2021) / Scopus

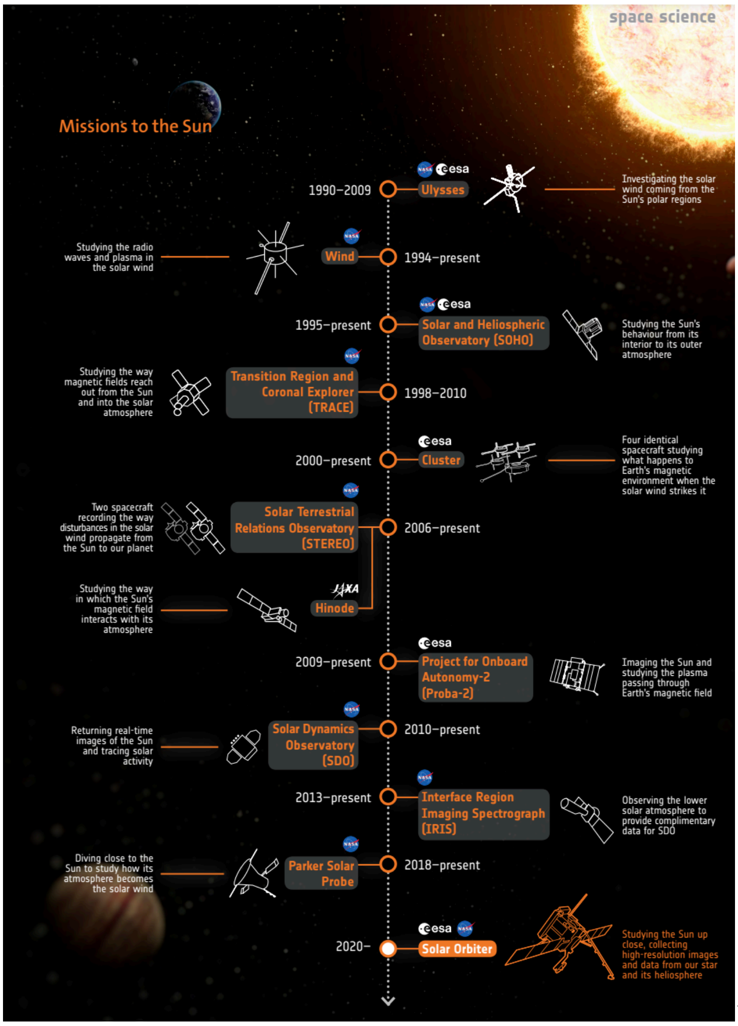
2 Science: case studies

2.1 Solar Orbiter

Title	Solar Orbiter
Summary	Solar Orbiter is a medium-class mission, and was the first selected within ESA's Cosmic Vision 2015-2025 Programme. The mission provides a stable and protected platform for solar observations from 10 instruments with a wide array of research applications. Launched in February 2020, Solar Orbiter is expected to have a seven-year nominal mission lifetime with the potential to extend its operation life by an additional three years. The flight profile of the mission will allow for the first long duration observations of the sun with additional remote and in situ data being transmitted back to Earth for analysis.
Type of impact	Technology development Increased employment and skills Increased knowledge and innovation Enhanced understanding of the earth and universe Political leadership in ESA Economic / CNI resilience
ESA contractor(s)	Airbus Defence and Space (ADS) BAE Systems Telespazio ABSL Space Products Rutherford Appleton Laboratory (RAL) Alter Technology TUV Nord ESR Technology Tessella Ltd
ESA contracts	ESA contracts for the Solar Orbiter mission support the development and operational capability of the spacecraft. ADS, as the prime on this mission were designated to design and build the spacecraft, as well as support the instrument integration on the platform for the scientific community. ESA contracts also support the continued operation of the mission, as well as the ground station capabilities that are necessary to transmit data and commands to and from the spacecraft during its mission.
Parallel / complementary activities	In parallel to ESA funding the spacecraft, national funding agencies supported the development of scientific instruments to be used in the mission. UKSA and STFC supported the development of four instruments from the UK, with three being led by UK institutions and the fourth containing a strong UK contributions. The four instruments are: • Solar Wind Analyser (SWA) – Led by Mullard Space Science Laboratory (MSSL) at the University College London (UCL) • Magnetometer (MAG) – led by Imperial College London • Extreme Ultraviolet Imager (EUI) – MSSL at UCL was a co-investigator • Spectral Imaging of the Coronal Environment (SPICE) – Primary Investigator on this project is the Rutherford Appleton Laboratory (RAL)

Activities

Within Space Science missions are developed within a long-term plan, but at the behest of the scientific community. The UK has a long history of supporting missions examining the Sun, initially as a purely scientific endeavour but over time also to deepen understanding of processes on the surface of the Sun as implications of 'solar weather' could be devastating to the modern world. Missions such as Ulysses (1990), Solar and Heliospheric Observatory (SOHO 1995), Cluster (2000), and PROBA-V (2013) have all been developed with UK instrument and technical expertise in support of scientific discovery. Even these are but a part of the long history of missions conducted by the UK, both within and outside of ESA over the past 30 years.



[12]

The primary activity being undertaken under the Solar Orbiter mission within the ESA funding portfolio is the development of the spacecraft on which the instruments will be launched into space. The spacecraft Prime contract was awarded to ADS UK (Astrium UK at contract signing) and their Stevenage facility.

The contract for the satellite development was signed in 2012, although initial research studies were awarded as far back as 2005. The development of the spacecraft took almost a decade with the launch ultimately taking place in February 2020. Since that time, Airbus has received additional funding to support the mission since the launch and have a strong continuing relationship with ESA to support any mission needs that may arise during operations. Significant sub-contractors were also awarded to UK businesses, including:

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[12] https://esamultimedia.esa.int/multimedia/publications/BR-345/BR345.pdf

- ABSL – provided battery systems to support mission critical systems
- RAL – developed SPICE instrument
- BAE – provided telemetry command processers to support the accurate flight of the spacecraft
- ESR Technology – worked heavily on the SPICE instrument and supported other engineering challenges in the antenna and other subsystems
- Tessella Ltd – designed attitude and control algorithms for the mission

The ESA contracts were focused on the development of the spacecraft, not the research and development of instruments. Instruments are supported by national research bodies and national space agencies. Given the UK interest in space weather, STFC provided addition support to the four UK instruments on the Solar Orbiter. ESA funding to instrument developers is tiny in comparison to the engineering contracts, with small amounts of funding to ensure that instruments are installed correctly and operating as intended on the spacecraft.

Impact

Economic

The immediate effects of ESA contracts accrue to the contractors themselves. Economically, the Solar Orbiter Mission has been of significant value to the UK space sector. The ESA contract for Solar Orbiter is significant, as €300m the contract with Airbus as the Prime represents one of the largest contracts ever signed by a UK firm on an ESA science programme mission. It has been estimated that the contract to ADS Stevenage has supported hundreds of high-skilled and high-value jobs in the UK space sector supply chain for the last decade.[13] This impact has been generated since at least 2005 when the first commercial studies were contracted to begin planning and designing the mission requirements. With the mission launching in 2020, the primary direct economic impact will have concluded to a large. However, ESA funding to UK firms (Airbus and Scisys) for Solar Orbiter will continue post-launch through to 2022 and will continue, with mission support, ground stations and other contracts still coming to UK firms. Some of this mission support will continue coming to the UK through the life cycle of the mission, which will only conclude in 2027 at the earliest.

The development of medium and large-scale missions in the UK has the advantage of supporting the development of advanced and in-demand technical engineering skills within the UK. Considering the time it can take from concept to launch, 15 years for Solar Orbiter, working on missions like Solar Orbiter can be career defining. The opportunity to work on exciting projects in industry or academia associated with ESA missions can attract and retain qualified staff and train the next generation of engineers and scientists for future public and commercial space activities. Although winning future ESA missions is not guaranteed, knowing that there is a chance to compete for large mission contracts in the future makes the UK an attractive location for skilled people.

Scientific

The science being conducted by Solar Orbiter is both remote sensing of the Sun and in-situ instruments (those surrounding the spacecraft itself). These two sets of instruments will work in tandem to generate one of the most complete pictures of the Sun ever collected. This will generate knowledge about how solar winds are generated, how the corona is heated, and what it is composed of in detail. Solar Orbiter has already generated its first observations (in 2021) but its scientific impact is in its infancy and will extend long into the future. As the mission continues to collect data for the next 10 years, that data will be used in present and future studies to improve our understanding of the Sun and its processes and how it may impact us on earth. Despite much of the science coming in the future, one of the first discoveries was generated by the UK supported EUI instrument which has the potential to unlock the mysteries about how the corona is heated.[14]

The most significant benefits to the UK will likely materialise from research based on the instruments that have been supported by UK institutions. This is driven both by the direct linkages between research questions and instrumentation design and by the in-depth knowledge of the instruments, their inner

[13] https://span.ac.uk/wp-content/uploads/2019/09/Case-Study-for-SolO-180919.pdf

[14] https://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter/Campfires_offer_clue_to_solar_heating_mystery

workings, and how best to exploit the expected data going forward. The instruments supported by UK institutes and scientists are:

- Solar Wind Analyser (SWA) – consists of a suite of sensors that will measure the bulk properties of solar wind including density, velocity and temperature.
- Magnetometer (MAG) – the instrument contains two elements that will precisely measure the magnetic field around the spacecraft. This will help scientists understand how the Sun's magnetic field is connected to the wider solar ecosystem and how it changes over time. This will deepen our knowledge around how the corona is heated and widely transported by solar winds.
- Extreme Ultraviolet Imager (EUI) EUI will take images of the solar chromosphere, transition region and corona. This is an area that scientists currently do not understand very well, particularly how these areas are heated, which remains a mystery. It is hoped that the data collected by the EUI will allow scientists to connect the in situ data to the its source.
- Spectral Imaging of the Coronal Environment (SPICE) – SPICE will reveal the properties of the solar transition region and corona by measuring the extreme ultraviolet wavelengths given off by the plasma. This data, in conjunction with data from the in-situ instruments can then be matched to form a wider understanding of the solar ecosystem.

Solar Orbiter is the most recent of a long line of solar missions intended to increase our understanding of the Sun and, importantly, the solar weather that it produces. Solar weather has the potential to be highly disruptive to modern life. Solar 'storms' albeit relatively rare, generate x-rays and solar radio bursts and accelerate solar particles to extremely high (relativistic) velocities that can cause detrimental effects to the electricity grid, satellites, avionics, air passengers, signals from satellite navigation systems and mobile communication systems.[15] Potential disruptions from a solar event could cause damage to critical infrastructure in space and on Earth putting billions of pounds worth of economic and social activity on Earth at risk.[16] Therefore, understanding the Sun and the drivers behind space weather events could drastically improve the resilience of critical infrastructure. The success of Solar Orbiter to date and the skills developed during the mission's development (and eventually the knowledge to be generated) are already contributing to ESA's and UK's work (led by the Met Office) under the SSS programme to develop a specific space weather mission (the Vigil mission, formerly known as the Lagrange mission) with the objective to observe and monitor rapidly changing solar activity and deliver early warning of possible harmful space weather in order that actions can be taken to protect critical infrastructure.

Additionality and ESA-added value

Science missions are often extremely expensive and require long-term public commitment (15-25 years) and missions, such as Solar Orbiter, are highly unlikely to take place without public investment as there is limited incentive for private sector investment. The cost is also prohibitively expensive for most countries. Sharing the cost across ESA member states and, in some cases with other international partners, makes these missions considerably more affordable and allows the UK to participate in more types of missions than they would be able to do alone. Pooling resources isn't only about costs but also about pooling technical expertise, it is unlikely that, at the current time, the UK has all the skills, capabilities to build a complex mission. As demonstrated by the map below of the contributors to Solar Orbiter, working through ESA on these complex missions allows the UK to leverage the skills, knowledge, and expertise of a much wider engineering base than we would be able to achieve on our own. Therefore, the UK would be unlikely to gain the scientific and economic benefits of Solar Orbiter without ESA.

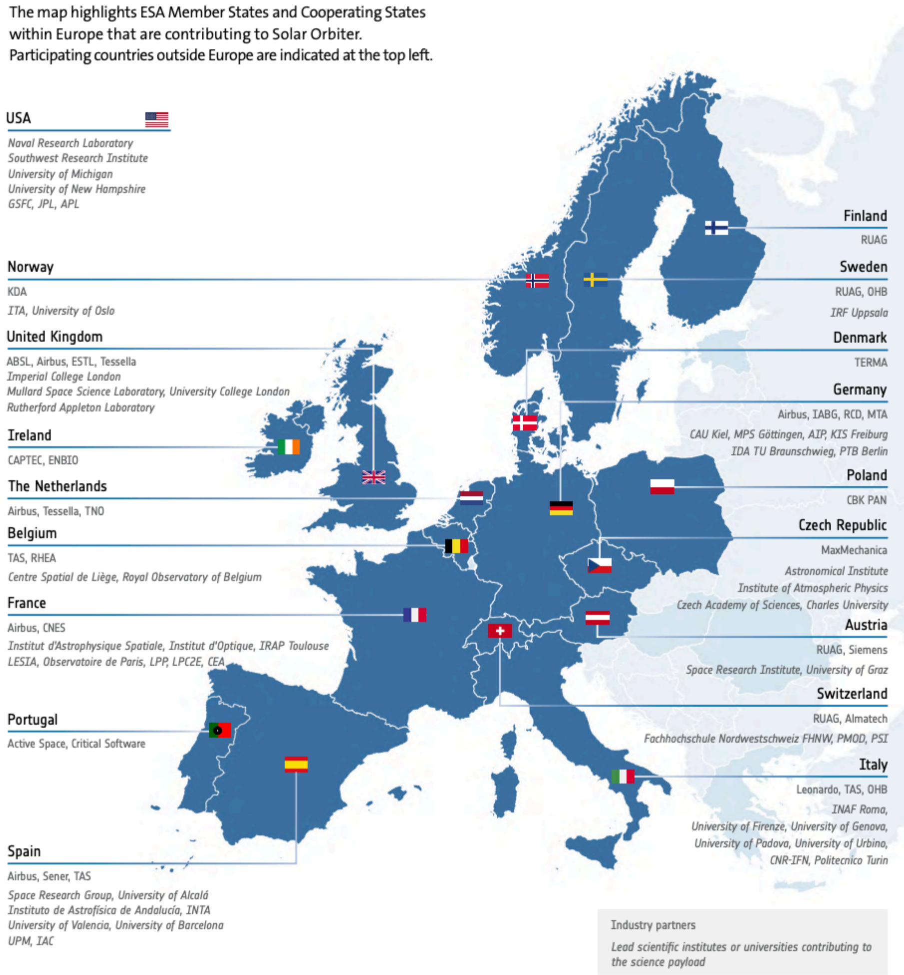
Solar Orbiter requires access to capability to launch the spacecraft beyond Earth's orbit – which ESA membership provides. This type of launch capability will not be provided by the current capability being developed in the UK and therefore the UK will continue to need to secure this type of access to space particularly for space science. If not in ESA the UK would need to negotiate access to this type of launch. Historically, this access has only been provided by space agencies and therefore being in ESA provide the UK with access to the complete mission 'package'. Options for accessing space beyond Earth's orbit is starting to change with commercial launch capability increasing, though as yet only Space X is addressing the type of launch needed for most science missions.

[15] https://www.raeng.org.uk/publications/reports/space-weather-full-report

[16] A study for ESA estimated the potential impact in Europe from a single, extreme space weather event could be about €15 billion https://esamultimedia.esa.int/docs/business_with_esa/Space_Weather_Cost_Benefit_Analysis_ESA_2016.pdf

The Solar Orbiter mission has also attracted additional international partners, with NASA supplying an instrument and providing the launch for the spacecraft. This type of collaboration is facilitated by ESA's relationships with other space agencies an where ESA acts a doorway for its member states to collaborate internationally. While ESA's reputation is predicated on the abilities (and funding) of its member states, the scale of ESA, and its in-house capabilities to develop, launch and operate missions, makes it an equal partner in international partnerships, something that most of its member states cannot achieve individually. And even the large member states such as the UK, might only be able to achieve in a narrow set off circumstances. Furthermore, from the perspective of NASA (and other agencies) it is significantly less bureaucratic to work with one agency.

The expertise gained under this mission is also contributing to the forthcoming Vigil mission (formerly Lagrange), which will study developments in solar weather to support activities on earth. The Solar Orbiter mission is furthering our understanding of the science so that Vigil can provide better forecasting of space weather events. This will support UK interests in protecting critical space and terrestrial infrastructure when possible. The UK has a long history and interest in space weather and solar science, as detailed above, and missions such as Solar Orbiter and Vigil allow the UK to invest in those areas with the support from other countries within an ESA framework.



[17]

[17] https://esamultimedia.esa.int/multimedia/publications/BR-345/BR345.pdf

2.2 PLATO

Title	**Planetary transits and oscillations of stars (PLATO)**
Summary	The Planetary transits and oscillations of stars (PLATO) mission is focused on identifying 'exo-planets' that is extrasolar planets -planets outside the Solar System. It is intended to undertake long-term observations of bright stars in the hopes of detecting small variations in brightness, which will identify exoplanets transiting in front of the stars. Once identified, the targets can be studied further by other telescopes and observatories on the ground and in space.
Type of impact	Technology development Increased employment and skills Increased knowledge and innovation Enhanced understanding of the earth and universe Political leadership in ESA
ESA contractor(s)	Thales Alenia Space (TAS UK) – (partner) Teledyne (e2v) – (image sensor system provider)
ESA contracts	TAS UK is a partner on the design, development, support and launch of PLATO. As a principal partner on the project, TAS UK is supporting OHB, the Prime, and represents one of the largest projects undertaken by TAS UK to date. Teledyne e2v are providing 112 Charge Coupled Devices (CCDs) which will provide the image sensors for the 26 cameras on PLATO.
Parallel / complementary activities	UKSA and UKRI are supporting the UK members of the scientific team that is designing and will conduct research using the data that will be generated by PLATO. Prof. Don Pollacco at the University of Warwick is the head of the Science Management branch of PLATO, connecting with scientists in ESA member states and internationally. UKSA is supporting Mullard Space Science Laboratory (MSSL) to lead on the design and construction of the electronics for the 26 cameras that will be deployed on the spacecraft. UKSA is also supporting the development of a data processing centre to ensure the highest levels of return within the scientific community to the UK.

Activities

TAS UK are currently working on the project as a subcontractor to TAS France, and have been contracted to deliver a wide package of work for this spacecraft. The current phase, begun in 2019, saw more than €14m to TAS UK with another €9m expected for the next phase in 2022. This next phase of the project is not an open tender, so is guaranteed to be delivered by TAS UK. TAS UK will be delivering the avionics for the spacecraft as well as the integration of the wider service module.

Teledyne e2v was awarded a contract directly with ESA (rather than via national instrumentation funding) to deliver CCDs for the 24 normal and two high speed cameras that will be deployed on the spacecraft. The combined contracts have a value €42m, and will include the manufacturing, assembly, testing, and delivery of 114 total CCDs. The combined imaging power of these instruments represent the largest optical array ever launched into space. The CCDs being produced by Teledyne e2v are considered the best the field. The CCD image sensors are essential for high sensitivity observations, necessary to observe very small changes in light levels, and contribute the bulk of the observational capacity of PLATO. Teledyne e2v, headquartered in Chelmsford, Essex has two significant facilities in the UK and are widely considered a leading company in this sector. They have a long track record of providing advanced sensors to world renowned ESA and NASA missions.

UKSA is also supporting activities to advance the scientific instruments for the mission. UKSA is supporting MSSL at UCL to develop the electronic hardware for the 24 normal speed cameras for the PLATO spacecraft. These cameras form the primary instruments on the spacecraft, alongside two additional high speed cameras.

UKSA and UKRI are also supporting the scientific community to prepare for the exploitation of the PLATO mission. Prof. Don Pollacco at the University of Warwick is the head of the Science Management team of PLATO, connecting with scientists around ESA and the world. To further exploit the mission data in the future UKSA and UKRI are also supporting the development of the PLATO data centre. This effort is being led by the

University of Cambridge. Both the PLATO data centre and the Science Management team are being supported by other academics at the University of Birmingham, Open University, University of Oxford and the University of St. Andrews.

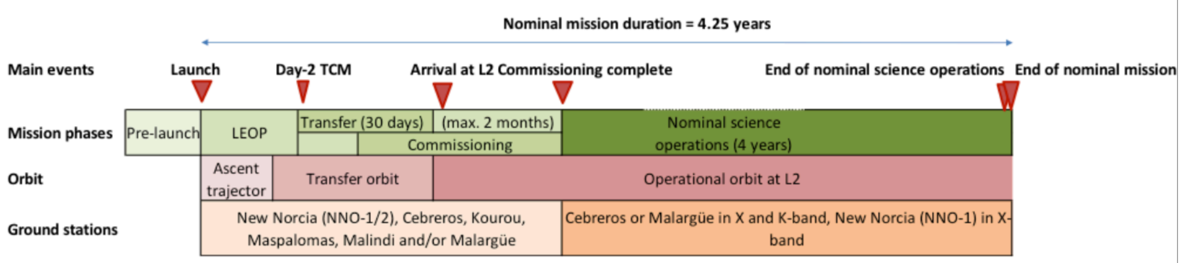
Impact

Economic

TAS UK has been a relatively small component of the wider TAS group but has been moving towards developing the scale and capabilities to Prime space missions in the UK. Although TAS UK has led some Phase A/B contracts for ESA (e.g. FORUM, SMILE) and led instrumentation contracts, these have not yet progressed into leading the full spacecraft build (In phases C/D) where the bulk of engineering and production takes place. PLATO represents some of the largest ESA contracts to date for TAS UK and are part of a concerted effort to develop capabilities at the company for leading future space science spacecraft. TAS UK is currently undertaking Phase 1 work for ESA's first Fast-mission, Comet Interceptor mission (Phase 2 combines phases A & B for Fast-class missions, F-class) and is bidding for Phase 2. TAS UK is well-placed to win and deliver this contract (it is in competition with one other European prime) and it would be the first opportunity for TAS UK to prime an ESA space science mission. At present the UK has a limited number of Prime capable firms, and with TAS UK stepping into that role the UK will be better positioned to take leading roles in a wider array of ESA space science missions in the future. The prospect of sustained investment in leading UK space firms will support jobs and increased revenue for UK firms. This will of course filter into the UK economy through wider tax revenue and value added to the economy. The support for TAS and Teledyne e2v helps to ensure that these firms are competitive and sustainable in the long run, with the prospect of winning more contracts more likely. It will also allow these firms to develop in-house skills and expertise that will enhance UK capabilities in the sensing and engineering sectors. TAS UK, for example, is working closely with its French counterpart, developing, deepening and transferring skills to the UK in assembly, integration and test of a structural model and flight mode platform and the AOCS (Attitude and Orbit Control Electronics). Winning prestigious contracts on space science missions often opens firms to additional opportunities in the future.

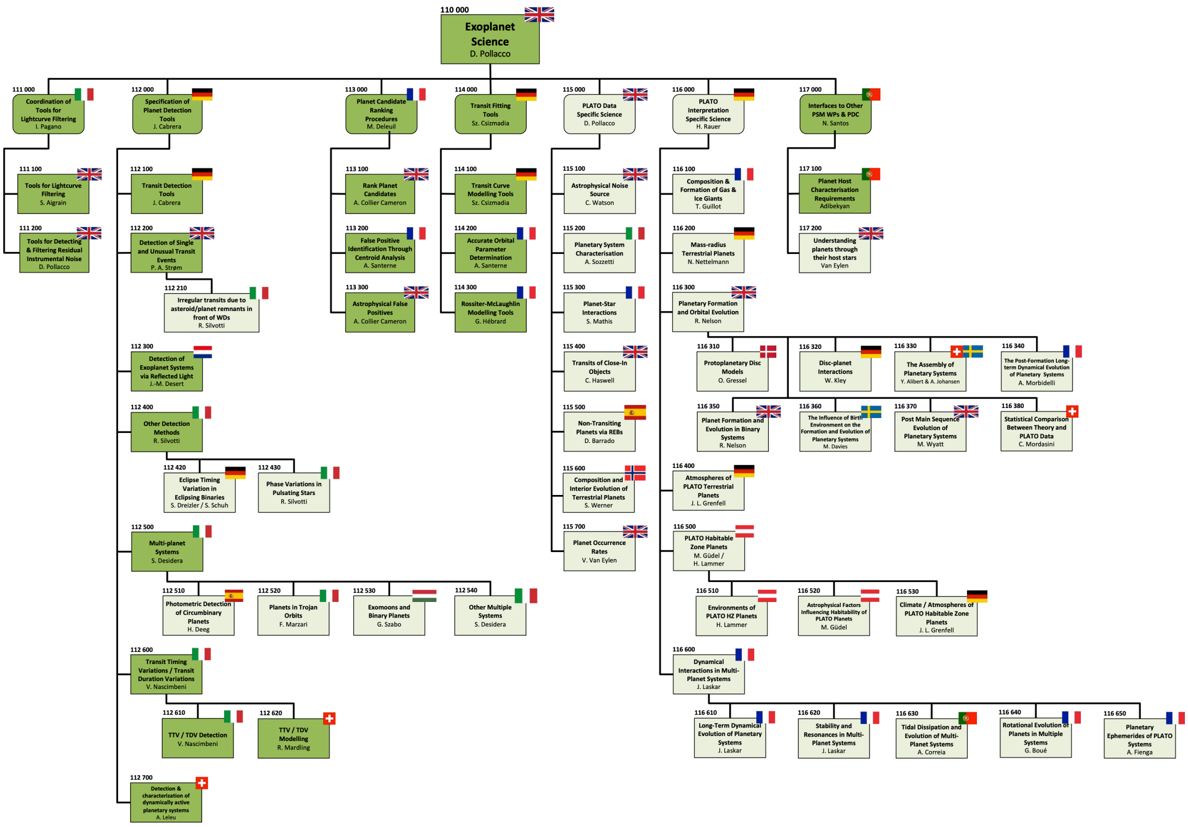
Scientific

On the science side, the impact of PLATO is expected to be significant. As the largest optical array launched to date, the spacecraft will be able to observe distant stars with a higher sensitivity than ever before allowing scientists to discover previously undetectable exoplanets due to the minute decrease in brightness of the stars around which they orbit. This is of particular importance to the exoplanet community as they search for planets that are of similar composition to earth. The capabilities of the telescopes allow for both short and long-term observations, with the ultimate decision about the mission objectives yet to be decided. Long observation phases may last between 2-3 years, with short term step and stare observations taking up the remaining telescope time. If all goes as intended a mission duration of 4.25 years is expected, with four years dedicated to scientific observations. A timeline of the mission phases post launch is detailed below.



The mission will support the exo-planet research that is already being undertaken in the UK. The community of exo-planet researchers in the UK is broad, with academic institutes across the country. Many of those institutions are participating in the exo-planet scientific team who will aim to exploit the mission both during and after it concludes. Participating scientists and institutions are able to better understand the parameters of PLATO, likely to improve their opportunities to make scientific discoveries. Participating in the mission science team participants also will have greater opportunities to task the satellite to their desired coordinates again increasing opportunities for scientific discovery.

The PLATO scientific team is large with UK making up 14 out of the 63 participants (22%), including the science lead:[18]



Additionality and ESA-added value

As for other science missions, PLATO will be costly and, although a new form of F-class mission will still take more than 10 years to reach the launch stage. It is unlikely to attract private sector investment and would be prohibitively expensive for the UK to develop and operate on its own, without sacrificing its ability to do other research at the same time. Participation in ESA allows the UK to channel its efforts into the science missions that are of interest to its researchers, as evidenced by the high participation in PLATO by UK scientists. Simultaneously, the UK is able to share the economic cost of developing missions while benefiting from the skills that are less developed domestically. ESA membership also provides the UK with secure access to launch capabilities for missions beyond Earth's orbit. This type of launch capability will not be provided by the current capability being developed in the UK and therefore the UK will continue to need to secure this type of access to space particularly for space science.

Exoplanets represent an area of academic and research strength for the UK, which has resulted in a large number of UK firms and scientific participants in PLATO. Participation in a mission of this scale and stature helps to enhance the UK's reputation as a leader in exo-planet research, something that is likely to continue as UK scientists exploit PLATO data for years to come.

Given the scale of the project, the UK has been able to position a few contractors in key positions with PLATO. Support from the ESA science programme will likely position these firms to win further contracts on this and other projects in the future. The prestige of ESA as a mission leader, allows these companies to be more competitive in the domestic and international markets. As mentioned previously, it is hoped that the success of this mission will lead to the development of a new mission Prime in the UK, further bolstering UK space capabilities, something unlikely to happen without ESA support. In addition, the scale and breadth of future ESA support for missions incentivises firms to develop these highly-skilled capabilities in the UK.

[18] https://warwick.ac.uk/fac/sci/physics/research/astro/plato-science/resources/psmdocuments/plato-uwa-psm-wbs-0010_i3.0_wp110000_exoplanet_science_structure.pdf

2.3 ARIEL

Title	**Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL)**
Summary	Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) is a second exo-planet mission. Working in conjunction with PLATO, ARIEL will be able to research identified exoplanets to investigate their chemical composition and thermal structures and improve understanding of a planet's chemistry is linked to the environment where it formed – and help find out whether there is life elsewhere in our Universe and if there is another planet like Earth. ARIEL will focus on warm and hot planets, ranging from super-earth sized planets to gas giants. ARIEL is expected to assess over 1000 planets during its mission life.
Type of impact	Technology development Increased employment and skills Increased knowledge and innovation Enhanced understanding of the earth and universe Political leadership in ESA
ESA contractor(s)	Airbus Defence and Space (ADS) UK
ESA contracts	The contract to design and construct ARIEL was signed in December 2021 by ESA and Airbus France – as the lead of a consortium made up of more than 60 contractors. ADS UK will work closely with ADS France and ADS will also provide expertise and support to ESA for the development of the payload module (led by RAL Space).
Parallel / complementary activities	The UK has lead roles in the science and instrumentation for ARIEL • Professor Giovanna Tinetti (UCL) is leading the science mission • STFC, through RAL Space, will manage the overall European consortium that is building the payload, which will be built and assembled and tested in Harwell, Oxfordshire • University of Oxford who are part of the team developing the space telescope that will be launched on the ARIEL spacecraft • STFC, through UKRI and the UKSA have supported the ARIEL science advisory team activities in the hopes of ensuring UK firms are well placed to for ESA contracts and sub-contracts to build the missions

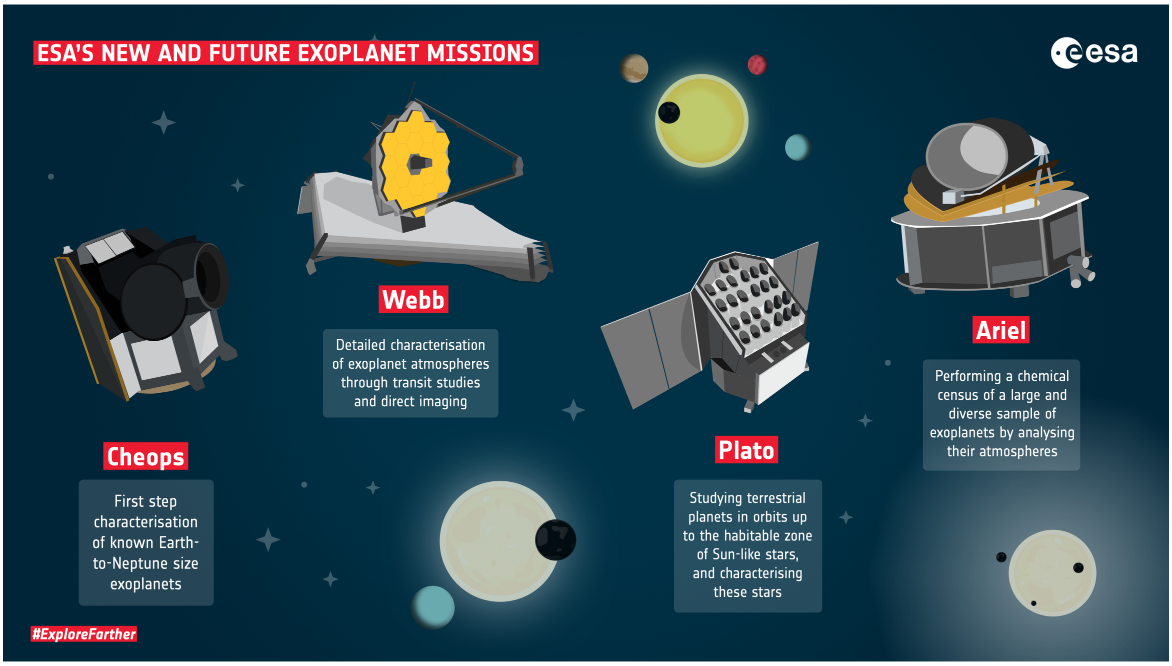
Activities

ARIEL is a UK supported mission to study exoplanets. The core objective of the mission is to study and investigate the atmospheres of several hundred planets orbiting distant stars to understand how planetary systems are created and evolve. The mission will launch in 2029 with an expected four-year mission lifetime.

ARIEL will be ESA's third dedicated exoplanet mission to launch between 2019 and 2029, with each mission tackling a unique aspect of exoplanet science. Cheops, launched in December 2019, is already producing world-class science, followed by PLATO with an intended launch in 2026 to find and study extrasolar planetary systems. Ariel, planned to launch in 2029, will focus on warm and hot planets, ranging from super-Earths to gas giants orbiting close to their parent stars, taking advantage of their well-mixed atmospheres to determine their atmospheric composition. UKSA has supported all these missions and continues to support exoplanet science in the UK through its support of ARIEL.

To date, there has been limited activities undertaken in the UK, as the €200m Prime contract awarded to ADS FR has only just started. Prior to the award of the contract to ADS FR, both TAS UK and ADS UK were involved in ESA contracts during Phase A of mission development. During this phase multiple contractors develop design studies for the mission, and then compete to move to the implementation phase as the prime contractor – meaning the UK was well-placed for the final build contract.

The value of the contracts to ADS UK have not yet been made public but are expected to be substantial. ADS UK will work closely with ADS France, leading on the engineering of the avionics, radio frequency communication and electrical design of the platform.



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Impact

Economic

Impacts stemming from the build, operation and use of ARIEL are largely yet to materialise, particularly in areas of increased employment and contractual returns. However, the ADS UK work will be spread across its sites at Stevenage, Portsmouth, and Guilford, dispersing the benefits to the economy across these locations. Having developed the concept under Phase A, Phase B will focus on early engineering challenges and building up the teams to deliver the project into the future. The development of ARIEL will see the support of numerous advanced jobs within ADS and its commercial partners. Much of that development is still to come, so exact numbers of staff retained or hired are not yet available.

There is significant potential for the development of young engineers and scientists through the ARIEL mission. Missions like this can be career defining and support the upskilling of younger staff members in academia and industry. With much of the work on ARIEL still to come, some young engineers will' grow-up' with this mission and carry that work forward for much of the next decade. This will enhance existing skills, while ensuring that the UK is prepared for future missions.

Scientific

Similarly, most of the scientific outputs are still to come. That it is not say that papers related to ARIEL are not being published. The scientific consortium is well established and early scientific knowledge and outputs are already being created related to the engineering and instrument development. As Figure 5 shows UK papers related to ARIEL have been published since 2015 and continue to the present day. Scientific discoveries about exo-planets research will, of course, not begin until after mission launch. The UK has leading role in the science and instrumentation for the mission at UCL and RAL Space, with further roles for from Cardiff University, Oxford University, and the UK Astronomy Technology Centre (among others) - enabling the UK space science community to steer the design and play a leading role in the research to come.

[19] Image courtesy of ESA
https://www.esa.int/Science_Exploration/Space_Science/Airbus_will_build_ESA_s_Ariel_exoplanet_satellite

Additionality and ESA-added value
ESA supports the development of the ARIEL spacecraft across its member states. ARIEL is currently being supported by the ARIEL Mission Consortium, which is comprised of 50 institutes across 17 ESA member states and NASA. The ability to leverage the expertise and knowledge from this broad base allows for more ambitious missions that the UK could undertake independently. Given the UK strength within exoplanet research, the UK is well positioned to take a leading role in the mission, both on the engineering and the science. The breadth of ESA missions means that there are ample opportunities for UK researchers and leading commercial entities to find roles that will allow them to thrive. If the UK chose to do this independently, the breath of opportunity would be narrowed, meaning that the UK would be a less attractive research and commercial destination for talented individuals. Missions such as ARIEL are key to inspiring the next generation of scientists and engineers and encouraging them to follow careers in STEM. ARIEL and PLATO (and also CHEOPS), focused on exoplanet research, are particularly interesting the wider public, addressing the significant question about the existence of, or potential for, life on other planets. The discovery of other planets, particularly those like Earth, routinely make headlines and promote the research being done by ESA, and by extension, UK scientists. The scale of the ESA missions is likely beyond what the UK is capable of on its own, and as a result produces more public engagement across Europe and the world than an entirely nationally funded mission would be able to achieve.

3 Earth Observation

3.1 ESA's Earth Observation programme

3.1.1 *Objectives*

The European Space Agency's (ESA) Earth Observation (EO) programme has three overarching objectives:

- Keeping observation techniques at the most updated technological state;
- Opening new horizons and creating cutting-edge products; and
- Pursuing scientific knowledge and transforming it to benefit the entire society.

3.1.2 *Structure*

ESA has invested heavily in EO since its inception with a view to advancing our understanding of the planet. ESA's EO programme comprises three principal elements:

- *Science*: Missions designed to address key scientific challenges, increasing knowledge about the planet, while developing breakthrough innovative technology in observation techniques. These missions deliver invaluable data, notably for policy-making and services that improve daily life on Earth. It is composed of Future EO missions, like Earth Explorers (EEs) and Scouts, Block 4 elements of Future-EO, as well as many Earth Watch missions (e.g. TRUTHS, ALTIUS) and programmes (e.g. Climate Change Initiative (CCI), InCubed, Global Development Aid (GDA)).
- *Meteorology*: Satellites developed in conjunction with EUMETSAT designed to offer imagery for weather nowcasting (relevant for the early detection of fast-developing severe weather), weather forecasting, and climate monitoring (e.g. MTG, MetOp-SG, AWS, Aeolus-2). Under the current terms of agreement, ESA is in charge of the development of the space segment of EUMETSAT programmes, and EUMETSAT lead the overall system (e.g. launch services, ground segments, and operations)[20].
- *Copernicus*: ESA is developing a suite of mission families called Sentinels, which aim to serve the observational needs of the European Union's (EU) Copernicus programme, as well as broader requirements for climate monitoring and prediction. ESA's Sentinel missions are one of two types of the Copernicus Space Component (the other being Contributing Missions developed by other space agencies).

While they have been categorised in the programme element where they are the most pertinent, missions can also be relevant for other elements (e.g. a mission focused on science may generate data useful in meteorology).

[20] EUMETSAT (2022), European Space Agency (ESA), available at: https://www.eumetsat.int/international-cooperation/european-space-agency-esa

Table 9 Examples of ESA EO programmes by broad application and state of development

Future-EO	Block 1/2/3/4 elements: Earth Explorer missions already flying (e.g. GOCE, SMOS, CRYOSAT, SWARM, Aeolus), in development (e.g. EarthCARE, Biomass, Flex, Forum, Harmony), and feasibility studies for candidate EEs Scout missions in development (e.g. CubeMAP, HydroGNSS)
Earth Watch	Optional EO programmes: Missions in development (e.g. TRUTHS and ALTIUS) Programmes such as CCI, InCubed and GDA
Meteorology	Missions in conjunction with EUMETSAT (e.g. MTG, MetOp-SG, AWS, Aeolus-2)
Copernicus	Sentinel missions developed specifically for the EU's Copernicus programme Sentinel missions in development (e.g. new suite of Sentinel Expansion missions, like CO2M, ROSE-L, and CHIME)

Figure 18presents a schematic overview of the many EO satellites that ESA has developed over the past forty years, back to ERS-1. The image shows the extension of the Agency's ambitions over time, beyond its initial focus on EO science into state-of-the-art meteorological satellites and satellites flying instruments to support the EU's fledgling Copernicus services. The image also captures missions, such as FORUM, TRUTHS, and the new suite of Copernicus Sentinel Expansion missions (e.g. CO2M and ROSE-L) that are currently in development and scheduled to fly in the next 5-10 years. An overview of the type and usefulness of data generated by ESA EO missions mentioned in this report (i.e. with notable UK involvement in mission development or exploitation) is subsequently provided in Table 13.

Figure 18 ESA's EO satellites and missions

ESA

3.1.3 UK in ESA's EO programme

EO has historically been a major focus of UK investment in civil space research, with a significant proportion of the UK national investment flowing through ESA's EO programme. UKSA set out 5 priorities for EO in its CMIN19 business case[21]:

- Leveraging the financial return from ESA in areas of strategic and long-term importance for the UK's position in future opportunities;
- Maximising the opportunities in Copernicus, other European Union (EU) programmes (c.f. p.30) and through international bilateral partnerships;
- Positioning EO as a fundamental infrastructure and tool underpinning industrial strategy, policy and societal needs;
- Investing in global innovation and growth through research and innovation in both the upstream and downstream; and
- Inspiring the next generation.

For CMIN19, the UK committed to supporting two main programmes and four smaller Earth Watch missions (one of which is TRUTHS, a UK mission proposal). The two larger programmes are Future-EO – the core foundational programme which prepares all the future EO missions and addresses data management; and Copernicus – the world leading European-led EO global monitoring programme which offers the most comprehensive datasets for environmental monitoring in the world.

As many ESA EO missions are coming to an end, and the EO landscape is experiencing rapid growth and change (from supporting £92 billion of the UK's Gross Domestic Product (GDP) in 2018 to £100 billion in 2020[22], overall reaching a global market size of £3.8 billion[23]), competition is at its highest. In this context, the UK invested €472m into ESA's EO programme at CMIN19 (covering the period 2020 to 2024), with the following overarching objectives:

- Securing a strategic position in the Future-EO programme, allowing the country to influence the technical and programmatical developments towards UK EO priorities and areas of opportunities.
- Ensuring strong participation in high profile and strategically important ESA missions (Earth Explorers, Earth Watch, Sentinels), enabling UK stakeholders to be at the forefront of EO technical and capability developments and maximise their collaboration opportunities. UK investments in ESA's EO programme also sought to demonstrate that the country is capable and committed to playing an active leading role in European EO (e.g. through TRUTHS, which the UK proposed, largely funds, and primes).
- Reducing the risk and uncertainties regarding the UK's participation in Copernicus by allowing strong UK industry engagement in consortia (which will run between 2021 and 2027 for Copernicus), as well as staying involved in data discussions and reinforcing the country's data framework. Significant UK participation in the Copernicus element of ESA's programme (Copernicus Space Component, or CSC) at this stage is critical to delivering

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[21] UKSA (2019), CMIN19 EO Business Case

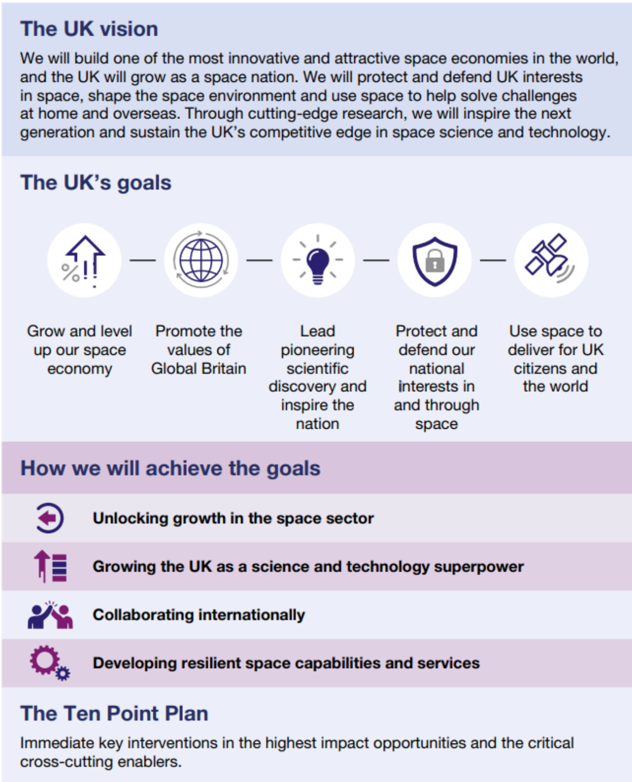
[22] know.space (2021), Size and Health of the UK Space Industry 2020, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/987497/know.space-Size_Health2020-SummaryReport-FINAL_May21.pdf; London Economics (2019); Size and Health of the UK Space Industry 2018, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774450/LE-SHUKSI_2018-SUMMARY_REPORT-FINAL-Issue4-S2C250119.pdf

[23] PwC (2020), Main Trends & Challenges in the Space Sector, available at: https://www.pwc.fr/fr/assets/files/pdf/2020/12/en-france-pwc-main-trends-and-challenges-in-the-space-sector.pdf

the cross-government priority policy of negotiating back into the EU part of Copernicus as a participating state. As of early 2022, the UK secured an agreement in principle to remain in the Copernicus component of the EU Space Programme as a third country until 2027[24]. If the agreement is confirmed, UK stakeholders will be able to bid for Copernicus contracts tendered through the EU and/or funded through the EU's Multi-annual Financial Framework, on top of the Copernicus contracts tendered through ESA (as part of the CSC).

Overall, the UK's CMIN19 investments into ESA's EO programme feed into wider governmental priorities, which we outline throughout the chapter. Chief among them is the NSS[25] (published in 2021 and outlined in Figure 19), as ESA contracts help grow the UK space economy, catalyse international collaborations, strengthen the UK's position as a science and technology leader, and develop space capabilities and services. The EO products, services, and data generated through CMIN19 contracts and ESA missions also help increase our understanding of climate change and design effective mitigation strategies, contributing to the Government's Net Zero agenda.[26]

Figure 19 The UK's National Space Strategy



HM Government

[24] HM Government (2021), UK involvement in the EU Space Programme, available at: https://www.gov.uk/guidance/uk-involvement-in-the-eu-space-programme#copernicus

[25] HM Government (2021), National Space Strategy, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1034313/national-space-strategy.pdf

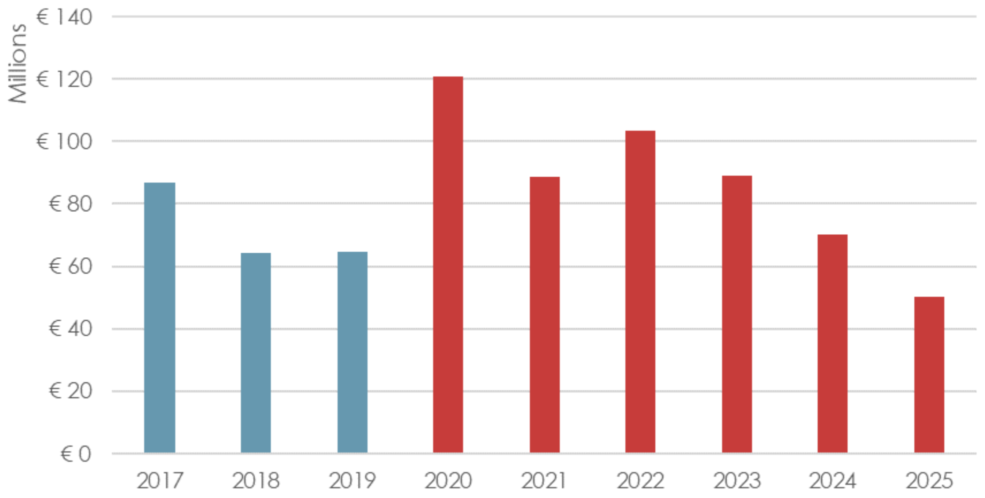
[26] HM Government (2021), Net Zero Strategy: Build Back Greener, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

3.2 Inputs and activities

3.2.1 The UK's CMIN19 investments in ESA's EO programme

At CMIN19, the UK committed to investing €472m in ESA's EO programme between 2020 and 2024 (the CMIN19 investment period), as illustrated in red in Figure 20. The EO programme is the UK's 3rd largest investment, representing 23% of its total commitments at CMIN19, only topped by the Telecommunications and Integrated Applications (24% of UK CMIN 19 investments) and Mandatory (31%) programmes.

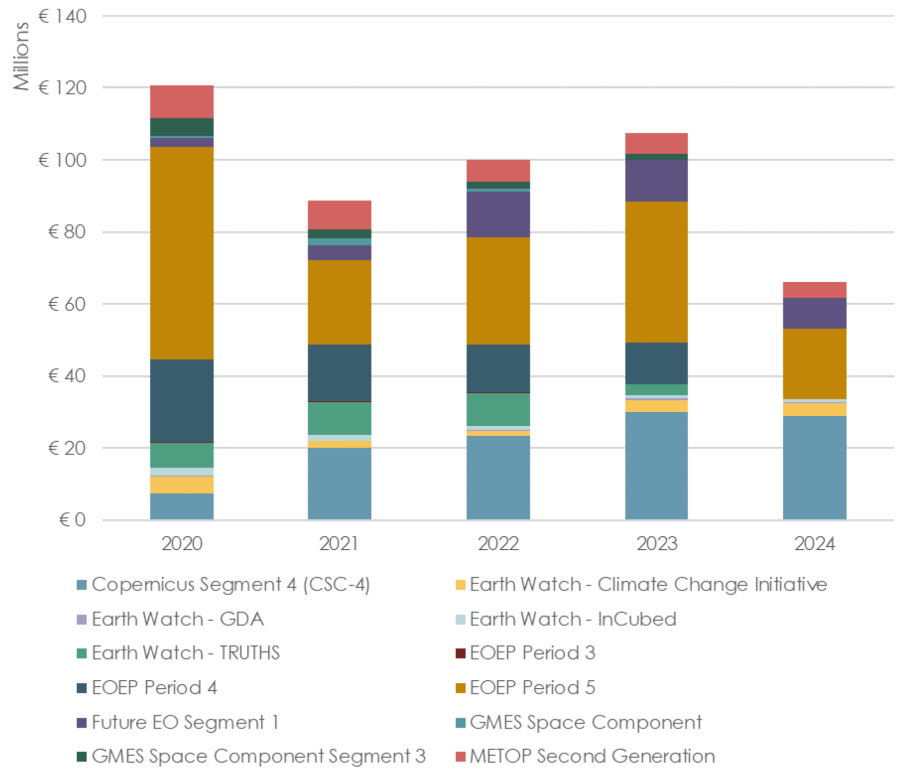
Figure 20 UK ESA EO commitments (2017-2024)



ESA datasheet on national obligations

The UK secured involvement in all three elements of ESA's EO programme (Science, Meteorology and Copernicus) for its stakeholders throughout the CMIN19 investment period (2020-2024), as outlined in Figure 21 and Table 10.

Figure 21 Breakdown of UK spending in the EO programme, per year (2020-2024, i.e. CMIN19 period)



ESA datasheet on national obligations

Table 10 UK ESA commitments by programme area (M€)

Programme	CMIN16 period			CMIN19 period				
	2017	2018	2019	2020	2021	2022	2023	2024
Copernicus Segment 4 (CSC-4)	€-	€ -	€-	€7.41	€20.09	€23.30	€30.05	€28.8
Earth Watch - Climate Change Initiative	€3.40	€2.19	€3.30	€4.55	€1.85	€1.51	€3.34	€3.52
Earth Watch - GDA	€ -	€ -	€ -	€0.34	€0.05	€0.30	€0.52	€0.52
Earth Watch - InCubed	€0.37	€2.36	€1.36	€2.28	€1.54	€0.91	€0.89	€0.74
Earth Watch - TRUTHS	€ -	€ -	€ -	€6.93	€9.28	€9.32	€2.97	€ -
EOEP Period 3	€3.40	€1.86	€0.74	€0.13	€0.11	€0.16	€0.04	€ -
EOEP Period 4	€26.09	€13.62	€14.14	€22.92	€15.71	€13.10	€11.60	€ -

EOEP Period 5	€25.86	€21.31	€33.81	€58.99	€23.54	€29.96	€38.95	€19.68
Future EO Segment 1	€ -	€ -	€ -	€2.39	€4.27	€12.52	€11.60	€8.51
GMES Space Component	€1.58	€1.28	€1.06	€0.78	€1.71	€1.00	€0.18	€ -
GMES Space Component Segment 3	€6.36	€5.80	€3.00	€4.94	€2.66	€1.87	€1.52	€ -
METOP Second Generation	€19.67	€15.70	€7.03	€9.14	€7.80	€5.92	€5.85	€4.37
Total	**€86.74**	**€64.11**	**€64.45**	**€120.79**	**€88.60**	**€99.87**	**€107.51**	**€66.16**

ESA datasheet on national obligations

Of the optional programme settlement, the UK's CMIN19 investment secured the country a strong role in Copernicus (4th largest funder with Spain) and in the Future-EO envelope programme (3rd largest funder). It also allowed the UK to be the primary funder of the TRUTHS mission (85%), which we profile as a case study in section 4.1, as well as some participation in other Earth Watch missions. These new UK commitments will support the mixture of key EO activities presented in Table 11, with mission descriptions provided in Table 13.

Table 11 UK investments in ESA's EO programme

ESA programme elements	Budget	Key UK activities via ESA	Related national activities
Copernicus (CSC-4)	€170m (2020-2028)	The UK continues to contribute to the ESA-funded part of CSC, which develops the space component (Sentinels) and data infrastructure and will span the period 2021-2027. As of early 2022, the UK secured an agreement in principle to remain in the Copernicus component of the EU Space Programme as a third country until 2027. If confirmed, UK stakeholders will be able to bid for EU-tendered and -funded Copernicus contracts, on top of the Copernicus contracts tendered through ESA (as part of CSC). CSC-4 includes the development of Sentinel Satellites (including Expansion missions) as well as other contributing missions. UK businesses are able to bid for contracts within any of these projects under the ESA contribution to the Copernicus programme, outside of the EU space programme. UK stakeholders secured involvement in most of the Sentinel Expansion missions. The following key ESA	The UK has a long history in developing instruments for Copernicus (previously known as GMES) satellites, which CMIN19 contracts build on. UK stakeholders also access and exploit Copernicus satellite mission data for research and downstream applications[27]. The UK is also a founding member and host nation for the European Centre for Medium-range Weather Forecasts (ECMWF), which operates the Copernicus Atmosphere Monitoring Service (CAMS) and the

[27] HM Government (2021), UK involvement in the EU Space Programme, available at: https://www.gov.uk/guidance/uk-involvement-in-the-eu-space-programme#:~:text=The%20UK%20welcomes%20the%20agreement,country%20for%202021%20to%202027.

ESA programme elements	Budget	Key UK activities via ESA	Related national activities
		contracts were awarded to UK contractors in CSC-4 from CMIN19 funding: • *CO2M*: €15.2m to TAS UK for phase B2 of the MAP (Multi-Angle Polarimeter) instrument. TAS UK also expects follow-on contracts for the development of its MAP instrument in CO2M, i.e. a phase C/D contract (~€22m, c. 2022/23) and contracts for the second and third flight models (~€9m each). TAS UK is building on its phase A/B1 contract, which was awarded by ESA in 2018. Other UK stakeholders also received funding for CO2M through various contracts (e.g. Teledyne UK (€6.3m) and NPL). All are sub-contractors to OHB System. The University of Leicester secured two contracts (€190k), one which it primes and the other one where it is a sub-contractor to the Finnish Meteorological Institute. CMIN19 contracts on the mission are explored in a case study (section 4.3). • *CHIME*: €10.6m to Teledyne e2v and €120k to ABSL EnerSys Space Products, as sub-contractors to TAS France • *ROSE-L*: €13m to Airbus Defence and Space UK (Airbus UK) for phase B2 of the complex radar payload, as a sub-contractor to TAS Italia. • *LSTM*: €920k to the University of Oxford, €200k to UKRI and €60k to the University of Leicester, as sub-contractors to ADS Spain. • *CRISTAL*: €16k to Isardsat, as a sub-contractor to ADS Germany.	Copernicus Climate Change Service (C3S)[28].
Future-EO	€52m (2020-2022)	This is an evolution of the former EO Envelope Programme (EOEP) programme. Currently, a number of Earth Explorer missions are under development, with Biomass (Earth Explorer 7) launching in August 2023 and FLEX (Earth Explorer 8) launching mid-2025. Additionally, the UK is/anticipates to play a prominent role in Earth Explorer 9 (FORUM, launching in 2026), Earth Explorer 10 (Harmony, launching end of 2020s), and Earth Explorer 11 (yet to be selected). In FORUM, the UK plays a leading role in the core scientific team. UK stakeholders secured many data exploitation contracts for missions already flying, like CryoSat-2 and SMOS, both as prime and sub-contractor. Many academic and research organisations were awarded CMIN19 funding, such as the Universities of Edinburgh, Lancaster, Reading, Leicester, Southampton, and Leeds, UCL, the Met Office, the National Oceanography Centre (NOC), UKRI, and Plymouth Marine Laboratory (PML). Small and medium-sized enterprises (SMEs) also secured contracts, like Argans, Trillium Technologies and Earthwave. Example of data exploitation projects include Digital Twin – Food Systems/Earth, CryoTEMPO, 4DAntarctica, A-TSCV, SO-FRESH, 4DAtlantic, and SO-ICE, Polar +. Various projects are also part of the EO4SD and AI4EO initiatives. Some	HydroGNSS builds on precursor missions (e.g. UKSA-funded TechDemoSat-1, NASA-funded CYGNSS, and SSTL-funded DoT-1), which used and demonstrated SSTL's GNSS (Global Navigation Satellite System) reflectometry technology. The selection of HydroGNSS as the second, 'bonus' Scout mission is also the result of strong advocacy by UK stakeholders at all levels, and the country's commitment to top-up the remaining ESA budget for the Scout programme.

[28] Met Office (2021), International co-operation, available at: https://www.metoffice.gov.uk/about-us/what/working-with-other-organisations/international/international-cooperation

ESA programme elements	Budget	Key UK activities via ESA	Related national activities
		CMIN19-funded contracts build on earlier phases of the projects funded prior to 2020, and some build on related precursor projects. Overall, all data exploitation contracts are linked to investments into the missions currently generating data, dating back decades. A case study was developed on CMIN19 CryoSat-2 data exploitation projects (section 0). One particularly notable UK-primed contract is the one secured for HydroGNSS, the second, 'bonus' Scout mission. Scout missions have a budget of ≤ 30 M€ and are implemented in 3 years, from kick-off to launch. SSTL (Surrey Satellite Technology Limited) received €25m to deliver the pioneering mission by 2024. The company also anticipates a €3m contract for early operations (post-launch in 2024). We developed a case study on these contracts in section 4.2. RAL Space (Dr Damien Weidmann) is also the scientific lead on the first Scout mission, CubeMAP, providing the science instruments. The mission is primed by GomSpace (DK).	
Earth Watch - TRUTHS	€28m (2020-2022)	Developed by NPL over the last two decades and proposed by the UK at CMIN19, TRUTHS will develop and launch a hyperspectral imager to provide benchmark measurements of both incoming solar radiation and outgoing reflected radiation. It will also serve as an in-space calibration laboratory for other satellites. TRUTHS is expected to deliver against national climate priorities. Funding 85% of the mission at CMIN19, the UK secured leading roles for its industry and research community. Airbus UK was selected as the prime contractor for the mission and received €9.15m for the delivery of phase A/B1. TAS UK (€665k for payload instrument and computing) and NPL (calibration) were chosen as sub-contractors to Airbus UK to support the development of phase A/B1. NPL also primes a contract to provide direct consultancy on the mission to ESA. Airbus UK and its subcontractors anticipate follow-on contracts for the next phases of TRUTHS, if the mission is green-lighted at the 'Gate Review' in July 2022. More detail can be found in the case study focused on the mission (section 4.1).	These A/B1 contracts build on decades of work conducted by NPL and later Airbus UK, funded by national grants (e.g. Centre for Earth Observation Instrumentation (CEOI)) and ESA, which developed and optimised the TRUTHS mission concept and increased the maturity of key technologies.
Earth Watch - Global Development Aid (GDA)	€2m (2020-2024)	This programme, begun at CMIN19 is working with the World Bank and Asian Development bank to develop data products and share materials for development aid and assistance activities. The UK is currently 25% over-returned in GDA due to its existing expertise in the domain.	UK inputs reflect learning acquired through the UKSA's International Partnership Programme (IPP).

ESA (website, Document 100) and consultations

UK stakeholders of all types and sizes have received contracts from CMIN19 funding, notably on very high profile missions. Many stakeholders were keen to highlight the UK's competitiveness and leadership in EO. Numerous contractors have reported bidding for other EO contracts, and most expect new CMIN19 contracts to be awarded in the coming months.

From the beginning of 2020 to Q2 of 2021, a total of 156 contracts were awarded to UK stakeholders, with a total value of €80m. In the same period, Airbus UK, Teledyne UK and TAS UK stood out as the largest EO contract recipients, as presented in Table 12. These figures, and the subsequent analysis, are based on ESA's geo-return data updated for Q2 of 2021, meaning it does not include all CMIN19-funded contracts, as many more have been and are expected to be awarded thereafter. Where consultees made the evaluation team aware of contracts post-Q2 of 2021, they were included in the analysis of outputs, outcomes, and impacts. This is notably the case of SSTL's €24m contract to prime the second, 'bonus' Scout mission HydroGNSS, which was awarded in October 2021.

Table 12 Top 10 EO contract recipients 2020-Q2 2021

Entity Name	Total Contract Value (M€)	% of total value of EO funding	Number of contracts
AIRBUS UK	€25.55	32%	6
TELEDYNE UK LIMITED	€23.05	29%	8
THALES ALENIA SPACE UK (TAS UK)	€10.88	14%	2
INTEROUTE COMMUNICATION LIMITED	€2.72	3%	1
UK RESEARCH AND INNOVATION	€2.02	3%	1
NATIONAL PHYSICAL LABORATORY (NPL)	€1.14	1%	12
UNIV. LEEDS	€1.06	1%	4
CGI (UK)	€0.94	1%	4
UNIV. OXFORD	€0.93	1%	8
ESR TECHNOLOGY LTD	€0.82	1%	6

ESA geo-return datasheet

Overall, the UK's participation in ESA's EO programme (including its CMIN19 investments) enables its stakeholders to participate in the development and/or exploitation phases of numerous missions. Once launched, these EO missions produce invaluable data for the European scientific community and industry, which use it to enhance our understanding of the Earth, develop downstream applications and inform policy-making to tackle pressing challenges like climate change and ecosystem services degradation. A non-exhaustive overview of some of the types (and usefulness) of data that has/will be generated by missions mentioned in this report is provided in Table 13.

Table 13 Overview of the type and usefulness of data generated by past and planned ESA EO missions with UK involvement (in the development and/or exploitation phases)

Mission	Description	Launch
	Science	
SMOS (EE2) Soil Moisture and Ocean Salinity	SMOS is observing soil moisture over the Earth's landmasses and salinity over the oceans. Soil moisture data are urgently required for hydrological studies and data on ocean salinity are vital for improving our understanding of ocean circulation patterns.	2009
CryoSat-2 (EE3)	CryoSat is acquiring accurate measurements of the thickness of floating sea-ice so that seasonal to inter-annual variations can be detected, and also surveying the surface of continental ice sheets to detect small elevation changes. Data from CryoSat will help determine regional trends in Arctic perennial sea-ice thickness and mass, and determine the contribution that the Antarctic and Greenland ice sheets are making to mean global rise in sea level. A case study was developed on CMIN19 data exploitation projects for the CryoSat-2 mission in section 0.	2010
EarthCARE (EE6) Earth Clouds, Aerosols and Radiation Explorer	Implemented in cooperation with JAXA, EarthCARE will address the need for a better understanding of the interactions between cloud, radiative and aerosol processes that play a role in climate regulation.	2023
Biomass (EE7)	By determining the amount of biomass and carbon stored in forests, the Biomass mission will provide crucial information about the state of our forests and how they are changing. This information will be used to further our knowledge of the role forests play in the carbon cycle.	2023
FLEX (EE8) FLuorescence EXplorer	FLEX will provide global maps of vegetation fluorescence that can reflect photosynthetic activity and plant health and stress. In turn, this is not only important for a better understanding of the global carbon cycle, but also for agricultural management and food security. This is of particular relevance due to the growing demand world population is placing on the production of food.	2025
FORUM (EE9) Far-infrared Outgoing Radiation Understanding and Monitoring	FORUM will provide new insight into the planet's radiation budget and how it is controlled. Its measurements are important because Earth's outgoing radiation at the far-infrared wavelengths is strongly affected by water vapour and ice clouds, which in turn, play a key role in regulating surface temperatures.	2026
Harmony (EE10)	In collaboration with the Sentinel-1 satellite, Harmony will provide data on land, ice and ocean processes. On land, Harmony will assess minor changes in the appearance of the ground surface, such as those caused by earthquakes and seismic activity. It will also examine glaciers to gain a more comprehensive overview of the rise in sea level and study the difference in sea surface temperature. Harmony will also gather unprecedented data on the interplay between the ocean and air surface, offering a valuable insight into the marine atmospheric boundary layer. These various measurements of the Earth's systems will provide new and important information for scientific research and disaster risk management.	~2027-28
CubeMAP (Scout) Earth System Processes Monitored in the Atmosphere by a Constellation of CubeSats	CubeMAP focusses on understanding and quantifying atmospheric processes in the upper troposphere and in the stratosphere. In particular, it will make observations in tropical and sub-tropical latitudes to observe gases such as water vapour, CO_2, methane, ozone and nitrous oxide as well as aerosols – all of which play a key role in the greenhouse effect and climate change.	2024
HydroGNSS (Scout)	HydroGNSS will provide measurements of key hydrological climate variables, including soil moisture, freeze–thaw state over permafrost, inundation and wetlands, and above-ground biomass, using a technique called GNSS reflectometry. HydroGNSS CMIN19 contracts were explored in more depth in a case study (section 4.2).	2024

Mission	Description	Launch
	Meteorology	
TRUTHS Traceable Radiometry Underpinning Terrestrial- and Helio-Studies	TRUTHS is set to provide measurements of incoming solar radiation and of radiation reflected from Earth back out into space as traceable International System of Units. These measurements will allow changes in Earth's climate to be detected faster, and they will be used to calibrate data from other satellites. In effect, TRUTHS will be a 'standards laboratory in space', setting the 'gold standard' for climate measurements. TRUTHS was developed more extensively as a case study in section 4.1.	2029
	Copernicus	
CO2M Copernicus Anthropogenic Carbon Dioxide Monitoring	CO2M will measure atmospheric carbon dioxide (CO_2) produced by human activity. These measurements will reduce current uncertainties in estimates of emissions of CO_2 from the combustion of fossil fuel at national and regional scales. This will provide Europe with a unique and independent source of information to assess the effectiveness of policy measures, and to track their impact towards decarbonising Europe and meeting national emission reduction targets. CO2M CMIN19 contracts were examined in more detail in a case study (section 4.3).	2025
LSTM Copernicus Land Surface Temperature Monitoring	LSTM will provide observations of land-surface temperature. The mission responds to priority requirements of the agricultural user community for improving sustainable agricultural productivity at field-scale in a world of increasing water scarcity and variability. Land-surface temperature measurements and derived evapotranspiration are key variables to understand and respond to climate variability, manage water resources for agricultural production, predict droughts and also to address land degradation, natural hazards such as fires and volcanoes, coastal and inland water management as well as urban heat island issues.	~2029
CRISTAL Copernicus Polar Ice and Snow Topography Altimeter	CRISTAL will measure and monitor sea-ice thickness and overlying snow depth. It will also measure and monitor changes in the height of ice sheets and glaciers around the world. Measurements of sea-ice thickness will support maritime operations in polar oceans and, in the longer term will help in the planning of activities in the polar regions. Since inter-annual sea-ice variability is sensitive to climate change, the mission will contribute to a better understand of climate processes.	2027
CHIME Copernicus Hyperspectral Imaging Mission	CHIME will provide routine hyperspectral observations to support new and enhanced services for sustainable agricultural and biodiversity management, as well as soil property characterisation. The mission will complement Copernicus Sentinel-2 for applications such as land-cover mapping.	~2029
ROSE-L Copernicus L-band Synthetic Aperture Radar	ROSE-L's longer L-band signal can penetrate through many natural materials such as vegetation, dry snow and ice. The mission will provide additional information that cannot be gathered by the Copernicus Sentinel-1 C-band radar mission. It will be used in support of forest management, to monitor subsidence and soil moisture and to discriminate crop types for precision farming and food security. In addition, the mission will contribute to the monitoring of polar ice sheets and ice caps, sea-ice extent in the polar region, and of seasonal snow.	2028

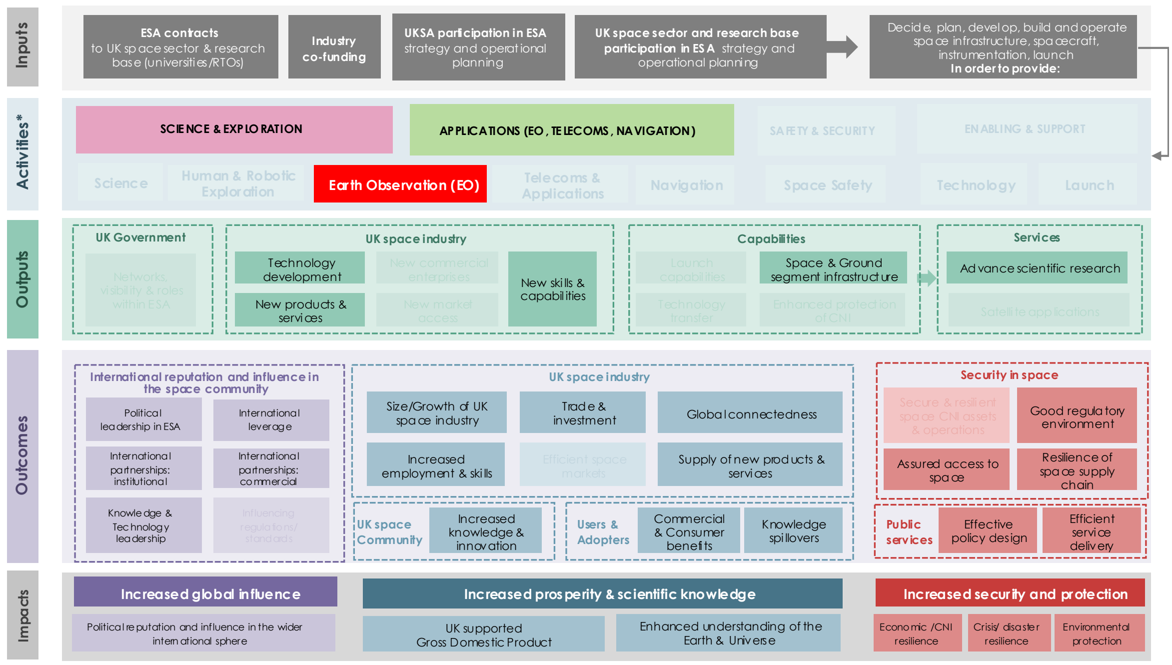
Descriptions from ESA, UN-OOSA, and FORUM mission website[29]

[29] ESA (2022), Earth Explorers overview, available at: https://www.esa.int/Applications/Observing_the_Earth/Earth_Explorers_overview; ESA (2022), CubeMAP, available at: https://www.esa.int/ESA_Multimedia/Images/2020/11/CubeMAP; ESA (2022), HydroGNSS, available at: https://www.esa.int/ESA_Multimedia/Images/2021/03/HydroGNSS; ESA (2022), TRUTHS, available at: https://www.esa.int/Applications/Observing_the_Earth/TRUTHS/TRUTHS_shapes_up; ESA (2022), Copernicus Sentinel

3.2.2 *The logic model for the UK's investment in ESA's EO programme*

Figure 22 presents an overview of the various outputs, outcomes and impacts achieved and anticipated from the UK's CMIN19 investments in ESA's EO programme (logic model).

Figure 22 Logic model for ESA's EO programme



3.3 Outputs

The consensus among consultees and survey respondents (30 respondents for EO) was that CMIN19 contracts have generally made good progress, in line with what was expected, and have already led to various types of outputs, as outlined in Figure 23.

Figure 23 Overview of some of the CMIN19 outputs

- Technology development, with notable increases in technology maturity in the 'valley of death' TRLs (technology readiness levels)
- New EO products and services, which are used by stakeholders in Europe and all over the world, including in the US, Nigeria, China and India
- New and strengthened skills and capabilities, which 90% of survey respondents reported, overall enhancing international competitiveness
- New papers already published, with considerably more expected once missions are launched and operational

Expansion Missions, available at: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions; ESA (2021), FORUM, available at: https://www.forum-ee9.eu/forum-the-video-updated/; ESA (2022), FLEX, available at: https://earth.esa.int/eogateway/missions/flex; UNOOSA (2021), ESA picks next Earth Explorer mission: Harmony, available at: https://www.un-spider.org/news-and-events/news/esa-picks-next-earth-explorer-mission-harmony

As most of the stakeholders were consulted in late 2021, this analysis is not intended to constitute an exhaustive representation of the impacts of CMIN19 contracts, as many outputs are yet to be realised. Nevertheless, the achieved outputs already feed into the NSS' key pillars, including the growth and strengthening of the UK's space economy (through increased capability and competitiveness), international collaborations, the growth of the UK as a science and technology superpower, and the development of resilient space capabilities and services[30]. CMIN19 contracts are thus already participating in achieving the UK's objectives for space, even in their early days.

3.3.1 Technology development

CMIN19 contracts involving technology development have consistently advanced technology maturity, notably providing funding in the 'valley of death' TRLs. All the contractors we consulted seemed pleased with their progress and did not flag any notable delay in the maturity level of their technologies. Some of the technologies developed through CMIN19 contracts were reported as key contributions to operational space infrastructure.

CMIN19 contracts' contribution to maturing technology is critical, as it brings us closer to missions being delivered, launched, and operational, including having the right space and ground segment infrastructure in place. This will in turn result in the generation of useful data, which has myriad socio-economic benefits, as discussed below. This is notably the case of TRUTHS contracts, which are critical in enabling the satellite to provide measurements and help other satellites calibrate themselves, once flying, overall resulting in more trustworthy data across the board. This will be useful for a wide range of stakeholders, from satellite operators, the scientific community and policy makers to space agencies and downstream service providers. The impact of CMIN19 contract-funded technology development is explored in more depth in three case studies, for the TRUTHS (section 4.1), CO2M (section 4.3), and HydroGNSS (section 4.2) missions.

3.3.2 New products and services

Many CMIN19 contracts were reported as having already resulted in new EO products and services, in the form of datasets, processed data (in various forms), algorithms, processes, tools, and platforms. While most of these were delivered to ESA, the end-users are wide-ranging. These contract outputs tend to be freely provided and used by the scientific community and decision-makers (at all levels of governance), who operate both in EO and beyond. While the outputs of CMIN19 contracts are particularly useful for European stakeholders, as ESA missions tend to be aligned with the strategic priorities of its Member States, they can also be exploited globally. For example, the data offered by a UK research institution is notably disseminated and used by stakeholders across the world, from India and China to the US and Nigeria. This feeds into the UK Government's international development efforts, notably the NSS' goal of promoting the use of space technology (inc. data and applications) to deliver on the challenges of the 2030 Sustainable Development Agenda, Paris Agreement and the Sendai Framework[31]. We explore the nature and impact of some of these new products and services

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[30] HM Government (2021), National Space Strategy, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1034313/national-space-strategy.pdf

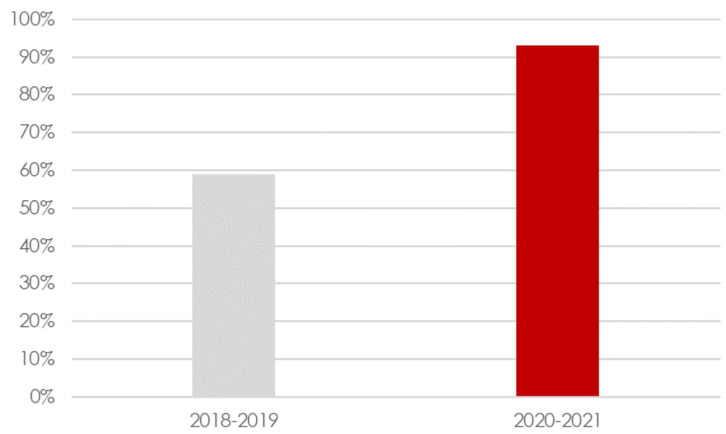
[31] HM Government (2021), National Space Strategy, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1034313/national-space-strategy.pdf

developed as a direct result of CMIN19 contracts in the CryoSat-2 data exploitation projects case study in section 0.

3.3.3 New skills and capabilities

UK stakeholders have also reported that their CMIN19 contracts have consistently resulted in significant increases in skills and capabilities, and that this is expected to continue in the coming years. Notably, 9 in 10 survey respondents indicated that their CMIN19 contracts had led to new and improved skills and knowledge.

Figure 24 Have your ESA contracts led to new or improved employee skills/knowledge? (n=29)



In some cases, CMIN19 contracts strengthen existing skills and capabilities (e.g. ROSE-L and TRUTHS in electrical, electronics, thermal, mechanical, radio-frequency engineering, functional avionics), but sometimes they also help build entirely new ones (e.g. TRUTHS and CO2M in advanced optical instrument design). The development of new skills and capabilities in the UK is particularly important in TRUTHS, as the mission's prime contractor's CMIN19 contract resulted in the establishment of a centre of excellence in advanced optical instrument design in the UK. TRUTHS' story around skills and capability development is very strong, as outlined in the case study (section 4.1), with the mission galvanising and expanding the numerous pockets of EO expertise in the UK. On top of the brand new capabilities in optical instrument design acquired through TRUTHS and CO2M, skills and capabilities have been developed and/or strengthened in other areas through CMIN19 contracts. This includes:

- The development of brand new capabilities in service provision for HydroGNSS, as the mission prime contractor is tasked with delivering a commercial and science service;
- The development of the UK's data handling and processing capabilities for a large contractor in ROSE-L;
- The strengthening of project management skills for the prime contractors of TRUTHS and HydroGNSS, which are high-profile missions; and
- The development of the capability to assimilate data on ocean surface currents and conducting data simulations, which enables a UK government executive agency to provide important data to ESA, helping the space agency define the priorities for future missions on the topic.

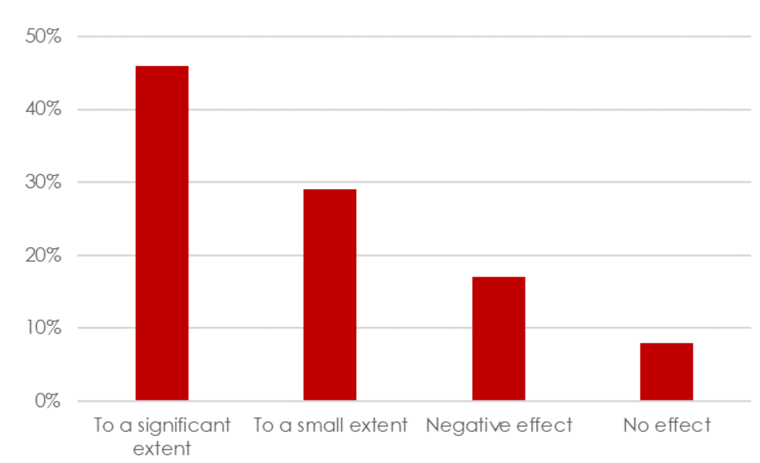
The experience of working on CMIN19 ESA contracts is particularly valuable for SMEs, especially those founded in recent years, as it provides them with a unique platform to upskill their employees and develop competitive capabilities, which are often entirely new to their company.

A common theme from our interviews and evidence synthesis is that junior staff (full time, students, interns, PhD candidates, post-doctoral researchers) particularly benefit from working on CMIN19 ESA contracts, building expertise and gaining invaluable real-flight experience in the early years of their careers. We explore this in a case study on HydroGNSS (section 4.2), where this benefit is particularly notable due to the very short mission development timeframe. Young individuals with STEM (Science, Technology, Engineering and Mathematics) and geography degrees access practical experience in highly complex mission, working with industry leaders across the UK and Europe, which constitutes a considerable learning and training opportunity. This upskilling benefit is anticipated to help keep these highly-educated and -skilled individuals in the space sector, avoiding a potential future skills shortage in EO in the UK.

Overall, the enhanced skills and capabilities acquired through the EO CMIN19 contracts are expected to enable UK stakeholders to build a broader range of instruments and infrastructure, making them more competitive internationally to secure follow-on contracts and projects. Two contractors have already secured follow-on contracts as a direct result of their CMIN19 contracts. This enhanced international competitiveness benefit was reported by nearly three quarters of survey respondents, with almost half of them explaining that CMIN19 contracts helped significantly. Additionally, prime contractors develop unmatched expertise on the missions they lead (e.g. TRUTHS and HydroGNSS), which could constitute a competitive advantage (in mission data exploitation and in the development of similar missions and instruments). This benefit was explained by many stakeholders we spoke to as being critical to their growth and, as discussed in other chapters of this evaluation, strengths can take decades to build but once established, put UK organisations in strong positions to take advantage of future opportunities and secure leading roles for UK industry and academia.

Overall, CMIN19 contracts' skills and capability development outputs are contributing to strengthening UK industry and the scientific community, working towards the UK Government's Science and Technology Superpower agenda, one of the key pillar of the NSS.

Figure 25 As a result of your ESA contract(s) since 1st January 2020, to what extent has your organisation experienced increased competitiveness within international space markets? (n=24)



ESA contractor survey

3.3.4 Publications and patents

ESA CMIN19 contracts have led to advances in scientific and technical research through the publication of papers (i.e. ~1-2 per contract among consultees), most often led by academia or research institutions, with the support of industry contractors. Stakeholders on large missions also tend to expect the publication of more papers by mission launch date (<5 per contract among consultees). These pre-launch publications tend to be focused on technology developments, which could have applications in other sectors (which would lead to technology transfers and spillovers). The overwhelming majority of publications are however expected once missions are launched and operational, as generating satellite data for the research community is one of the key purposes of EO missions. The impact of increased data and knowledge from EO satellites is explored subsequently in section 3.4.7.

Projects like EO4SD Marine Coastal Resources Management generate knowledge that can feed into international organisation and governmental reports (e.g. World Bank, UN's IPCC and UK government), which can then influence the international/national agenda and policy-making. The IPCC notably highlighted that EO satellites are a critical tool to monitor the causes and effects of climate change, directly acknowledging ESA's Climate Change Initiative[32]. For example, ESA missions like ERS-1, -2, Envisat, CryoSat-2, and Sentinel 1 have provided essential data on ice sheets and glacier mass loss in the last few decades, which help monitor, understand, and respond to sea level rise.

While the impact of CMIN19-related publications is not yet known, one contractor reported that single publications have already been downloaded hundreds of times. That same company also explained that their papers feed into ESA MOOCs (futurelearn), which over 1,700 students accessed. This means publications are disseminated beyond scientific journals and reports, influencing academic and training curricula. Some stakeholders also reported taking part in conferences and trade events to present mission design data, disseminating findings to academia, industry, and policy-makers and potentially leading to future spillover benefits as new knowledge is applied elsewhere – often in unpredictable ways.

Overall, consultees did not yet expect any patents, often as a result of the intellectual property (IP) agreement with ESA or because IP protection is not necessary due to the high specificity of the technology or the fast-moving nature of technology evolution. Nevertheless, a few stakeholders reported that they are considering whether they should apply for patents (although this was flagged as unlikely).

3.3.5 Output timescales

CMIN19 contract outputs generally took anywhere between 6 months to 3 years after contract award to be realised. The speed was explained to depend on the starting TRL and the existing infrastructure. Overall, when the satellites were already launched and operational, ground opportunities were realised much quicker. The overarching point is that the present analysis represents a snapshot in time, with most stakeholders consulted in late 2021. This means that many outputs from CMIN19 contract are yet to be realised.

[32] ESA (2021), Satellite data provide valuable support for IPCC climate report, available at: https://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Satellite_data_provide_valuable_support_for_IPCC_climate_report

3.4 Outcomes and impacts

Figure 26 Overview of selected CMIN19 contract outcomes and impacts

Increased prosperity and scientific knowledge

- Commercial opportunities, which are anticipated to result in significant follow-on sales (ranging from tens of thousands to tens of millions of pounds).
- Increased employment and skills, with a majority of survey respondents reporting having already or anticipating retaining and/or creating jobs. High value skills (e.g. AI, ML) have also been secured, with most survey respondents agreeing that the UK space sector and supply chain's resilience is enhanced
- Leveraging of public and private capital and synergies, with over 8 in 10 respondents reporting that their ESA contracts somewhat influenced the level and content of internal R&D
- Knowledge and technology transfers to and from the space sector, with notable spillovers in the defence, marine, telecommunication, petroleum sectors

Increased global influence

- Increased relationship and network development, with new strategic partnerships created or anticipated, and most survey respondents reporting increased reputation, credibility and visibility
- Enhanced leverage and influence within ESA and beyond, notably through the UK's leadership in TRUTHS and HydroGNSS

Increased security and protection

- Better data, informing responses to challenges (e.g. climate change, ecosystem services disruption, disasters), leading to applications and benefits for policy making (75% of respondents), the security of Earth assets (55%) and ultimately, the protection of the environment, as highlighted by 96% of survey respondents

CMIN19 contract outputs have, and will, result in wide-ranging outputs and impacts, as outlined in Figure 26. It is nevertheless important to acknowledge that, as outlined in section 3.2.1, many CMIN19 contracts have been awarded/are anticipated after Q2 of 2021. Additionally, contractors were consulted in late 2021, relatively recently after their CMIN19 contract award. Therefore, the analysis in the following sections should not be taken as an exhaustive account of the outcomes and impacts generated by CMIN19 contracts. Instead, we will present an overview of different types of benefits, some having been already realised, but most still anticipated.

In the following sections, we will explore the various outcomes and impacts from CMIN19 contract outputs highlighted by consultees, which consistently feed into the NSS' four pillars, helping achieve the UK's goals for space.

3.4.1 Commercial outcomes

We found clear evidence that the work undertaken as part of contracts awarded since 2020 has and will lead to commercial opportunities, i.e. the supply of new products and services. The potential for a new spin-out was also raised, which would lead to new jobs created. Many more commercialisation opportunities may still arise, as the CMIN19 contracts progress.

Experiences vary among the contractors consulted regarding CMIN19 contracts' contribution towards helping them find new customers. Some explained that their ESA-funded activities did not directly help them find any clients, while others highlighted that they received interest from commercial stakeholders during the course of their ESA-funded work through network and contract exposure. Nevertheless, most contractors reported that their CMIN19 contract outputs have commercial potential, in various ways, as the following sections explore.

Overall, if realised, the commercial opportunities outlined in the following sections would contribute to increase the size and growth of the UK space industry, increase employment and skills, knowledge and innovation and knowledge spillovers to non-space sectors (e.g. defence, marine, telecommunication, petroleum). This would in turn contribute to supporting UK GDP. Ultimately, these commercialisation opportunities would feed into all of the UK's NSS pillars and thus help the country achieve its objectives for space.

3.4.1.1 CMIN19-developed technology and infrastructure

CMIN19 contracts are anticipated to lead to spillover commercial benefits. Indeed, beyond the benefits of ESA missions themselves, some of the technology and infrastructure developed through CMIN19 contracts can be adapted and used by contractors for their own private missions, helping expand and/or improve their commercial product and service offering. However, the realisation of these benefits entails private (internal) investments to undertake further developments and adaptations, because the outputs of CMIN19 contracts are not mature enough or market-ready yet. Various examples of such commercial opportunities highlighted by consultees are outlined below.

A large contractor anticipated to build on the enhanced data handling and processing infrastructure developed for ROSE-L to use it for its own satellites. The company has been developing services based on EO for many years: generating, processing and deriving data, and selling it to oil, marine, defence, and telecommunication stakeholders. ROSE-L contract outputs will enable the contractor to increase the quantity and speed of data it processes from its private satellites, helping the company offer new/improved commercial products and services to its clients in wide-ranging sectors. Overall, CMIN19 contracts have a strategic commercial importance for this large UK stakeholder, as there is a large demand for EO data from optical radars, so it is very important for the company to be involved *both* in putting its own satellites in orbit *and* in data processing (for commercial and institutional satellites).

As extensively outlined in the CO2M case study (section 4.3), the mission prime contractor reported a similar commercial opportunity, expecting to build on the technologies and processes developed through its CMIN19 CO2M contract to use them on its own satellites. The data from these private missions would then be sold on the commercial market as a service. The company anticipates that the realisation of these commercial opportunities could occur within 4 to 6 years, and follow-on sales could reach the millions to low tens of millions of euros, with benefits sustained from market introduction onward. Internal investments to develop, launch and operate the commercial satellites would however match this figure, and replacement satellites would be needed every few years (4-6+) due to competition and technological advances.

HydroGNSS' prime contractor also explained that the commercialisation of technologies developed for the payload and spacecraft of the mission was highly probable, which we explore in depth in the case study developed on the mission (section 4.2). The technology is expected to be adapted and used on other institutional or commercial satellites, as early as the end of 2022 for platform components and after mission launch in 2024 for payload instruments (which will prove the technology works and de-risk it for the commercial market).

Overall, beyond the commercialisation potential of elements of HydroGNSS, the company's approach to small, reliable but quickly and cheaply developed satellites, implemented through this CMIN19 contract, could itself lead to many more missions if ESA adopts it. This UK stakeholder would be in a pivotal position to secure such institutional or commercial contracts due to its experience as a prime contractor for CMIN19-funded HydroGNSS activities. Overall, follow-on revenue for the various commercial opportunities stemming from the work on the mission is estimated in the tens of millions of pounds.

3.4.1.2 CMIN19-developed standardised hardware

Some companies expected the commercialisation of hardware developed through their CMIN19 contracts without further adaptation being required. Indeed, one contractor noted that ESA is gradually transitioning to become more commercially aware of the financial risk of developing bespoke hardware, now commissioning hardware that can be reused elsewhere more often. The company noted that this has a positive impact for contractors, which can subsequently commercialise the hardware easier, without adaptation. Overall, the consultee highlighted that this move toward standardised hardware improves profitability (better pricing, schedule, warranty), reduces risk (fewer mistakes) and strengthens the supply chain. This UK contractor also explained that its CMIN19-funded technology developments for EarthCARE (i.e. batteries) could be reused in other ESA missions, such as CHIME, ARIEL, and LSTM. This outcome does not seem to include technology related to mission instruments, which remains relatively bespoke, as large contractors on missions like TRUTHS, CO2M and HydroGNSS reported having to undertake adaptations to their CMIN19 contract outputs to exploit commercial opportunities.

CMIN19 contracts can also help secure export opportunities. One consultee reported that the fact that standardised technologies are developed for, and qualified by ESA constitutes a selling point for international customers (e.g. Taiwan, Italian, Canadian, Japanese).

3.4.1.3 CMIN19 data-related products, services, and tools

Stakeholders also indicated that they expected to diversify the data-related outputs of CMIN19 data exploitation contracts (e.g. datasets, platforms, tools) to commercialise them on the market, supplying new/improved products and services.

For example, one stakeholder reported that it would adapt the framework for data processing it developed in the context of its EarthCARE contract to then provide it as a product/service to commercial clients (e.g. satellite operators, companies going to process satellite data). One SME, also exemplified this type of commercial opportunity, as its 3 CMIN19-funded products and visualisation platform were expected to lead to 10 different services for industry and academia by the end of 2023.

Research organisations are also creating potential for commercialisation through CMIN19 contracts, although the timeframe for the realisation of these opportunities varies. One research institute notably reported that it expected to eventually commercialise novel mapping and monitoring capabilities from the work it is conducting on its CMIN19 contracts. A UK executive agency also indicated that it anticipated improving the quality of its forecasts and enhancing its offering to existing customers through its CMIN19 contract-developed data capabilities. Ultimately, this would increase the take-up of its products and services, which are key to the resilience of the UK's CNI. For example, it explained that it would soon be able to add ocean systems to its global forecasting system. This could subsequently help the Royal Navy and ship routing companies improve the safety and accuracy of their activities and services. It could also assist stakeholders involved in emergency response, notably for oil spills. This executive agency expects to also use these new capabilities to deliver products through the Copernicus Marine Service, i.e. getting paid to provide free data to end-users or selling data when it is not freely available.

Overall, the commercialisation of data-related products and services would increase downstream stakeholders and end-users' access and thus use of EO data. Ultimately, this results in a wide-variety of long-term benefits, which we explore in section 3.4.7.

3.4.1.4 CMIN19-developed skills and capabilities

The new skills and capabilities developed as outputs of CMIN19 contracts can also lead to commercial opportunities. It was notably reported by one consultee, who explained that the knowledge and capabilities acquired through its ESA contracts since 2020 (e.g. AI4Wildfires) were leveraged to bid for commercial (non-ESA) contracts worth £14m (which is significant compared to the hundreds of thousands of euros invested by ESA). Many stakeholders, including research institutions, also explained that the cutting-edge knowledge and capabilities developed through CMIN19 contracts would help in other projects down the line (tree of knowledge development concept).

3.4.1.5 Follow-on sales

While not all consultees managed to provide quantitative figures, all agreed that the exploitation of the different types of commercial opportunities outlined in the previous sections would generate revenue (ranging from tens of thousands to tens of millions of pounds). Some quantitative figures were already provided for specific examples, such as CO2M and HydroGNSS. Those should however be interpreted with caution due to the uncertain nature of future market conditions, revenue, and external factors. Overall, as indicated by consultees and survey respondents, the overwhelming majority of follow-on sales have not yet been realised, which is unsurprising given the early stage of programmes and projects.

Some survey respondents also reported that CMIN19 contracts have or will help them access new markets, and reduce transaction costs and entry barriers to international space markets.

3.4.2 Increased employment and skills

Most contractors consulted explained that CMIN19 contracts helped their organisation sustain the employment of their staff, and many times led to the creation of new jobs. CMIN19 contracts are widely reported as helpful in attracting and keeping people in the EO and space sector, contributing to the growth of the industry and avoiding future skill gaps or brain drains. Several stakeholders argued that high-profile and exciting missions like TRUTHS and HydroGNSS have and will continue to attract individuals into careers in these sectors because they are entirely UK-led and ambitious, giving a sense of purpose around EO in the country. This directly feeds into the growth of the UK space sector pillar of the NSS.

Reflecting the potential for Artificial Intelligence (AI) and Machine Learning (ML) techniques to revolutionise the ability for EO data to quickly and efficiently deliver actionable insight for customers, there has been a corresponding increase in demand by CMIN19 contractors for individuals trained with those skills and capabilities. A large contractor also reported that ESA contracts incentivise companies like itself to recruit in areas not directly related to CMIN19 contracts to prepare for the future, once the mission is in another stage (i.e. recruit in the whole mission ecosystem: design, manufacturing, testing, data handling). Overall, most stakeholders explained that CMIN19 contracts enable them to build and broaden their organisation's skills base and capabilities through the recruitment of new individuals, ensuring that they sustain their competitiveness in the future. Stakeholders indicated that this helped strengthen the resilience of the UK space sector and its supply chain. Overall, this CMIN19 contract outcome contributes to making the UK a science and technology superpower, which is one of the key pillar of the NSS to achieve the country's objectives for space.

Some examples of increased employment and skills highlighted during our consultations include:

- One SME expected its workforce to have nearly quadrupled by early 2023 (from 3 to 11 FTE, 4 new jobs already added by November 2021), which it attributed to CMIN19 contracts.
- Another SME reported between 8 and 10 new employees in the past 2 years that would not have been hired without CMIN19 contracts.
- The prime contractor for TRUTHS explained that it was building UK capability in advanced optical instrument design by recruiting between 5 and 10 optical engineers and architects. These numbers were reported as significant considering the skills and experience required from the candidates. Overall, this large stakeholder estimated that at least 100 FTE will be supported by TRUTHS (created and sustained), through to its completion (in 2029).
- HydroGNSS' prime contractor anticipated to create new jobs, in the tens, over the next 3 years (by the launch of the mission in 2024) from its CMIN19 contracts (especially on the payload side due to the pioneering nature of the instruments). New jobs are also expected on the data exploitation side in the science community once HydroGNSS is operational, as explained in the case study developed on the mission (section 4.2).
- One research institution attributed 3 new posts to its CMIN19 contracts and explains that they have led to growth that otherwise would not have occurred.

A consultee nevertheless reported that employee retention is challenging when ESA contracts are short-term. The uncertainty resulting from the UK's exit from the EU, notably around the country's participation in Copernicus (c.f. section 0), and its late commitment to Horizon 2020 have resulted in the company's UK branch not being prioritised for internal investment, which would have helped retain the jobs created.

Overall, these new and retained jobs were reported for Scotland, London, the South West and South East of England, and to a lesser extent for the North East and North West of England. By creating and sustaining employment in regions like Scotland, the South West and Northern England, CMIN19 contribute to the UK Government's Levelling-Up Agenda[33].

3.4.3 Relationship and network development

There was a strong consensus among industry and academic consultees that CMIN19 contract activities have considerably helped create and strengthen relationships. This was highlighted as leading to international partnerships (commercial and institutional) and increased knowledge and technology leadership through enhanced reputation, visibility and credibility. Around half of survey respondents reported having formed, or anticipating new strategic international partnerships. This directly feeds into the NSS' pillar of international collaboration, central to achieving the UK's objectives for space.

CMIN19 activities enabled UK contractors to develop collaborations with other UK organisations, as well as European and international stakeholders (companies of all sizes and types, including research organisations, government agencies, local authorities, NGOs,

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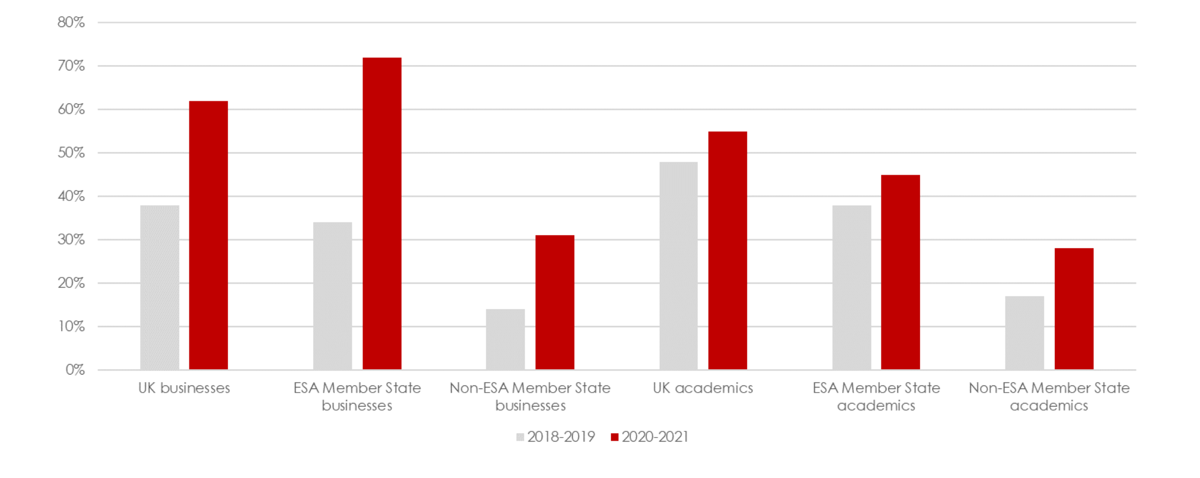
[33] HM Government (2022), Levelling Up the United Kingdom, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1052046/Executive_Summary.pdf

national space agencies), as outlined in Figure 27. This also includes non-EO organisations. For example, a research institution reported that ESA facilitated partnerships with international financial sector actors, various space agencies (e.g. LAPAN and NASA) and governmental agencies and academics in West Africa and the Caribbean. This benefit is particularly valuable, as ESA contracts provided a shortcut and enabled organisations to get in touch much easier, significantly reducing the large internal investment traditionally required for relationship development.

Figure 27 Do your ESA contracts involve collaborations with… (n=29)



These contracts have also systematically enabled closer collaboration and links between contractors and ESA. This is notably the case for one consultee, which expects its involvement in CMIN19 EarthCARE contracts to lead to the creation of a relationship with ESRIN, the ESA Centre for Earth Observation in Italy, which is strategically important to secure future data exploitation contracts once the mission is launched. For a large stakeholder, priming TRUTHS entailed a different, more sophisticated engagement with ESA around securing the required skills around Europe while conserving UK leverage and benefits. UK stakeholders in general built closer links to ESA through the entire mission selection process for TRUTHS. Similarly, negotiations and collaborations in the context of HydroGNSS have also strengthened the relationship between the UK and ESA. The case studies for both missions (sections 4.1 and 4.2)outline this aspect in more detail.

This networking and relationship development benefit is strategically important, as it is often expected to help secure further ESA contracts and lead to new collaborations. For some, especially research organisations and ancillary service SMEs, the follow-on contracts obtained through the network they developed from CMIN19-funded activities are crucial to their growth, as they do not tend to commercialise products and services to the private market. The follow-on contracts are not limited to Europe, as one consultee explains that its CMIN19 contracts helped catalyse work with international stakeholders, like in Australia on wildfires. HydroGNSS' prime contractor also expected new collaborations with NASA and other research organisations around the world on GNSS reflectometry, as a result of its leadership in the ESA mission.

Contractors' activities around their CMIN19 contracts have also consistently led to enhancing their reputation, as notably reported by almost all consultees. As in other programme areas, most of them reported benefiting from an 'ESA stamp of approval' effect, which demonstrates that they are capable and entrusted with delivering high-stakes and high-scrutiny contracts.

UK stakeholders expected that this enhanced credibility and legitimacy would help them secure follow-on contracts and funding (e.g. Horizon 2020 and Copernicus), and external funding (when it is sought). This 'ESA stamp of approval' is also helpful in exploiting commercial opportunities, akin to a 'de-risked' label on the technology, products, services and/or processes, providing reassurance to the market due to ESA's reputation as an exigent client. This was notably reported by two consultees, which explained that their CMIN19 contracts helped articulate their company's marketing (i.e. reliable, quality products, having been developed for and used by ESA), notably valuable to enhance exports (see section 3.4.1.2).

CMIN19 contracts also already provide contractors with visibility, notably for TRUTHS' prime contractor, which explained that its leadership in the mission has considerably increased its exposure in the UK and European environment. A UK executive agency also explained that dissemination events around CMIN19 contracts are useful in increasing visibility (e.g. international scientific workshop where participants present their work). Again, this is expected to help secure follow-on collaborations, contracts and funding, which feeds into the NSS' pillars of growing the UK space sector, collaborating internationally, and establishing the country as a global science and technology superpower.

While some reputational benefits have already been reported, the realisation of the full extent of this impact is expected in the coming years, when EO missions are launched and operating successfully, as outlined in the TRUTHS (section 4.1) and HydroGNSS (section 4.2) case studies. For example, once flying, TRUTHS will demonstrate that the UK, as a country, is capable of developing a high-profile and complex mission, from inception to launch and operations, which will significantly enhance its reputation. UK leadership in ESA's pioneering Scout mission, HydroGNSS, was also reported as being crucial in giving the country an edge in mission development in the age of New Space. Overall, this would provide the UK and its stakeholders with international leverage.

3.4.4 Increased investment

CMIN19 contracts have led to some increases in private (including internal) and public capital investment. Most stakeholders (over 8 in 10 survey respondents) reported that CMIN19 contracts somewhat influenced the level and content of internal R&D, notably to deliver their ESA contracts and/or to exploit commercial opportunities. For example, HydroGNSS' prime contractor explained that it increased internal R&D as a result of its CMIN19 contract, both in GNSS reflectometry and to respond to the need to set up distribution services for the mission data. The lead for CO2M also invested in an on-site optical laboratory in Bristol (i.e., a $100m^2$ ISO8 clean room), developing the company's ground infrastructure specifically for the delivery of the MAP instrument. Some stakeholders also highlighted that CMIN19 funding's contribution to maturing technology and bridging the TRL 'valley of death' subsequently helps secure private capital, as investment risks are much lower and returns can be obtained in a relatively shorter timeframe. Additionally, certain contractors reported having access to World Bank and Asian Development Bank investments and private funding due CMIN19 contracts. Overall, leveraging additional private and public capital means CMIN19 contracts are generating a higher return than the UK's investment at the Ministerial by increasing R&D activity and the development of ground infrastructure. This contributes to growing the UK space sector, developing resilient space capabilities and services, and establishing the UK as a science and technology superpower – core pillars of the NSS.

Various stakeholders, notably large UK contractors, also reported synergies between ESA funding and other sources of investments, helping the companies' overall roadmap for technological capability development. This was also the case for a research institution, which explained that it used IP developed with other funding in its CMIN19-funded Blue Economy and

EO4SD Marine and Coastal Resource Management projects. Similarly, being an NPL-developed concept, precursor studies for TRUTHS were funded through internal NPL, national (e.g. CEOI), and ESA investments prior to its selection as an ESA mission. This was instrumental to de-risk phase A/B1 of the mission and thus enable the work currently being undertaken under CMIN19 ESA funding (c.f. TRUTHS case study in section 4.1).

3.4.5 *Knowledge and technology transfers*

The outputs of CMIN19 contracts have already resulted in knowledge and technology transfers both within and outside the space sector. This was mainly the case within consortia, occurred reciprocally, with partners both in the UK and in Europe. These transfers were generally reported to be around 'soft' IP, rather than hard IP. However, some stakeholders explained that they did not transfer much knowledge with companies outside of their group to protect their intellectual property. Examples of transfers reported by consultees include:

- Intra-consortium transfers, which an SME notably flagged around its Digital Twin Antarctica project. The company also highlighted an outward transfer to a German company, where it applied its technology to a new part of EO, which marked the first time it was done;
- Knowledge transfers between the scientific community and ESA;
- Sharing of knowledge and capabilities between key manufacturers' subsidiaries.

Various stakeholders also reported spillovers to and from the space industry as a result of CMIN19 funding. Technology developed through other activities, such as defence, were reported being used for TRUTHS. Here, putting defence equipment on a high altitude platform for the first time will offer lessons and developments that will feed back into the defence sector. One stakeholder reported that this type of activity is expected to help it sustain its competitiveness across the various sectors it operates in. Technology, products and services developed for CMIN19 EO contracts could have a wide field of application, beyond the space sector, such as CO2M's MAP instrument, as it measures gas, and EO4SD forest management, as it is the objective of the project. Other cross-sector transfers were anticipated by our consultees:

- Unexpected benefits in terms of the use of EO in other domains (in sectors adjacent, e.g. land management);
- Knowledge and capabilities developed through ESA contracts could be transferred to other parts of companies' businesses, notably in the aviation and defence sectors;
- Data assimilation capability developed through CMIN19 contracts could be used for numerous types of data (in wide-ranging sectors); and
- CMIN19 contracts around TRUTHS open up new opportunities in the defence and nuclear sectors (although this impact is uncertain at this stage).

Big data, AI, and ML techniques developed through the EO missions may improve the statistics methods used by stakeholders in wide-ranging sectors, such as financial services and insurance, ultimately leading to benefits like productivity improvements and cost savings[34].

3.4.6 *Leverage*

UK leadership in high-profile missions secured through CMIN19 investments are demonstrations of the country's leverage. This benefit is extensively developed in the case studies focused on

[34] know.space (2021), UK Space Science: a summary of the research community and its benefits

the TRUTHS (section 4.1) and HydroGNSS (section 4.2) missions. Indeed, the selection of HydroGNSS as a 'bonus' second Scout mission is a demonstration of the UK's influence in ESA, with UK stakeholders' advocacy at all levels being credited for the success of the mission selection. Additionally, the UK's proactive leadership in TRUTHS (notably in the mission selection) enabled the country to steer EO at ESA towards its national priorities, enhancing its leverage and influence. The eventual success of UK industry and academia in delivering TRUTHS and HydroGNSS is also anticipated to increase the UK's reputation and influence within ESA and in the wider international sphere. For example, being one of two Scout missions, which pioneer new approaches and techniques to delivering useful and credible science faster and cheaper, the success of HydroGNSS will inform the future of space development at ESA. This means the UK has important influence in defining the future of EO at ESA and beyond. This is particularly valuable in achieving the NSS' goal of protecting and defending UK national interests in and through space.

3.4.7 Wider, longer-term benefits

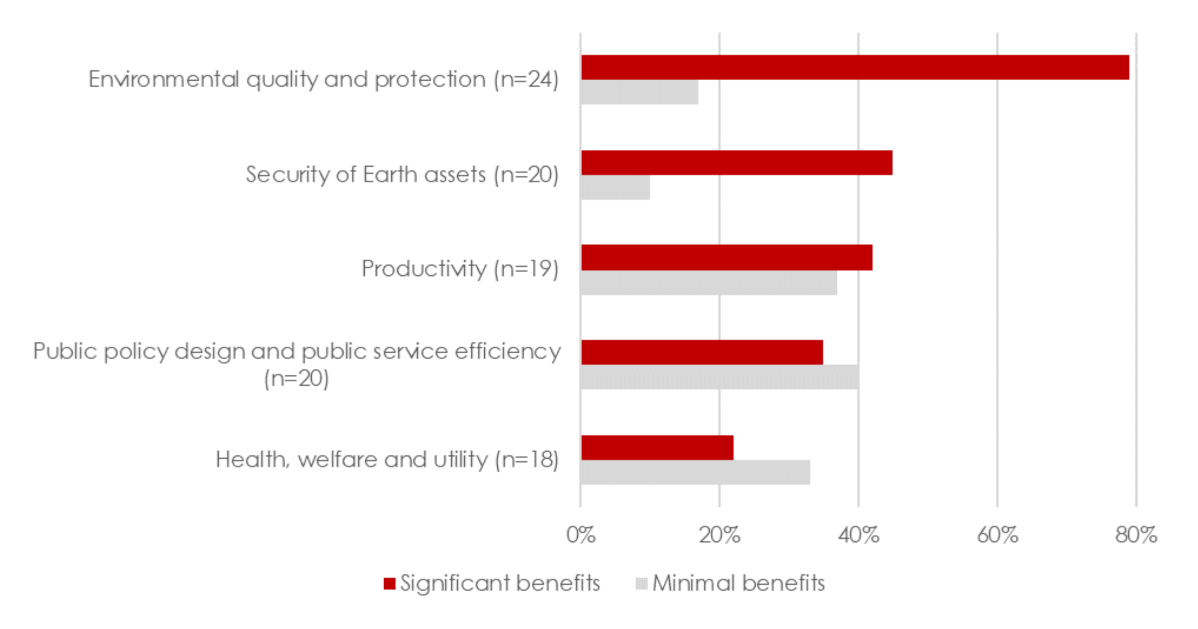
Being the essence of ESA's EO programme and the UK's objectives for space, CMIN19 contract outputs and outcomes are naturally expected to lead to wide-ranging long-term benefits. Chief among them, and central to the purpose of EO, is environmental protection. Indeed, CMIN19 contracts are either contributing to bringing us closer to having satellites launched and operational, or are helping end-users exploit the data of missions already flying. This means that CMIN19 contracts participate in providing independent, more accurate and comprehensive EO data to wide-ranging stakeholders (c.f. the 4 EO case studies in section 4). This will subsequently help them better understand and monitor anthropogenic climate change and its effects, and better manage environmental resources (e.g. forests, marine and coastal areas, wetlands). These environmental benefits were highlighted by several stakeholders, who noted they will help protect critical ecosystem services and thus public service delivery (e.g. transportation infrastructure, food security, and stable housing all depend on stable and healthy ecosystem services).

A better environment also results in health and welfare benefits for societies around the world. Enhanced EO data helps increase crisis and disaster resilience by improving our environmental disaster response, contributing to keeping people and ecosystems safe and healthy. For example, marine coastal management work was reported to help responsive action to oil spills in West Africa. Additionally, CMIN19 contracts are anticipated to ultimately lead to improved ocean forecasts for weather forecasting operators, which will subsequently help with search and rescue efforts, enable more efficient disaster response (e.g. oil spills, nuclear disasters), prevent potentially dangerous situations for boats and their crew, and help mitigate pollution (e.g. marine plastics).

The enhanced data, methodologies and tools developed through CMIN19 contracts are also anticipated to help scientific productivity and ensure effective policy design in high-stakes and high-priority fields (notably through the better modelling and monitoring of climate change, pollution, and deforestation). For example, one stakeholder reported that some American and Canadian end-users of satellite data products and services found that they helped reduce the time it takes to find, acquire, and prepare data for analysis. 4D visualisation tools also help in story-telling, raising public and policy-makers awareness to the effects of climate change, catalysing interest to the challenge and earth science more generally. Similar benefits were reported around efficiency for stakeholders using EO data (e.g. World Bank and Asian Development Bank). This contribution to effective policy design, especially in the field of climate change, feeds into the UK Government's Net Zero agenda.

Overall, CMIN19 contracts' contribution to making EO data more fit for purpose and better exploited results in some commercial and consumer benefits (i.e. environmental, health and welfare, public service provision, and productivity benefits). This was echoed by the majority of survey respondents, who particularly highlighted applications and benefits in environmental quality and protection (with 96% reporting some benefit in this field). The UK's CMIN19 investment into ESA's EO programme thus considerably contributes to achieving the NSS' 5th objective, i.e. 'Use space to deliver for UK citizens and the world'.

Figure 28 Thinking about your recent ESA contract(s) (i.e. those that started since 1st January 2020), do you expect them to lead to applications and benefits in…



3.4.8 *Outcome and impact timescales*

As highlighted throughout the analysis, this evaluation provides a snapshot in time only one to two years after the examined CMIN19 contracts were awarded, with many more contracts awarded/anticipated after Q2 2021 (c.f. Section 3.2.1). This means that an overwhelming majority of the outcomes and impacts from CMIN19 investments into ESA's EO programme are yet to be realised. There could also be unexpected outcomes and impacts, which are naturally hard to predict, but this potential should nevertheless be acknowledged.

The previous sections have outlined some of the outcomes and impacts that consultees have already achieved, or anticipate. Unless specified for specific examples, stakeholders only offered broad timescales for the realisation of the outcomes, again reflecting that these are still early days.

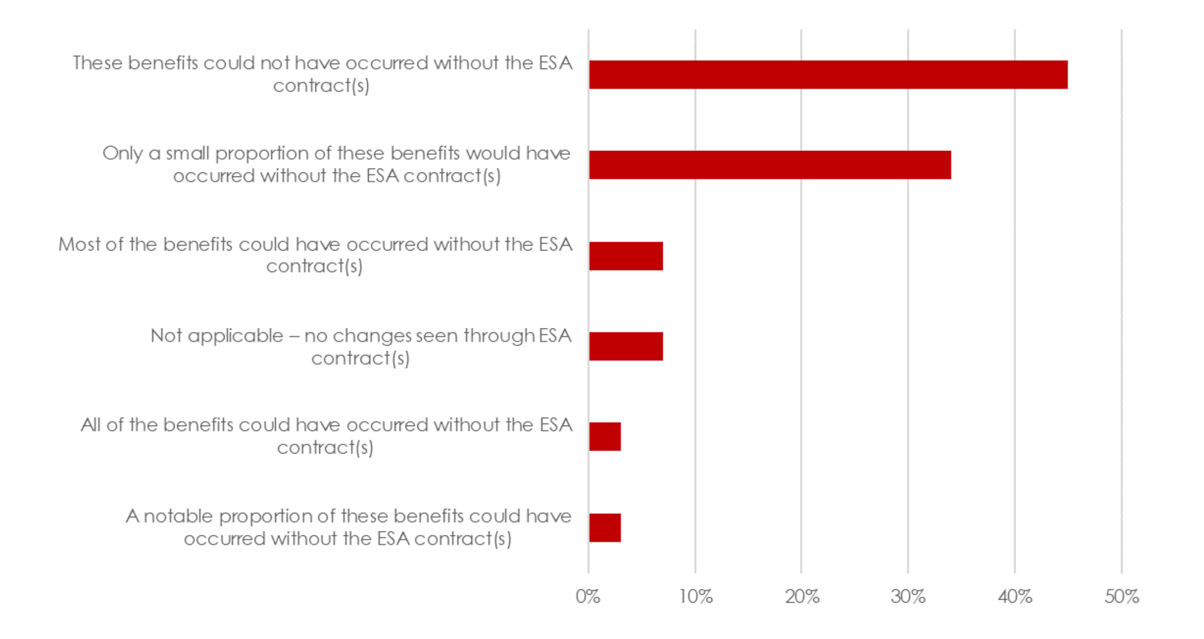
Generally, outcomes were anticipated to be realised within 6 months to 5 years from contract start. Benefits from commercialisation are notably contingent upon the technologies and processes developed for ESA missions reaching a sufficient level of maturity to secure subsequent internal or private capital required to make them market-ready.

The timescales for the realisation of impacts also varies depending on the type. It can take decades to achieve environmental benefits for challenges like climate change, or much shorter (4 to 6 years) for resource management challenges like deforestation. Importantly, the speed of realisation of wider impacts depends on the level of subsequent funding awarded, both for ESA projects but also for parallel projects and initiatives (due to synergies). Productivity and policy-making impacts can be realised much quicker, usually in the months to years after EO data and tools are generated and rendered available. However, these benefits can take a long-time to be widely implemented (at sector-level).

3.5 Attribution and additionality

While it is difficult to determine the attribution of every output, outcome, and impact of CMIN19 contracts, most contractors (nearly 80% of survey respondents) highlighted that the benefits outlined in the previous sections would not have occurred or would be considerably limited without CMIN19 ESA funding.

Figure 29 Which of the following statements most accurately describes the extent to which the benefits reported above are linked to your ESA contracts? (n=29)



Additionally, ESA investments in previous decades have been highlighted as critical for the realisation of the CMIN19 contract benefits. Past ESA investments have helped develop skills and capabilities in the UK, build a strong, competitive supply chain, and enabled missions to be launched and generate data. CMIN19 investments were thus emphasised as being part of a much longer impact story for the UK. For example, interviewees told us that key data exploitation benefits would not have occurred without CMIN19 funding, and would also not have been realised if ESA had not funded the development of the CryoSat(-2), SMOS, Sentinels, ERS missions for the past 20 years, as there would not be any mission data to exploit, thus contracts to award. A large contractor attributed its contract award for ROSE-L to the skills and capability developments in the UK achieved through decades of ESA contracts. National and internal investments in precursor studies, notably for HydroGNSS and TRUTHS, have been crucial to their selection as ESA missions, and thus, the realisation of the impacts outlined in the previous sections (c.f. the case studies for the respective missions in section Earth Observation: case studies).

Importantly, most of the outcomes of CMIN19 contracts are contingent upon a sufficient level of funding in the future, to ensure that the UK maintains its level of involvement in the development of the various missions, and to guarantee that these missions are launched and operational.

3.5.1 ESA-added value

For CMIN19 contractors

The broad consensus among consultees was that UK investments in EO are particularly fruitful because they are channelled through ESA. Indeed, the large majority of contractors highlighted that it provided them with access to ESA's considerable network, technical expertise (including in niche domains), synergies and complex mission project management capabilities, which UK stakeholders learn from. While UK industry has become highly capable through its past involvement with ESA, those involved in complex missions like TRUTHS explained they still require ESA's technical and project management support, on top of its crucial financial resources.

Various stakeholders explained that ESA funding is particularly attractive due to the scope of the contracts and the number of funding opportunities offered by the Agency, which notably enable SMEs to compete. ESA's role in promoting international collaboration was also described as critical by many contractors. Some notably explained that they had access to much more prestigious partners through CMIN19 contracts (e.g. World Bank, NASA, Asian Development Bank). A UK executive agency reported that participating in ESA projects allows it to work with stakeholders around Europe, which is important as there are not many groups in the UK who do its sort of work. Overall, most consultees highlighted that CMIN19 ESA contracts enhanced the UK space sector's global connectedness. From a follow-on perspective, consultees also highlighted that the possibility of doing extension to ESA calls is important, as it enables companies to suggest additional services to those already contracted.

Many stakeholders said that the geo-return mechanism of contracts was ultimately beneficial because it fostered relationships with actors all around Europe, diversifying networks, despite leading to odd consortium structures at times.

Consultees involved in Copernicus missions explained that the UK's participation in ESA's EO programme is critical to enable their contracts. For example, CO2M would have been a difficult mission to participate in without ESA, as a key interviewee was of the view that there is reticence from European industrial partners to involve British actors in consortia due to the UK's exit from the EU. Indeed, consortia would have to find a contingency in case the UK ceases its participation in Copernicus, as it is an EU programme and recurring Sentinel satellites will be EU-led. This challenge was relevant for CO2M specifically and in getting the concept off the ground, but not for the bigger picture going forward, interviewees noted.

Most consultees reported that there was a lack of funding sources that could constitute an alternative to ESA contracts, meaning the contracts would not take place without CMIN19 funding. They explained that existing national UK funding was too limited in scope and resources (i.e. funding level and technical support), precluding the level of ambition and means necessary to achieve the benefits entailed by ESA contracts. Additionally, private capital was explained to be difficult to secure because of the relatively long timeframe for returns (often ~10 years if starting at low TRL) and the risky nature of low TRL R&D. ESA contracts providing 100% of funding for research organisations' projects was a considerable enabler in the projects taking place and the realisation of the benefits because not a lot of funders invest in the development part of R&D with ESA's level of funding and focus. ESA's vision was also described as an enabler for projects. Nevertheless, a minority of consultees highlight that they could have found alternative funding for their activities, but the focus might have been on something different than their ESA contract.

When some benefits would still be realised without CMIN19 funding, their scale would be significantly smaller. For example, some stakeholders explained that they could potentially still access ESA mission data, but they would be much less knowledgeable and capable in how the data is produced and the intricacies of it. Overall, relevant end-users would be less informed about the potential of EO without UK participation in ESA. This was noted as particularly relevant for decision-makers (e.g. World Bank, Government, Asian Development Bank). A few stakeholders also explained that commercialisation impacts could still occur when they possessed existing clients (e.g. existing commercial activity in the US), but the market size would be significantly limited without ESA funding the mission they participate in.

Regarding wider benefits, CMIN19 contracts outputs, outcomes and impacts may not all be ground-breaking in isolation, but they could catalyse wider, much more significant changes and benefits. Each ESA EO missions is part of a larger ecosystem of missions, and many complement each other (e.g. the high priority Sentinel Expansion missions (e.g. CO2M) to the other Sentinel missions, HydroGNSS to Earth Explorer missions, TRUTHS to calibrate other satellites' data). This creates synergies that are particularly helpful in driving long-term change. Therefore, environmental, productivity and health/welfare benefits could occur without ESA EO contracts, but the CMIN19-funded activities are significantly helpful in securing these long-term benefits.

For the UK

As with other ESA programmes evaluated, the UK's investment in ESA's EO programme is critical to the UK achieving its objectives for space, as the ambition and means necessary to achieve them are only reachable with the synergies offered through the country's participation in ESA. This has been emphasised throughout the report, which consistently showed that CMIN19 contract outputs, outcomes and impacts feed into the NSS' key pillars to achieving the UK's five goals for space.

One interviewee notably indicated that ESA input would be difficult to replicate, notably in terms of access to expertise around Europe and number of missions. Another reported that participation in ESA does not only help achieve the UK's objectives for space, but also its climate and international development goals. Overall, collaborative programmes, such as ESA's, were explained as essential if the UK and Europe want to compete with the large spacefaring nations like the US, Russia and China.

Consultees highlighted that participation in ESA is essential to achieve UK goals in space but that the UK should be more aggressive in its national activities as well. Various stakeholders explained that the UK's national funding opportunities are currently too limited, precluding synergies (like CNES generates for the French industry and research community). Some highlighted that a national programme parallel to ESA's would be helpful to enhance the competitiveness of UK stakeholders on the market and in winning key roles on flagship ESA missions. This is particularly relevant due to the potential for 'low-cost' missions, in the context of the rise of New Space.

Overall, consultees considered that the UK was well-represented within ESA senior leadership. They also reported that this ensured that the country's strategic goals for space and its space sector's capabilities and needs were reflected in ESA's strategy and planning. Overall, a large majority of survey respondents agreed that the UK's participation in ESA enhanced the country's ability to influence the global regulatory environment regarding space and assured the UK's access to space.

Reduced or withdrawn participation in ESA's EO programme

If the UK were to significantly reduce, or cease its participation in ESA's EO programme, most consultees reported that they would experience stunted growth, major downsizing and/or jeopardised survival. This would particularly affect SMEs and smaller organisations, as ESA funding often constitutes a bigger share of their activity and revenue. This would lead to numerous layoffs, missed opportunities and a loss of leadership in EO, for the UK in general, UK industry, and the UK scientific community, within ESA and internationally. The country would also lose out on the significant opportunities for international collaboration it has access to through ESA. The UK was described as not having enough resources, expertise, and human capital to match ESA consortia and project management (driving and procuring space missions) by some stakeholders. The country was also reported by one interviewee as not being attractive enough for space giants to seek a deep bilateral partnerships (e.g. NASA-UKSA). Stakeholders also explained that the UK's non-participation in ESA's EO programme would be particularly negative symbolically, thus affecting the country's reputation.

A large UK contractor argued that EO would be very limited in the UK without the country's participation in the ESA programme, notably explaining that activities would be confined to university laboratories, with perhaps a little work with the US on heliophysics. Another contractor reported that bilateral partnerships would have to be focused and targeted, and would be spread very thin. This would force the UK to drop out of certain domains, as it would not have the resources to maintain the current level of activity on its own.

Some companies explained that they would survive and grow without UK participation in ESA's EO programme, but they would not be involved in geospatial work anymore and would not develop cutting-edge capabilities in AI, big datasets and operationalising models, which are very specific skillset that come directly from working with ESA. Multinationals were also expected to shift their operations to mainland Europe, leading to economic losses for the UK.

It was widely reported that this scenario would result in the UK losing its leadership in EO, which would subsequently be very challenging to get back.

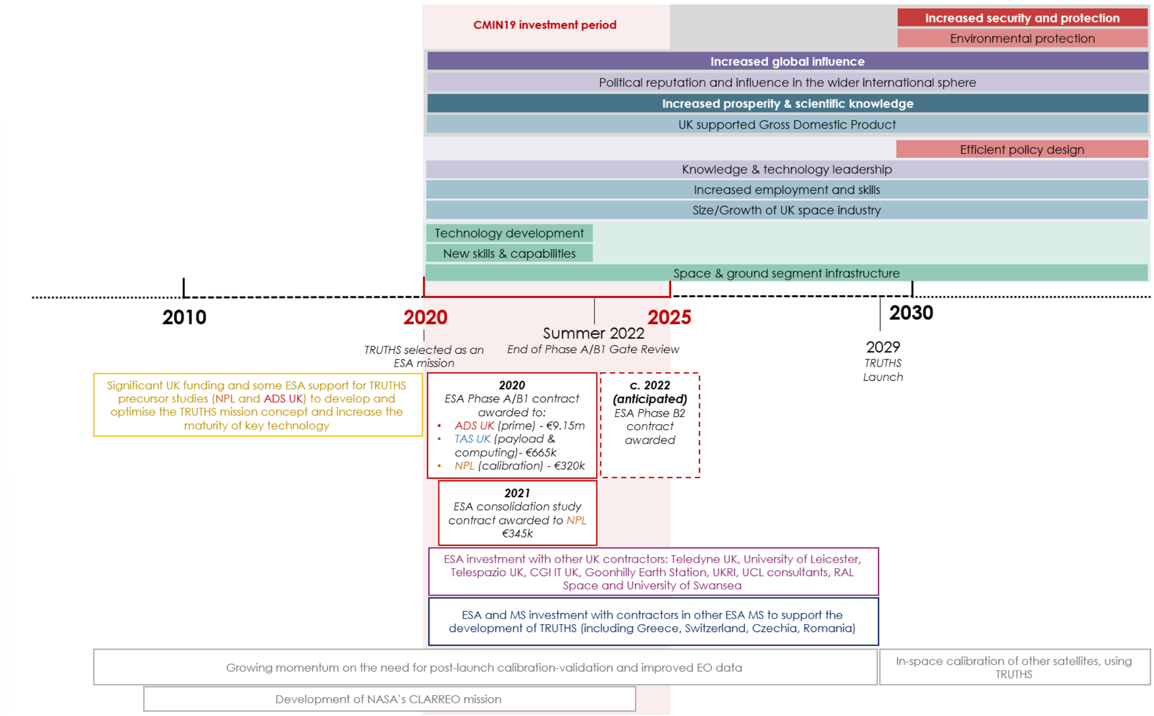
4 Earth Observation: case studies

4.1 TRUTHS mission

Title	TRUTHS (Traceable Radiometry Underpinning Terrestrial and Helio Studies)
Summary	TRUTHS (Traceable Radiometry Underpinning Terrestrial and Helio Studies) is a UK-led mission which aims to create a space-based climate and calibration observatory. It will collect measurements of the Sun radiation and the sunlight reflected off Earth's surface traced to an absolute metrological reference, which will subsequently be used to calibrate the observations of other satellites. Selected as an ESA mission at CMIN19, TRUTHS is currently in feasibility and preliminary phases. The funding awarded to date has already led to benefits, which are expected to grow exponentially as the mission is implemented. Chief among them is the development of new skills and capabilities for the UK in advanced optical technology and design and mission project management. Activities around TRUTHS have also attracted talent to the industry, created new jobs, and strengthened networks and relationships with key stakeholders. Overall, UK leadership in TRUTHS is enhancing the country's international visibility, credibility, and competitiveness. Once the mission is operational, TRUTHS will improve EO data from other EO satellites, enhancing confidence, and ultimately resulting in better science, forecasts and policies around climate change. This is critical in reaching Net Zero targets and will help the UK become the home of trusted climate data and services. Wide-ranging stakeholders are expected to benefit from better and more fit for purpose EO data, from actors in the nuclear and defence industries to those in the insurance sector. The mission, and the associated impacts, would not have occurred without ESA funding.
Type of impact	Main: • Technology development • New skills & capabilities • Space & ground segment infrastructure • Knowledge & technology leadership • Size/growth of UK space industry • Increased employment & skills • Effective policy design Other: • Networks, visibility & roles within ESA • Technology transfers • Political leadership in ESA • International leverage • Increased knowledge & innovation • Supply of products and services (indirectly, through calibration of other satellites) • Commercial & consumer benefits • Knowledge spillovers • Efficient service delivery
ESA contractor(s)	Prime contractor: Airbus UK, NPL Sub-contractors (in the UK): NPL, TAS UK
ESA contracts	Awarded to Airbus UK (as prime contractor): • Phase A/B1 (system Feasibility Studies and Pre-Developments), €9.15m (2020) Awarded to NPL: • (as prime contractor) TRUTHS mission accompanying consolidation study (2021)

	• (as sub-contractor) Phase A/B1 (2020) Awarded to TAS UK (as sub-contractor): • Phase A/B1, €665k (2020)
Complementary activities	Work around the concept and elements of TRUTHS was funded before its mission selection at CMIN19, notably through CEOI and ESA grants. For its hyperspectral sensing activities, Airbus UK reported linking up its ESA TRUTHS developments, UK defence-funded activities, and its internal investment for the development with UK partners of an airborne demonstrator. TAS UK is trying to align its internal investment with that of UKSA and ESA to create synergies.

Timeline of the TRUTHS CMIN19 impacts



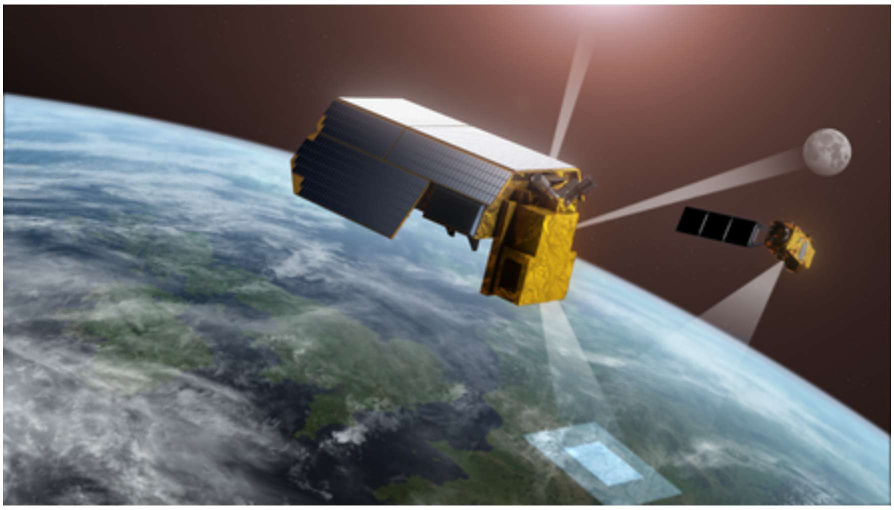
Activities

TRUTHS (Traceable Radiometry Underpinning Terrestrial and Helio Studies) is a UK -led mission which aims to create a space-based climate and calibration observatory. Its objectives are as follow:

- Collect measurements of the Sun radiation and the sunlight reflected off Earth's surface traced to an absolute metrological reference, enhancing our ability to estimate the Earth radiation budget (and attribution) and enabling climate benchmarking;
- Create a metrology laboratory in space to establish a fiducial reference dataset to cross-calibrate other sensors, improving the quality of their data, anchored to a primary SI (International System of Units) reference in space; and
- Collect SI-traceable measurements of the solar spectrum, to address direct science questions and climate.

TRUTHS will carry 2 instruments (the Cryogenic Solar Absolute Radiometer (CSAR) and the Hyperspectral Imaging Spectrometer (HIS)) and will fly in a circular polar orbit, with a 61 days repeat cycle.

TRUTHS satellite



Source: ESA

This ESA mission builds on 20 years of nationally-funded industrial and localised studies. Biases and uncertainties in satellite measurements of the Earth and the Sun have been recognised early on, and have been contributing factors in EO data not being used as widely as it could be and not being fully embedded within systems. While work on improving pre-flight calibration had been undertaken in collaboration with the US, a gap remained, as ground calibration degrades over time. This emphasised the need for post-launch cal-val. While NPL-conceived TRUTHS was not initially successful at securing ESA funding (e.g. ESA's 2009 EE8 call), its concept opened a dialogue on better quality data and cal-val, raising the project's visibility and credibility in the sector. In parallel, climate change gradually became a front-and-centre challenge, on top of the agenda at every level of governance.

This contributed to the inception of the US-led CLARREO Pathfinder mission, which aimed to become a calibration reference for climate. It secured initial NASA investment, including for the development of demonstrators onboard the ISS (due in 2023/24). This helped build momentum in the international community, showcasing the scientific benefit of better data and cal-val. This put NPL and Airbus UK in a position to secure support through the CEOI programme and funding from ESA to optimise and simplify the TRUTHS mission concept and increase the maturity of the key technology to TRL5/6. Mission integration and the ground segment were also studied and costed, enabling the mission to be considered mature. Ultimately, the decades of previous work have de-risked phase A/B1 and thus, helped pass CMIN19, where TRUTHS was selected as an ESA mission (with 85% UK funding). Seen as able to provide an interoperable and harmonious solution, TRUTHS' uniqueness is noted as having helped it stand out at CMIN19.

Many UK stakeholders are (or will be) involved in TRUTHS. This includes:

- Ground segment: CGI IT UK and Telespazio UK
- Payload: Airbus UK , TAS UK , and Teledyne e2v
- Computing: TAS UK
- Calibration: RAL Space and NPL

Goonhilly Satellite Earth Station is also tasked with delivering on skills and capability development and outreach.

Airbus UK was awarded and primes a €9.15m (2020) contract to conduct the preliminary phases of TRUTHS, i.e. phase A/B1. The purpose of these activities is to conduct pre-development on key engineering parts and determine whether the mission is feasible, affordable and whether it will deliver its intended scientific objectives. TAS UK and NPL were also awarded contracts in 2020 to contribute to phase A/B1. NPL also primes a 2021 contract to provide direct consultancy on the mission to ESA, mainly regarding cal-val principles. Overall, phase A/B1 helps inform decision-makers on whether subsequent phases should be funded and how to implement them. Airbus UK is thus expected to have the mission fully designed and concept-proven by the end of this contract in July 2022, providing a realistic cost budget and ensuring all technologies have reached TRL 5 or above, making TRUTHS ready for implementation.

As of November 2021, phase A (i.e. mission feasibility) has been completed and passed the Preliminary Requirements Review. This means that the complexity of the mission is now fully understood, the mission concept is selected, and instruments and systems have been revised or consolidated.

Phase B1 will consist in final requirements for consolidation, the start of detailed design and analysis, hardware pre-developments, and the implementation of algorithms and code simulators. Phase B1 is expected to be delivered in July 2022, where a decision ('Gate Review') will be made on whether the mission is consistent with a good value for money to be further advanced, ahead of CMIN22 in November 2022. If the mission is green-lighted, funding to build TRUTHS will be determined at CMIN22 and the launch (anticipated for 2029 onboard Vega-C) will be funded at subsequent Ministerial (CMIN25). The mission is expected to be operational 3 to 6 months after launch and generate data by 2031.

Impact

As highlighted during consultations with Airbus UK, TAS UK, NPL, UKSA and ESA stakeholders, the activities from phase A/B1 contracts, funded since 2020, are already having positive impacts (though the full realisation of the benefits from the mission will only be realised in the long-term, once it is launched and operational).

For contractors

- Stakeholders are building new skills and technical capabilities in advanced optical technology and design, core areas of the mission, which are relatively new to the UK. Airbus UK is notably transferring capabilities to the UK from its centres of competence in Germany and France, TAS UK is doing the same from its French subsidiary. Intra-UK transfers are also occurring, notably between TAS UK and NPL. Overall, the development of new UK capabilities will help build the high-value components of TRUTHS on UK soil. It could also help UK stakeholders better position themselves to secure future opportunities in EO and advanced optical technology-related work due to their unmatched expertise on the mission. This competitive advantage would be valuable both for the exploitation of mission data and in the development of missions and concepts using data or calibrations from TRUTHS (which are anticipated to be channelled through UK 'big data' digital infrastructure, and are likely to be numerous in the age of New Space).
- Knowledge and technology transfers are also occurring from the defence sector to space. Indeed, Airbus UK is using skills and capabilities developed through its defence activities (linked to internal investments) in TRUTHS. This is notably the case of the hyperspectral imager, which Airbus UK aims to use on high altitude platforms for the first time through the mission. Using an important UK-developed defence-sector technology in TRUTHS will lead to capability development for Airbus UK, which is important for sustaining its competitiveness across sectors.
- As the programme is entirely run from the UK, stakeholders are also gaining project management skills through their involvement in TRUTHS. Airbus UK secured a leadership and coordination role, noting that it is facing much bigger management challenges at an early stage than a prime contractor would in a typical ESA mission. As TRUTHS is not a conventionally-developed mission, there was the expectation that the bulk of the work would be undertaken by UK stakeholders. Airbus UK thus had to match industry capabilities to the various development activities, which proved complex due to the relative fragility of UK supply chains. Airbus UK, and industry in general, have been learning considerably from ESA's processes to delivering a space mission, meaning ESA is central for the development of capability in industry in terms of project management.
- Overall, this upskilling has led/will lead to the creation of jobs, especially around key engineering positions. As of November 2021, Airbus UK was seeking between 5 and 10 optical architects and engineers, which was explained to be a significant number considering the skills and experience required in the applicants. The mission's skills and capability development benefits are also helping stakeholders sustain employment, notably for TAS UK. Airbus UK expects the total number of positions that will be supported by TRUTHS, through to its completion, to be in the order of at least 100 FTE. This includes staff involved in various phases of the mission, from engineering and procurement, to manufacturing, assembly and testing. This may result in significant economic benefits, as space sector workers tend to be highly skilled and productive (2.6 times more productive than the UK average, as noted in the know.space Size and Health of the UK Space Industry 2020 report).
- CMIN19 contracts notably helped strengthen the relationship between Airbus UK and its partners and suppliers. They also led TAS UK to grow its links with NPL, connect with more specialist companies, and create a partnership with Switzerland's PMOD/WRC (Physical Meteorological Observatory in Davos/World Radiation Centre). NPL was also able to build partnerships across the board and work with many different companies and organisations internationally through its TRUTHS participation, including since 2020. This may result in future collaborations for UK stakeholders and enhances the visibility of UK expertise and activities, both in Europe and internationally.

- While reputational benefits will depend on whether TRUTHS is successful once implemented and operational, some impact is already visible in terms of credibility and exposure. Leadership and involvement in TRUTHS was reported as being beneficial to Airbus UK and TAS UK 's image, both in the UK and internationally, reinforcing the 'ESA stamp of approval' they benefit from.

For the UK space industry

- Established skills (e.g. electrical, electronics, thermal, mechanical, radio-frequency engineering, functional avionics) are being strengthened, with TRUTHS galvanising the numerous pockets of EO expertise existing in the UK. Reinforcing these skills is critical for UK stakeholders to sustain their capability and remain at the forefront of EO and space more generally, as they are key to scientific, operational, commercial and export missions across all applications.
- Activities around TRUTHS have led to investments in training younger individuals with STEM degrees and geographers, with a particular emphasis on engineers to build a long-lasting UK optical instrument capability. This is expected by various industry stakeholders to result in this highly-skilled and trained workforce staying in the space sector. The exciting and high-profile nature of TRUTHS is also likely to attract talent to the industry, which we were informed is particularly needed to avoid a skills gap following the retirement wave of UK EO workers trained around ERS-1. Overall, TRUTHS was described to us as providing a "sense of purpose" in the country around EO.

For UK government

The work around TRUTHS before and since 2020 has also been important in network and relationship development, enhancing the UK's reputation and visibility.

- The work undertaken around mission selection and phase A/B1 for TRUTHS has led to significant collaboration between UKSA, ESA, ESA Member States space agencies and delegations at PB-EO (e.g. with mission funders like Greece, Switzerland, Romania and the Czech Republic, and others like France and Germany), reinforcing the working relationship between these actors and UK visibility within ESA. UK proactive leadership in TRUTHS' mission selection and development enabled the country to steer EO at ESA towards national priorities, enhancing its leverage in ESA. UKSA also highlighted that these activities enabled discussions with new Member States and helped build relationships with non-EU ESA members, particularly relevant in the context of the UK's exit from the EU.
- There is also an acknowledgement, notably by US and Chinese stakeholders, that the UK is leading in the vision for traceable, high accuracy climate data, and constitutes a centre of excellence for these capabilities. Overall, the UK's leadership in TRUTHS increases the country's visibility and credibility, as it is seen as capable of delivering a complex and high-profile ESA mission from the beginning to the end. In turn, this may inspire UK stakeholders to further propose and lead missions, contributing to building up the country's leadership in space and at ESA.

For wider society

A major impact expected to be achieved from TRUTHS, which the activities since CMIN19 have brought us closer to, is the improvement of science, forecasts, and policies around climate change.

- TRUTHS will not only measure incoming and outgoing solar radiation between Earth and the Sun, but will also provide a point of reference and enable the cross-comparison and calibration of other EO satellites' measurements from space. It will, for the first time, enable high-accuracy traceability of climate data in accordance with the International System of Units, creating a space-based top of the atmosphere climate observation system. These features have led NPL scientists to refer to TRUTHS as a 'standards laboratory in space', which will make a significant contribution to reaching the UK 's objective of becoming the home of trusted climate data and services.
- TRUTHS will therefore improve confidence in EO data across the board by greatly reducing uncertainty, meaning EO data will be more fit for purpose and better exploited. Wide-ranging stakeholders are expected to benefit from improved EO data, including beyond the space sector. For example, insurance sector actors will be able to maker better risk decisions. The defence and nuclear industries are also notable examples of sectors that could benefit from TRUTHS-enabled improved data. Governments will also be able to monitor the effectiveness of their climate change strategies, resulting in better policy-making, as the mission will provide a baseline through which climate change can be detected. TRUTHS will thus be an anchor of the global monitoring system for climate change, hence its important expected contribution in reaching Net Zero objectives, notably in the UK .
- Overall, the improvements in science, forecasting, and policy-making around climate change enabled by TRUTHS will lead to environmental, health and welfare, productivity, public service efficiency, and security and resilience benefits, mainly through better prevention and mitigation of climate change. NPL highlights that the mission, its outputs and its outcomes will also result in considerable cost savings for stakeholders across the board, as the cost of not having a TRUTHS-equivalent infrastructure reaches the trillions of pounds.

Additionality and ESA-added value

TRUTHS and the achieved and expected impacts outlined above would not have happened without ESA funding, as the capabilities needed for such a mission are not easily established and would not have been brought to the UK without the very high level of ambition that ESA funding enables. This is valid for CMIN19 funding, but also for ESA investments in previous years, which have helped build UK capabilities and ambition in the industry and scientific community.

ESA funding since 2020 also helps UK stakeholders to maintain and enhance their leadership in wide-ranging space and EO-related areas, which they could lose without TRUTHS-related work. This was notably reported by NPL, a leader in cal-val, who explained that beyond stunting its growth, not working on the mission would actually lead to a decrease in its size. This was noted as leaving an open door for countries like Australia to seize this leadership, as they are also working on such capabilities.

An exclusively nationally-funded TRUTHS mission may not be possible, as UKSA does not have the capability for procuring and driving space missions to match ESA's. The UK Ministry of Defence was seen as perhaps being the best alternative, albeit still far from being a substitute for ESA. While UK industry has built capability from working with ESA through various missions, notably around the Agency's processes for delivering space missions and ensuring the reliability of space infrastructure, it is still arguably not able to build the most demanding satellites (like TRUTHS) without ESA's support (processes, technical, and financial).

Overall, the implementation of TRUTHS and the realisation of the expected impacts are contingent on the outcome of the go/no-go decision milestone in July 2022, and the subsequent level of funding awarded at CMIN22.

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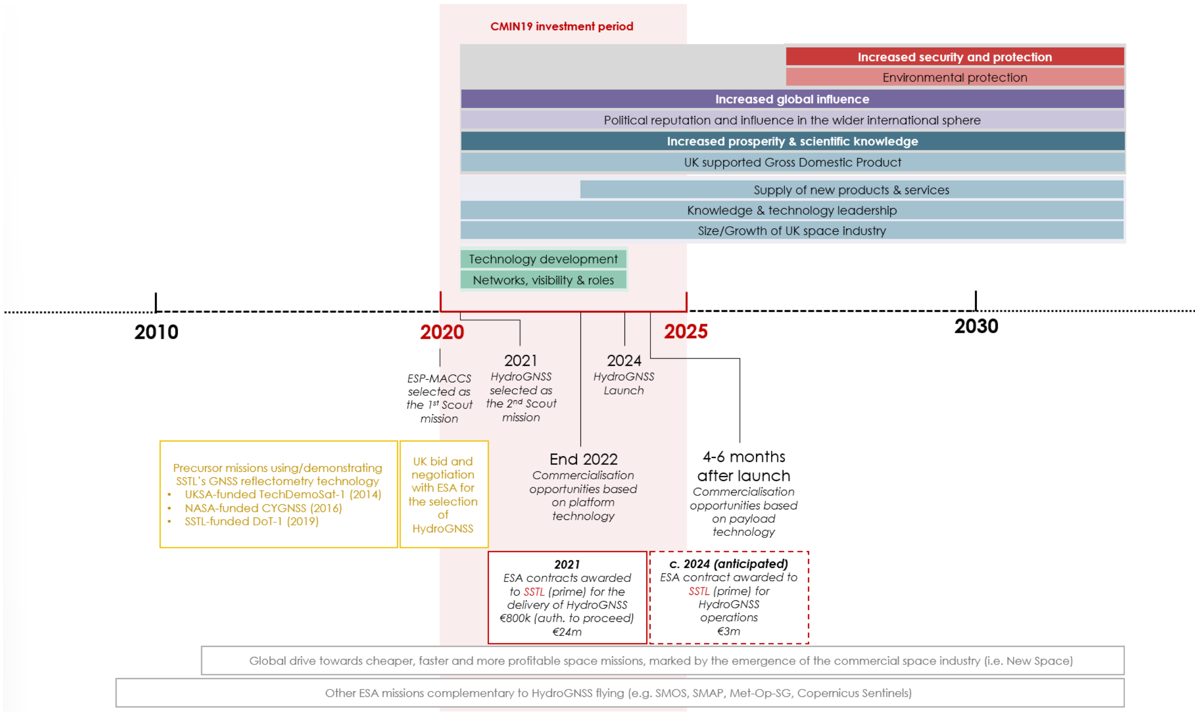
4.2 HydroGNSS mission

Title	**HydroGNSS**
Summary	HydroGNSS is part of ESA's new Scout missions, which pioneer new approaches and techniques for delivering useful and credible science, faster (~4 years) and cheaper (max. €30m) than in 'standard' ESA missions. New to CMIN19, this type of mission embraces the concept of New Space. HydroGNSS will complement Earth Explorer research missions by providing more frequent and precise measurements of key hydrological climate variables. This will enhance our understanding of climate change, resulting in significant environmental benefits. Building off UK industry's work in GNSS reflectometry, HydroGNSS marks the first time commercial technology and electronics can be used in an ESA mission. The success of the mission's approach will inform the future of space development at ESA. The road to HydroGNSS's mission selection is a demonstration of UK technological leadership and influence within ESA. Activities funded by CMIN19 contracts are expected to lead to closer ties between UK stakeholders and the Agency, new collaborations and follow-on missions, and the commercialisation of elements of the payload and platform. Overall, follow-on revenues from HydroGNSS are anticipated to reach the tens of millions of euros.
Type of impact	Main: • Networks, visibility & roles within ESA • Technology development • Knowledge & technology leadership • Size/growth of UK space industry • Supply of products and services Other: • New skills and capabilities • Technology transfer • Political leadership in ESA • International leverage • Increased employment & skills • Increase knowledge & innovation • Commercial & consumer benefits • Knowledge spillovers
ESA contractor(s)	Prime contractor: SSTL Sub-contractors (UK): NOC, the Nottingham Geospatial Institute
ESA contracts	Awarded to SSTL: • Authorisation to proceed contract, €800k (first half of 2021) • Main contract: €24m (Oct. 2021)
Complementary activities	HydroGNSS complements the SMOS, SMAP, Biomass, Met-Op-SG, and Copernicus Sentinel missions. It also builds on DoT-1 (launched in 2019, UK), NASA CYGNSS (launched in 2016, US), providing new higher latitude capability, and TechDemoSat-1 (launched in 2014, UK)

Timeline of the HydroGNSS CMIN19 impacts



Activities

Building off UK industry's work in GNSS reflectometry, HydroGNSS marks the first time commercial technology and electronics can be used in an ESA mission. The success of the mission's approach will inform the future of space development at ESA.

The mission is new to CMIN19 and is primed by the UK's SSTL, which was awarded a €800k contract in the first half of 2021 that aimed at getting up to speed before the main mission contract was awarded. It consisted in pushing along early technology (notably advancing the TRL of the Advanced Delay Doppler Mapping Receiver (payload) from TRL 2-3 to TRL 5, a pre-requisite for ESA Scout missions) to ensure HydroGNSS is delivered on time.

SSTL was awarded the main mission contract (€24m) in October 2021, which covers activities until 2024, including:

- Building the scientific payload by advancing the TRL of SGR-ReSI-Z (Advanced Delay Doppler Mapping Receiver);
- Designing and manufacturing the platform (main spacecraft, payload data ground segment), using building blocks (i.e. technologies starting at relatively high TRLs, MERRByS service);
- Mission integration;
- Launch procurement;
- Launch (in 2024); and
- Early operations, which should then be followed by a €3m contract for operations.

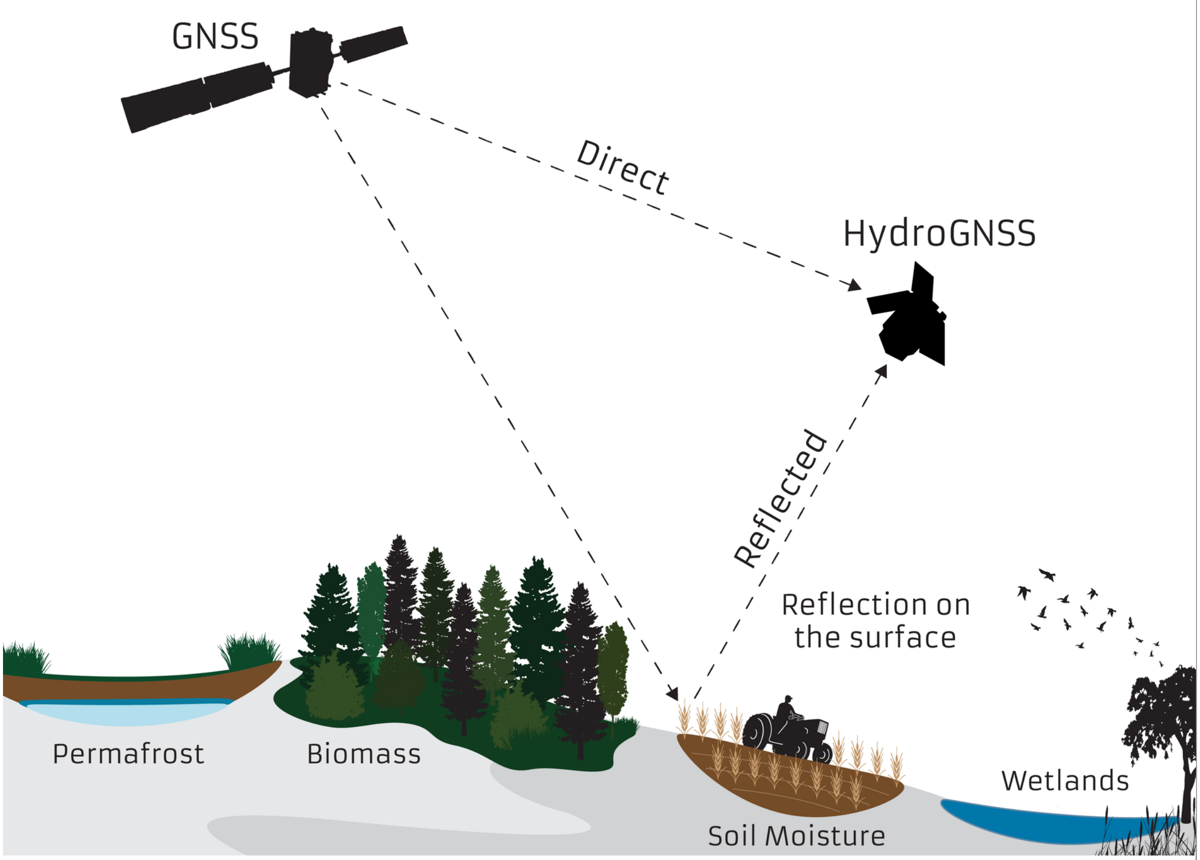
The contract also entails the development of a data delivery framework.

Overall, HydroGNSS will comprise 2 satellites and provide global coverage every 15 days, with more frequency measurements at high latitudes. HydroGNSS will possess unique abilities, notably finer resolution over smooth surfaces, deeper penetration of soil, vegetation and snow, and sensitivity to freeze/thaw at high latitudes. Level 1 and Level 2 data will be disseminated via https://earth.esa.int/eogateway.

SSTL's HydroGNSS work builds on years of experience, data and investment in GNSS reflectometry, and on missions like DoT-1 (launched in 2019, demonstrating avionics), NASA CYGNSS (launched in 2016, carrying SGR-ReSI and demonstrating significant capabilities of GNSS-R for soil moisture and inundation) and

TechDemoSat-1 (launched in 2014 carrying a SGR-ReSI prototype receiver, which demonstrated the feasibility of GNSS-reflectometry for ocean wind sensing, soil moisture, biomass and ice). HydroGNSS will complement other missions, such as SMOS, SMAP, Biomass, Met-Op-SG, and the Copernicus Sentinels.

HydroGNSS concept



Source: ESA

Impact

As the contracts were awarded fairly recently (end of 2021) from funding agreed to at CMIN19, the impacts outlined below are not yet realised, but expected to be achieved in the coming years.

For contractors and the UK space industry

SSTL is developing its capabilities and anticipates many opportunities for commercialisation and/or follow-on contracts from its CMIN19 HydroGNSS contract:

- SSTL anticipates that the mission will help attract talent to the UK space sector, helping build its capabilities. The missions is thus expected to lead to the creation of new jobs (in the tens) over the years until 2024. This will be particularly prevalent on the payload side of the mission, as SSTL's activities are pioneering, requiring specialised engineering. SSTL also expects to develop its capabilities in sensor development and in GNSS reflectometry for science. After launch in 2024, new jobs are anticipated on the data exploitation side in the scientific community. New capabilities on the service provision side are anticipated, as SSTL will have to provide a commercial and science service for HydroGNSS, which is beyond its traditional activities. The short timescale of the mission also enables young engineers to acquire real-flight experience, which is described as a considerable learning opportunity.
- While ESA bought the data of the mission as a service, meaning it will be provided to the scientific community for free, many commercial opportunities and follow-on contracts are anticipated from HydroGNSS activities. The platform elements of the mission (i.e., related to the spacecraft) could be used in future UK national missions, as the innovative work will have been paid for through the HydroGNSS ESA

contracts (from CMIN19 funding). It could also be commercialised for other small ESA missions or sold on the commercial market relatively soon, by the end of 2022.

- On the payload side, the commercialisation of the instruments developed for the mission is highly probable, as they can be used on other institutional and commercial satellites to better monitor essential climate variables. This commercial avenue can only occur after HydroGNSS' launch and early operations, which will demonstrate that the instruments work and thus de-risk them, reassuring the market. Therefore, this type of commercialisation can be expected to begin from 4 to 6 months after mission launch in 2024. The activities undertaken under HydroGNSS and the success of the latter could create the opportunity for several follow-on missions to build a bigger constellation, if ESA adopts SSTL's low mass and low cost approach to L-Band sensing and/or if these small satellites are bought in the commercial market. This would provide measurements of essential climate variables at a much higher frequency (from bimonthly with HydroGNSS to daily with a constellation). Overall, the scale of the follow-on revenue from these follow-on opportunities is estimated to be in the tens of millions of euros.

For UK government

The mission selection and activities around HydroGNSS have and are anticipated to enhance the visibility and influence of the UK and its stakeholders:

- The award of ESA contracts for HydroGNSS is the outcome of significant UK leadership and influence within ESA, and its success is expected to grow the latter. Indeed, after the CubeMAP mission was selected as the first Scout mission, the UK stepped up by complementing the leftover ESA funding dedicated for Scout, securing the selection of UK-led HydroGNSS as a second (and 'bonus') Scout mission. This achievement required advocacy from the UK, navigating strong opinions from other Member States and fostering support from the other delegations at PB-EO. As emphasised by UKSA and ESA stakeholders, the impacts of HydroGNSS would have not been realised without the considerable level of efforts displayed by UKSA and the UK at all levels of governance.
- Negotiations and collaborations in the development of HydroGNSS have also strengthened the relationship between the UK and ESA. SSTL notably highlighted that questions around the use of commercial components on spacecrafts have traditionally been difficult, but that the engineering relationships have been excellent for HydroGNSS, spilling over to positive relationships at management level.
- Stakeholders involved in HydroGNSS also emphasised that the development of the mission will further strengthen networks and relationships, notably due to the close engagement with the scientific community it entails. Future collaborations are anticipated with other European stakeholders on how HydroGNSS's platform and approach are made available. SSTL also expects new collaborations with NASA and other research organisations around the world who are interested in GNSS reflectometry, which SSTL has pioneered, notably through this mission. Participation in the new Scout programme through HydroGNSS provides SSTL with a considerable endorsement from ESA, which further fosters new collaborations.

For wider society

Once completed and operational, HydroGNSS will have significant environmental benefits:

- The mission will provide higher quality data and measurement of key hydrological climate variables (including soil moisture, freeze-thaw state over permafrost, inundation and wetlands, and above-ground biomass).
- The data gathered by HydroGNSS will be provided to ESA as a service, and offered to the scientific community (i.e. end-users) for free, who will then exploit it. This will contribute to enhancing scientific productivity and inform policy-making. The mission's payload is compatible with Galileo and GPS (Global Positioning System), and is reconfigurable in orbit. This flexibility enhances the potential for exploitation by end-users and thus, the environmental, productivity, and policy design benefits.

Additionality and ESA-added value

The work undertaken in HydroGNSS would not have occurred on the same scale without ESA funding, as the UK does not currently support missions of this type. This means that the impacts outlined above would probably have been more limited. SSTL would have still been able to commercialise products and services around GNSS reflectometry, as it has an existing client in the US. However, the market size would have been significantly limited.

SSTL highlighted that now is the right time to leverage ESA investments by developing a parallel national programme to make the UK's industry and scientific community more competitive on the market and in winning flagship roles on valuable parts of ESA missions. This is particularly relevant, given the potential for 'low-cost' missions in various ESA programmes.

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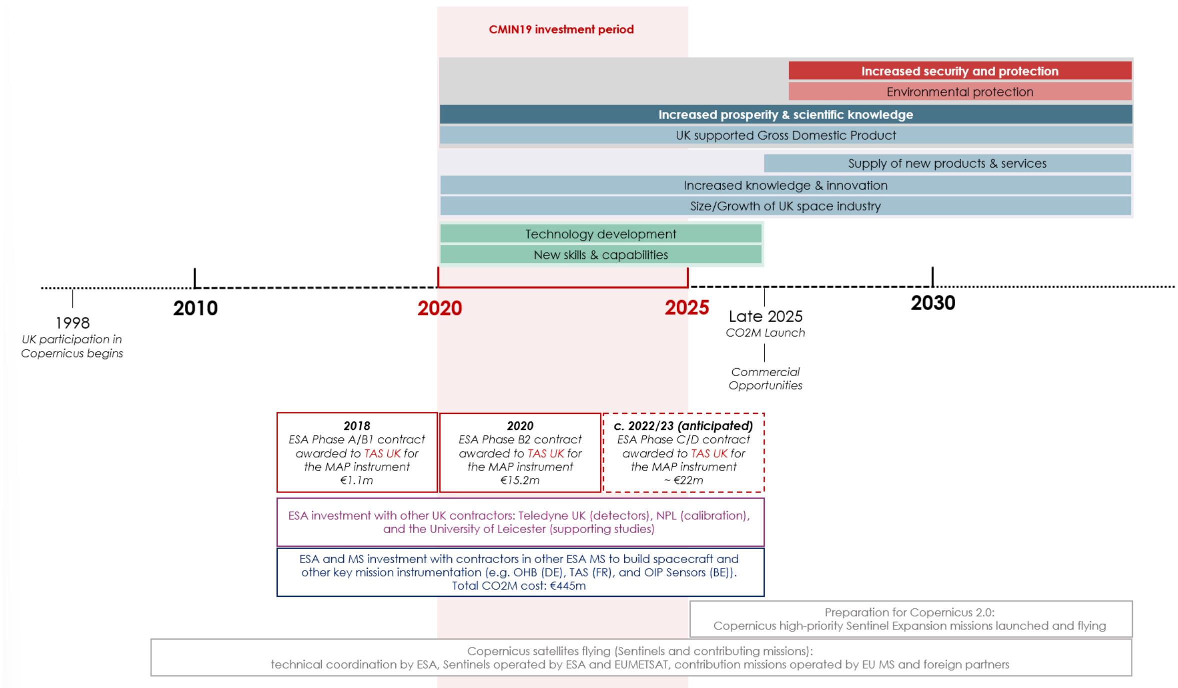
4.3 CO2M mission

Title	CO2M
Summary	CO2M is a high priority mission, part of the Copernicus segment of the EO programme. CMIN19 ESA contracts have been critical for advancing the technology readiness level of the UK-led Multi-Angle Polarimeter instrument, a key part of the mission's payload. They have also fostered internal investment by UK industry (TAS UK), which developed its ground infrastructure through a new optical laboratory in Bristol. Many other outputs have been realised and are expected in the coming years from the activity of UK stakeholders since 2020, such as the retention and creation of jobs, the strengthening and development of new skills, the creation of new collaborations, and the publication of papers. Overall, the CMIN19 ESA contracts brought Europe and the UK closer to better and more reliable data on the causes of anthropogenic climate change, which will be a valuable tool for effective climate policy design. They have also enabled the UK to remain involved in important data discussions, helping consolidate the country's data framework.
Type of impact	Main: • Technology development • New skills & capabilities • Size/growth of UK space industry • Supply of new products and services • Increased knowledge & innovation Other: • Networks, visibility & roles within ESA • Technology transfer • Increased employment & skills • Commercial & consumer benefits • Effective policy design
ESA contractor(s)	Prime contractor: OHB System AG Sub-contractors (in the UK): TAS UK, Teledyne UK Ltd, NPL, University of Leicester
ESA contracts	Awarded to TAS UK Ltd. (sub-contractor): • Contract to develop a satellite instrument for the payload (MAP), €15.2m (2020) Awarded to NPL (sub-contractor): • Calibration services (2020)
Complementary activities	CO2M is part of the European Commission's Copernicus programme. Led by ESA, it is one of the six high-priority Sentinel Expansion missions being developed to prepare for Copernicus 2.0. It will help address EU policy and gaps in Copernicus user needs, expanding the current capabilities of the Copernicus Space Component. TAS UK is lining up various sources of investments. While the ESA contract is very significant and important in itself, TAS UK is also leveraging national and internal investments to fully realise the opportunities created by the ESA mission, i.e. commercialisation. TAS UK mainly obtained national funding through the CEOI and some via the NSIP (National Space Innovation Programme), and together with internal investments, it was used to develop a compact version of the MAP instrument that could then be flown separately on other (dedicated) missions to measure aerosols (discussed below), e.g. through UK national funding.

Timeline of the CO2M CMIN19 impacts



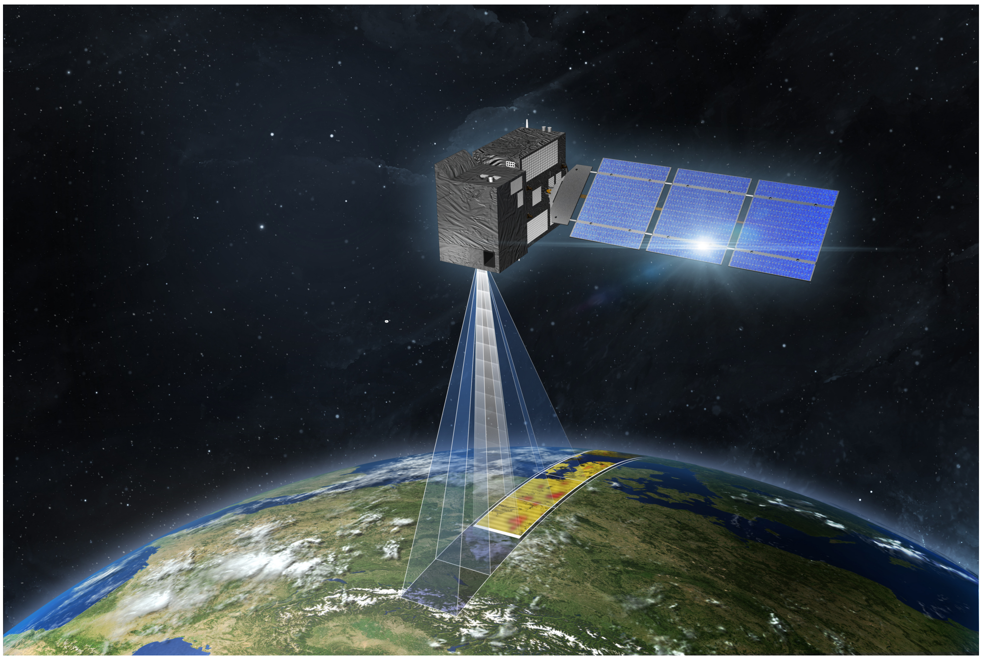
Activities

The prime contractor for CO2M is OHB, with TAS France responsible for the entire payload, which is composed of three instruments: a combined CO_2/NO_2 instrument provided by TAS France, CLIM (cloud imager) provided by OIP sensors in Belgium, and MAP, provided by TAS UK . MAP is a multi-angle (<40 angles) multi spectral (7 bands, 400-900nm) polarimeter, and is based on well-recognised approaches (POLDER, 3MI).

TAS UK received CMIN19 funding (€15.2m) to conduct phase B2 of MAP (up to the system preliminary design review in March 2022). It builds on previous contracts in 2018-2019, which delivered phases A/B1, i.e. feasibility and preliminary definition of MAP. Phases C/D (proto-flight model) funding is expected to amount to ~€22m when awarded later on. Additional models for the second and third flight models (FM2 and FM3) are anticipated to have a value of ~€9m each, assuming the UK continues its participation in the Copernicus programme. NPL also received funding in 2020 to undertake pre-mission calibration, building on its cal-val expertise.

Overall, CO2M is aimed to be launched by the end of 2025, after which it will start measuring atmospheric CO_2 produced by human activity and offering data covering various scales, from the Earth as a whole down to cities. MAP will enable the differentiation of anthropogenic CO_2 from other sources by increasing the retrieval accuracy through its measurements of the aerosol field.

CO2M satellite



Source: ESA

Impact

Consultations with TAS UK, NPL, UKSA and ESA stakeholders highlighted that CMIN19 CO2M activities were setting up a strong basis for impacts, both for the UK space sector and the wider global community.

For the contractor

- CO2M CMIN19 contracts are expected to create commercialisation opportunities for TAS UK in EO, supporting UK GDP:
- While the outputs of the contracts cannot be put on the market as they stand, the technology developed can be used by TAS UK to fly further components, which can then be used to provide services on the market offering measurements to end-users. TAS UK anticipates that this commercialisation and market offering could happen within 4 to 6 years and could lead to million to tens-of-millions of euros in follow-on sales. While the company expects that the benefits will be sustained from market introduction onwards, replacement satellites will need to fly updated instruments every few years (4-6+) due to competition and technological advances.
- TAS UK could build on MAP and its components to sell more equipment, as the instrument measures gas (aerosol density) and thus, has potential for a wider field of application.
- These commercial opportunities are contingent on the completion of the ESA contracts for CO2M, as early operations of the mission will demonstrate that MAP works and thus, de-risk it, making the technology more attractive to the market.

For UK government and the UK space industry

CO2M CMIN19 contracts help increase the UK's global influence and the visibility of its stakeholders in the EO sector. They do so by:

- Strengthening and creating relationships with key parties, notably partners and suppliers. This includes the fostering of new relationships between the UK space sector and Switzerland's Micos Engineering, Italy's Optec, and the reinforcement of the links between TAS UK and Teledyne e2v.
- Enabling the UK to be part of the Copernicus Space Component-4 and, thus to remain involved in all data discussions, which many see as critical considering the significant transformations currently taking place. UKSA explained that UK contracts in the Copernicus element of the EO programme contribute to consolidating UK data infrastructure, which is essential for all data exploitation activities associated to space missions. Conserving free and unrestricted access to Copernicus data for UK academia and the downstream applications industry is also essential, due to its considerably high value and use in EO.

For wider society

CO2M CMIN19 contracts lead to increased policy coordination and policy making (through better data) and thus aids in environmental protection:

- When completed, the MAP instrument is expected to significantly benefit the environment by
- . CMIN19 ESA contracts brought Europe and the UK closer to better and more reliable data on the causes of anthropogenic climate change, which will be a valuable tool for effective climate policy design.

Additionality and ESA-added value

The impacts outlined would not have happened without the ESA contracts since 2020, as there are currently no alternative forms of funding in this area of work, according to TAS UK. Subsequent ESA funding (phase C and beyond) is critical to the full realisation of the anticipated benefits.

Additionally, many stakeholders highlighted the challenges resulting from the uncertainty surrounding the UK 's exit from the EU and the UK 's continuing participation in Copernicus. On the one hand, Copernicus participation by non-EU member states is not without precedent, as Norway and Switzerland are participants. On the other hand, ESA indicated that UK -EU negotiations to secure the UK 's continued involvement in Copernicus were disrupted by negotiations in other domains, and that ESA is reaching a deadline where it will have to go forward without the UK.

In this context, TAS UK indicated that CO2M would have been a difficult mission to participate in without ESA, as there is reticence from European industrial partners to involve British actors in consortia. Indeed, consortia would have to find a contingency in case the UK ceases its participation in Copernicus, as it is an EU programme and recurring Sentinel satellites will be EU-led. TAS UK indicated that this challenge was relevant for CO2M specifically and in getting the concept off the ground, but not for the bigger picture going forward.

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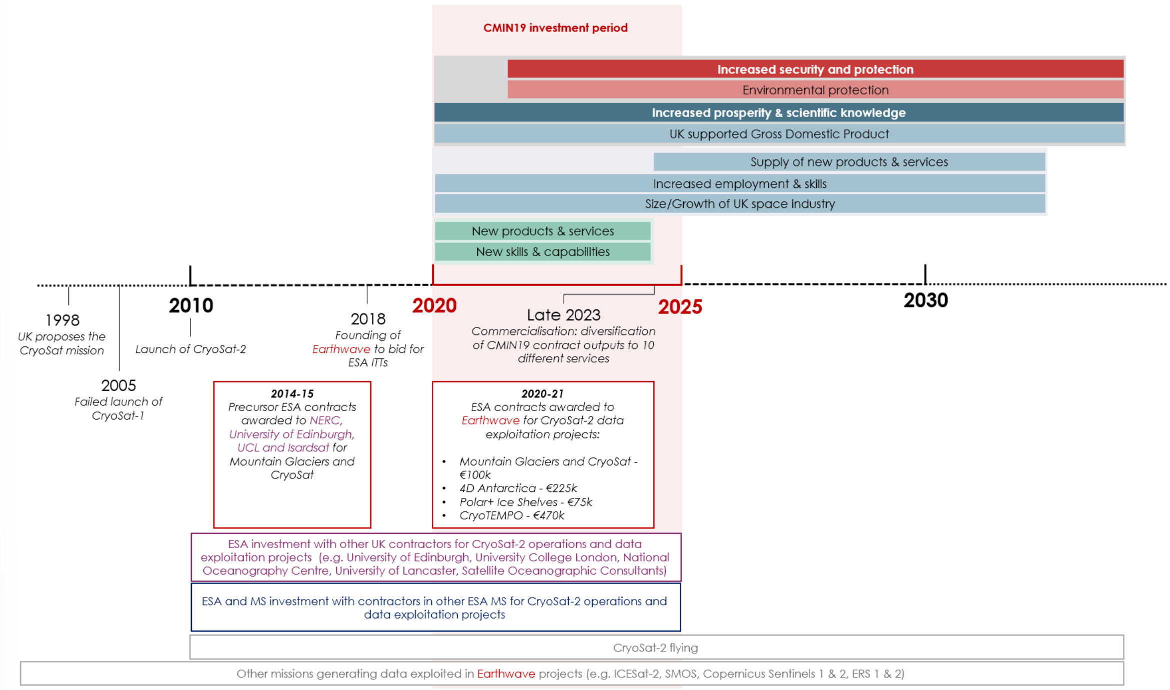
4.4 CryoSat-2 data exploitation projects

Title	**CryoSat-2**
Summary	CryoSat-2 is an ESA environmental research satellite that has been operational since October 2010, generating data on the polar ice caps. CryoSat-2's data has been extensively exploited since 2010 and fed into numerous ESA-funded projects, notably 4 in which the Scottish micro-enterprise Earthwave participated in. Through these CMIN19-funded CryoSat-2 data exploitation projects, Earthwave was able to develop new EO products and services (e.g. tools, datasets, a visualisation platform), build new skills and capabilities, enhance its reputation and credibility, and expand its network. The company's CMIN19-funded activities have made it more competitive in winning follow-on work, funding, and in seizing commercial opportunities. These ESA-funded contracts have also led to the creation of new jobs and scientific publications. Overall, Earthwave's data exploitation projects increase our understanding of the effects of climate change on the cryosphere, which can lead to environmental, policy, and health and welfare benefits. The outputs of the contracts also help increase scientific productivity. These benefits would be considerably limited without CMIN19 ESA funding, and would not have occurred at all without ESA's decades of investments into CryoSat-2. The UK's consistent contribution to ESA's EO programme was key to securing a leading role for UK stakeholders since the inception of the UK-proposed mission in 1998.
Type of impact	Main: • New products & services • New skills & capabilities • Size/growth of UK space industry • Increased employment & skills • Supply of products and services Other: • Institutional partnerships: Institutional • Knowledge & technology leadership • Increased knowledge & innovation • Commercial & consumer benefits • Effective policy design • Efficient service delivery
ESA contractor(s)	For CryoTEMPO: Prime contractor: University of Edinburgh, University of Lancaster Sub-contractors: Earthwave Ltd, University College London, University of Liverpool, Shepherd Space Ltd., isardSAT For Mountain Glaciers and CryoSat: Prime contractor: University of Edinburgh Sub-contractors: Earthwave Ltd., isardSAT For 4D Antarctica: Prime contractor: University of Edinburgh Sub-contractors: Earthwave Ltd. (project manager), University of Lancaster, University of Leeds, British Antarctic Survey (NERC), Shepherd Space, For Polar + Ice Shelves: Prime contractor: University of Leeds Sub-contractors: Earthwave Ltd., University of Edinburgh

ESA contracts	For CryoTEMPO: Awarded to Earthwave Ltd, as a sub-contractor to the University of Edinburgh: - €470k (2021) For Mountain Glaciers and CryoSat: Awarded to Earthwave Ltd, as a sub-contractor to the University of Edinburgh: - €100k (2021) For 4D Antarctica: Awarded to Earthwave Ltd, as a sub-contractor to the University of Edinburgh: - €225k (2020) For Polar + Ice Shelves: Awarded to Earthwave Ltd, as a sub-contractor to the University of Leeds and the Technical University of Denmark: - €75k (2020)
Complementary activities	The CryoSat-2 mission and the numerous data exploitation projects are all complementary in enhancing our understanding of the cryosphere and the effects of climate change on ice caps.

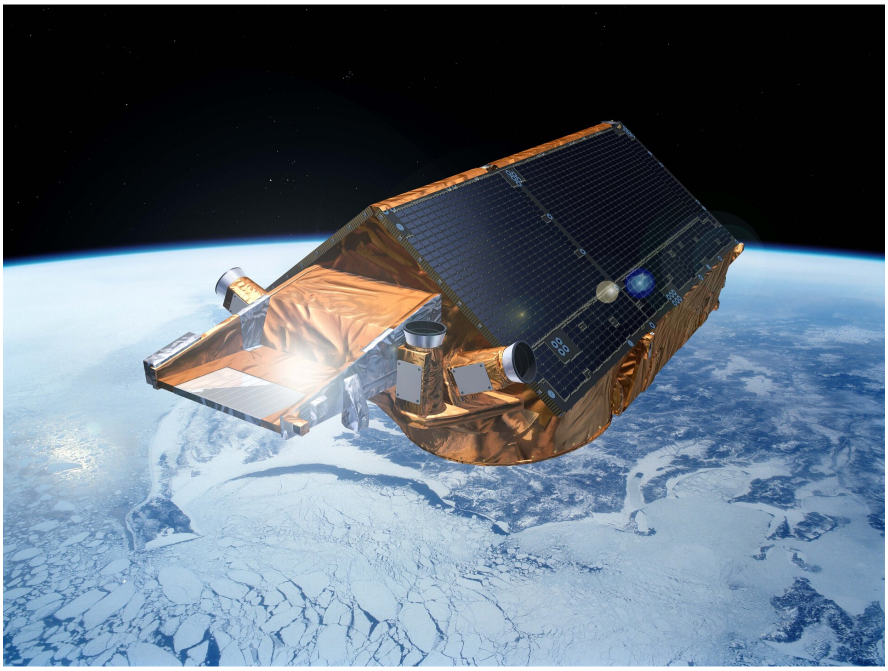
Timeline of the CryoSat-2 data exploitation projects CMIN19 impacts



Activities

CryoSat-2 is a UK-proposed, now operational ESA environmental research satellite that has been operational since October 2010, generating data on the polar ice caps. It measures the thickness of the ice (and thus its volume) and tracks any variation. This sets it apart from previous satellites that could only measure the ice area and ice extent. CryoSat-2's data has been extensively exploited since 2010 and fed into numerous ESA-funded projects.

CryoSat-2 satellite



Source: ESA

Earthwave Ltd., a Scottish-based data analysis micro-enterprise, has received various ESA contracts since 2020 to serve as a sub-contractor on projects exploiting CryoSat-2 data. It was awarded:

- €470k in 2021 for CryoTEMPO, a project which seeks to deliver 2 sets of thematic products, exploiting CryoSat-2's SARIn mode (synthetic aperture radar interferometric) and the novel Swatch processing technique. Overall, these products aim to offer increased spatial and temporal coverage of time-dependent elevation of land ice, which is a critical metric for tracking ice mass trends. CryoTEMPO's outputs will support the wide variety of end-users working in the areas of sea ice, polar oceans, land ice, coastal areas and hydrology. The project is scheduled to run from 2019 to 2022. This work builds on research and development activities undertaken under the CryoTop and CryoTop-Evolution projects.
- €100k in 2020 for Mountain Glaciers and CryoSat. This project aimed to generate swath elevation over the high Mountain Asia and Alaska regions, using data from the CryoSat-2 radar altimeter. Swath elevation was then scientifically exploited to determine the mass balance of the mountain glaciers and their contribution to sea level rise. The project ran from 2019 to 2020.
- €225k in 2020 for 4DANTARCTICA. Earthwave leads a consortium of 12 partners to advance our understanding of the Antarctic Ice Sheet's supra and sub-glacial hydrology, its evolution, and its role within the broader ice sheet and ocean systems. The project is scheduled to run from 2019 to 2022 and will exploit data from CryoSat-2, among other missions (e.g. SMOS, Sentinel 1 & 2, ERS 1&2).
- €75k in 2020 for Polar+ Ice Shelves, a project which aims to produce a suite of datasets to characterise Antarctic ice sheet changes over the last decade and investigate the physical processes driving this evolution. It will notably exploit data from CryoSat-2, among other missions launched in the past 25 years.

Impact

For the contractor & the UK space industry

Significant skills and core capabilities have been developed through Earthwave's work on these CryoSat-2 data exploitation projects such as 4D visualisation, algorithm development and data exploitation:

- This upskilling and capability development is particularly important for the company, as it is young and relatively small. Junior staff have benefited the most from these learning opportunities, building expertise in wide-ranging fields, from cloud technology and big data processing to EO and EO-related technologies. These CMIN19 contracts have also helped strengthen employees' scientific and analytical skillset.

- Earthwave has trained 7 to 8 individuals in UK placements or sponsorships (i.e. interns, PhD students, post-doctoral researcher). This is particularly important, as it contributes to avoiding skills shortages in EO in the UK, and may help keep these highly-educated and -skilled individuals in the space sector. Overall, 4 new jobs were created as of November 2021, with an additional 2 expected to be created by March 2022 and another 2 by early 2023. This means Earthwave's workforce will have grown from 3 to 11 FTE in 4 years.
- Earthwave's work around 4D visualisation is particularly valuable, as it led to entirely new capabilities for the company, which are in high demand from end-users.

Additionally, work on CMIN19 contracts have already helped (and are expected to continue to help) Earthwave secure funding for new projects and build new products and services:

- The core capabilities developed by Earthwave are expected to enable the commercialisation of services to industry. With significant interest for commercial services, Earthwave would diversify its portfolio to meet industry's needs, adapting and expanding its CryoTEMPO products and Mountain Glaciers platform to 10 different services by the end of 2023.
- The enhanced reputation and credibility from its work on ESA contracts will also help Earthwave secure further funding. For example, the company's CryoSat-2 data exploitation activities have led to a follow-on ESA project, i.e. Digital Twin Antarctica, which builds off 4D Antarctica and will help reach decision-makers and the public by facilitating story-telling around the effects of climate change on the cryosphere. 4 to 8 new ESA contracts are also expected in the near future.

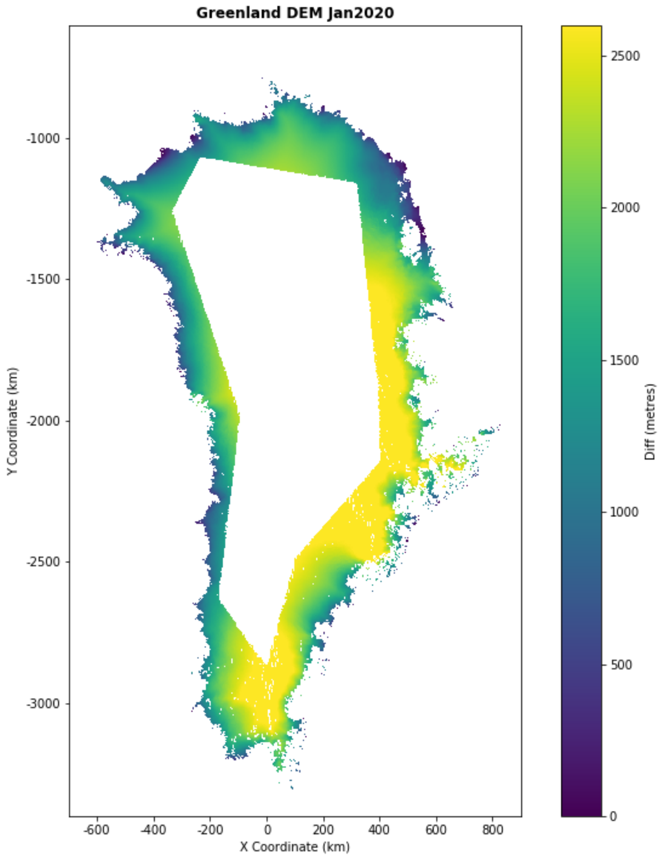
Visibility and relationships are critical for the company's growth. Indeed, Earthwave expects to participate in follow-on work resulting from the significant press attention generated by the Mountain Glaciers and CryoSat project. The CryoSat-2 data exploitation projects have enabled Earthwave to develop its relationship with ESA and with stakeholders across the UK and Europe, including the University of Edinburgh (both with academics and their business development team) and DLR German Aerospace Centre, which the company expects could lead to new collaborations/projects.

For wider society

Earthwave indicated during consultations that its activities on the 4 CryoSat-2 data exploitation projects have led to (or will by the end of 2022) new products and services, mainly for ESA and the scientific community. These, in turn, will increase capabilities in global environmental protection and enhance global policy-making:

- 2 products were developed for CryoTEMPO, including a dense set of elevation measurements for individual observations over and around polar regions, Patagonia, and the Himalayas and a monthly 2km resolution digital elevation model with data sources from a rolling 3 month window. Earthwave has operationalised these products, providing Level 3 data to ESA. Earthwave has also created a webservice for ESA and NASA (Cryo2Ice Coincident Data Explorer), which provides easy access to the data measured when ESA's CryoSat-2 and NASA's ICESat-2 satellites are aligned. This improves the accuracy of sea ice thickness measurements and ice-sheet elevation time series.
- Datasets and a platform on the effects of mountain glaciers' elevation changes on global sea levels.
- Various datasets for 4D Antarctica, notably a dataset composed of ice-sheet wide hydrology and lithospheric products, EO datasets, and ice-sheet and hydrology models.
- A suite of EO datasets to characterise how ice shelves have changed in the past decade for Polar + Ice Shelves.

Example DEM created using Earthwave's CryoTEMPO EOLIS DEM product



Source: ESA (CryoTEMPO-EOLIS project)

- Overall, Earthwave's CMIN19-funded products, services and tools will help acquire a better and more accessible understanding of the changes within the cryosphere and the science that can be done around that, as well as the impacts of climate change on sea level rise. This will, in turn, help climate change prevention and mitigation efforts, leading to better policy-making and increased health and welfare.
- The datasets, algorithms, methodologies, visualisation platform, and tools developed in the context of these projects are also helping the global scientific community be more productive, improving science in this high-stakes and high-priority field. End-users in the US and Canada have already reported that using Earthwave's platforms helped reduce the time it takes to find, acquire, and prepare data for analysis.

Additionality and ESA-added value

- ESA funding is essential to the realisation of the benefits outlined in the previous sections for four reasons:
- First, there are currently no equivalent funding opportunities to these ESA contracts. While grants from national space agencies could have been secured, the scope of the projects would have been significantly narrower, considerably limiting the impacts.
- Second, collaborating with ESA through the contracts enabled Earthwave to access the Agency's expertise and core contacts. ESA notably facilitated the collaboration with the German SME and the interactions with NASA (end user). The Agency provides industry with a wealth of opportunities to bid for, which gave Earthwave a foot in the door and offered it the platform it needed to develop its skills, capabilities, and reputation. Therefore, the company would not be as competitive as it is today in securing follow-on projects and commercial opportunities had it not benefited from ESA's resources.
- Third, Earthwave was created in 2018 to bid for ESA contracts, with most of contract awards occurring in 2020. The company thus heavily relies on ESA to fund its activities, meaning its growth would be

significantly stunted and its survival would be jeopardised if it did not have access to the Agency's funding.

- Fourth, the four projects undertaken by Earthwave rely on data from CryoSat-2. This means that the decades of ESA funding behind the mission have been critical to these data exploitation projects taking place. The decades of UK investments into ESA's EO programme have also been critical to ensure that UK stakeholders secured leading roles in the mission, building skills, capability, and mission expertise in the country.

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5 Telecommunications and Integrated Applications

5.1 ESA's Telecommunication and Integrated Applications programme

The Telecommunication and Integrated Applications (TIA) programme funds contractors in ESA Member States to undertake research and development (R&D) activity to produce leading-edge satellite communications (satcom) products and services[35] that might not otherwise be economically viable. Its emphasis is on developing new space-enabled application and services that benefit not just the space sector, but all areas of the wider economy. It also offers differing levels of support to projects with different levels of operational and commercial maturity. TIA has three components:[36]

- **Core competitiveness**: This centres on the support and development of new or next-generation satcom products and technologies up to their first flight opportunity
- **Partnership projects:** ESA works with satellite operators and manufacturers, co-funding investment in new technologies with them. This component looks to accelerate the introduction of new technologies to the market. Some partnerships are ESA-initiated, while others are initiated by industry (through the TIA Partner programme).
- **Business Applications & Space Solutions (BASS):** this provides funding for the development of applications and services that use the data from satellite infrastructure to improve existing solutions or fill gaps left by terrestrial ones. It has broader remit than satcoms, and additionally includes Earth observation (EO), Global Navigation System Services (GNSS), plus microgravity capabilities (developed jointly with the HRE programme).

The TIA programme also includes business incubation and Tech Transfer activities. Previously invested under the GSTP, this line of activity includes ESA's national and regional network of Business Incubation Centres[37] (ESA BICs), Innovation Brokers and Applications Ambassadors. The BIC supports companies developing space technology and applications.

TIA is also headquartered at ESA's European Centre for Space Applications and Telecommunications (ESCAT) facility, located at the Harwell Campus, Oxfordshire.[38]

5.1.1 *Programme logic model*

Figure 30 below presents the UKSA ESA logic model, tailored for the TIA programme, with the elements not relevant to the programme shaded out. The TIA programme is fairly broad scope supporting projects with a range of different objectives and at different TRLs. However, broadly speaking, TIA projects can be divided into activities pertaining to two areas: satcoms and applications. While the inputs for both activities come from the same source, the expected outputs, outcomes and impacts have potential to be very different.

Satcoms

Supporting satcoms projects via TIA is expected to develop new space-enabled telecoms capabilities for the UK, and new satcoms capabilities within the UK space supply chain. This ultimately leads to the development of new technologies and services that reach market, as well as an improved UK skills base. In turn, this leads to improved commercial performance for

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[35] https://business.esa.int/what-TIA

[36] https://www.esa.int/Applications/Telecommunications_Integrated_Applications/TIA/About_TIA

[37] The BIC is 50% funded by a UK partner, currently STFC.

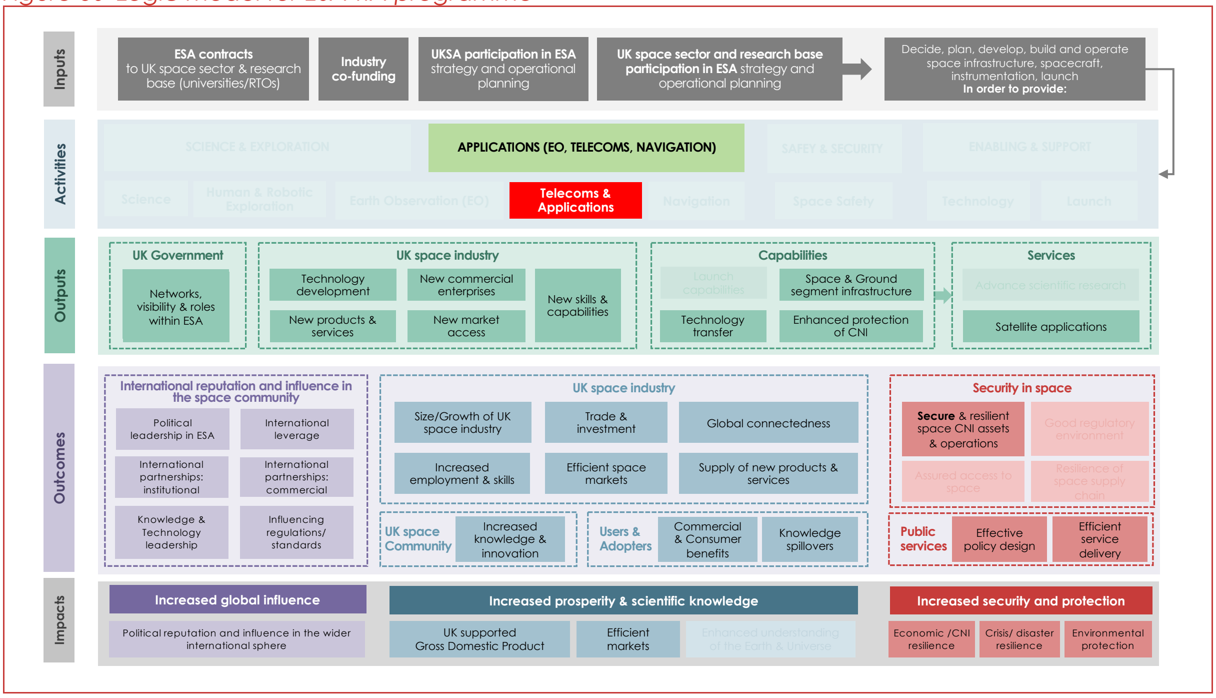
[38] https://www.esa.int/About_Us/Corporate_news/ESA_ECSAT

TIA-supported contractors, and the UK space sector as a whole. The pursuit of technology through ESA promotes UK telecommunications capabilities to a wider international audience than could be achieved through other means. The UK also benefits from having sovereign capabilities in strategically important satcom technologies, while the reputation of the UK space industry also improves given that it is now developing successful ground-breaking technologies. ESA also provides further opportunities due to increased international exposure for UK satcom companies.

Applications

By funding applications projects, TIA aims to support the development and commercialisation of innovative new services which are not directly connected to the space sector, but support both economic growth and the wellbeing of citizens by helping address issues in a wide variety of domains such as healthcare provision, transportation, environmental monitoring, and food production. Not only do the supported contractors benefit commercially, but consumers also benefit from more effective and efficient delivery of services. In some cases, the technologies will also have a direct effect on the efficiency and effectiveness of publics service delivery and policy design (e.g services for monitoring flood plains, delivering healthcare in remote regions). On a longer term scale, this also provides increased security and protection to the UK for example through improve economic resilience, disaster resilience, and environmental protection.

Figure 30 Logic model for ESA TIA programme



Technopolis (2021)

5.2 UK's involvement in TIA

5.2.1 *Background*

Though an optional programme, the UK has historically invested heavily in the TIA programme and through UKSA, contributed c.£765m to the TIA programme between 2008 and 2019, around a quarter of all member state subscriptions. Through this central role in TIA, the UK has been at the forefront of shifting the focus of the TIA programme over time towards more commercially orientated activities and less on flagship ESA missions. The related establishment of ESA's newest facility (ECSAT), at Harwell in Oxfordshire, is an exemplar of the UK's position with TIA and the centre also serves to stimulate further UK involvement in the programme.

The UK is a global leader in satellite telecommunications and in 2018 telecommunications and applications (excluding direct to home broadcasting) made up 40.5% of UK Space revenues.

5.2.2 Objectives

The objectives of UK participation in the TIA programme is to use TIA as a tool to[39]:

- Develop UK space technology & capabilities
- Make the UK the best place to start and grow a space business
- Grow the size and value of the UK space sector

The CMIN19 business case specifies that the UK's involvement in the TIA programme seeks to "sustain a globally competitive telecommunications space sector", and to "support socio-economic aims, for example through the development and adoption of 5G Space technologies and connectivity for all and optical telecommunications". The CMIN19 business case also notes that the TIA programme also contributes to the ESA Space Safety and Security framework, thereby supporting Critical National Infrastructure and Safety and Security from Space.

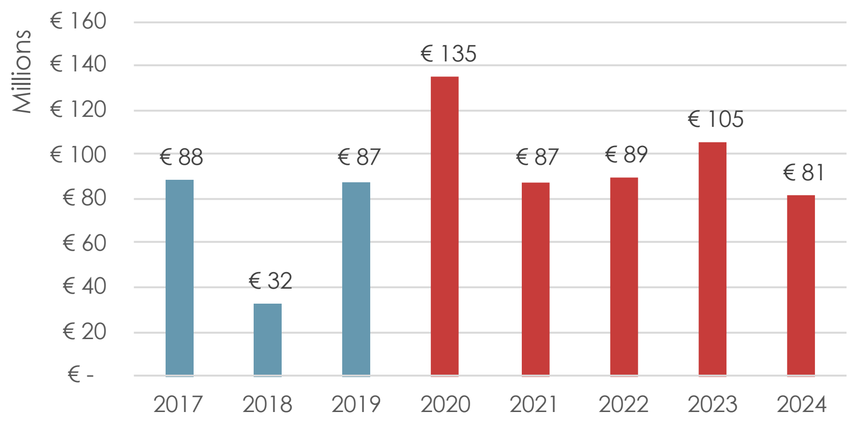
More generally, UKSA also sees TIA as a vehicle to enable a more cohesive space sector with more widespread partnership working. UKSA stakeholders have spoken of concerns of silo working the UK space sector, especially between the positioning, navigation and timing (PNT) industry, and the satcoms industry. There is a hope that the lines of the two will become more blurred as more telecoms payloads are used for locational activity – this is also something that UKSA is looking to further develop via TIA.

5.3 Inputs and activities

As shown in Figure *31*, the UKSA has committed €495 million to TIA over the CMIN19 investment period, an average of €99 million a year. This compares to an average of €69 million over the CMIN16 period, representing an increased financial commitment by UKSA to TIA for the CMIN19 period. As shown, the largest financial commitments come in 2020 and in 2023. The figures represent a higher figure than the agreed commitments at CMIN19 due to the carry over of funds from the previous CMIN agreements, and in some cases where the agreed commitment period extends beyond the more common 3-5 year period. Delays in contract agreements can also result in spending occurring outside the original agreement period.

[39] Technopolis (2019) An evaluation of UKSA funding through the TIA programme.

Figure 31 UK commitments to the TIA 2017-2024



ESA datasheet on national obligations

In practice TIA has more complicated structure, including a number of strategic programme areas, in addition to the three main components listed above. Some of these are of strategic interest to the UK and were clearly identified in the CMIN19 business case. Table 14 presents the 2020-2024 UK commitments to the key TIA activities of interest.

Table 14 UKSA budget commitments to TIA

Programme area	Key UK activities via ESA	Budget (2020-2024)	% of total TIA budget
Space for 5G	. This is a competitive programme that has been developed to support the delivery of cost-effective 5G and 6G solutions that enable the integration of satellite technologies into communication networks. The UK has collaborated with industry by providing resources and opportunities to explore the potential applications of 5G across both space and non-space sectors, as detailed in the UK Government's 5G Strategy. OneWeb's Sunrise programme sits in this line, along with Lacuna's Smart Park trackers, Hisky's Virtual Network Operator (VNO) service, the Darwin autonomous vehicle project and CGI's 5G/6G Hub..	€65m	13%
4S – Safety & Security	The UK is targeting services and technologies that have direct relevance to the UK and European Governmental market, aligning closely with other departments to support the digitisation of Government and ensuring that satcom meets governmental needs and supports CNI). UK's current investments include Inmarsat's Invision programme, Iris and ArQits Quantum Key Distribution Service (QKDSat).	€21m	4%
Optical Telecoms (ScyLight)	TIA support is directed at areas of interest such as Quantum comms, photonics, optical processing and laser downlinks. This is of particular interest to the UK through the Hydron programme (all optical satellite).	€16m	3%
Future Preparation	Horizon scanning, preliminary studies and investigations, emerging sector challenges/opportunities, regulations and standards.	€6m	1%
Core Competitiveness	UK pursues products, services and technologies at higher radio frequencies; service developments in the ground segment; smart manufacturing; technologies that reduce the size weight and	€198m	40%

	power in the space and ground segments; and cross-cutting products and services that directly serve markets such as IoT, mobility.		
Business Applications (BASS)	CMIN19 has a greater focus on themes that matter to the UK, such as infrastructure and healthcare as well as cutting edge technologies such as AI and clean electric vehicles supported by space.	€88m	18%
Partnership Projects	Three key partnership projects for the UK are: • IRIS Phase 3: which uses satellite communication, satellite navigation and security applications to improve efficiency and security in air traffic management operated by Inmarsat. • Oneweb Sunrise programme is seeking to develop its constellation of 700 satellites in low earth orbit for the next generation to keep ahead of the competition. • Quantum Key Distribution Satellite (QKDSat) is a Partnership Project to demonstrate how a space-based infrastructure employing quantum mechanics can help to meet secure communication needs for multiple parties	€101m	20%
TOTAL		**€494.5m**	**100%**

Technopolis (2021): UKSA CMIN19 Business Case, ESA datasheet on national obligations

The majority of UK's funding is allocated via Core Competitiveness (40%), with partnerships and the three strategic areas (5G, 4S and Scylight) each at 20% and applications at 18%.

Over the period 2020 to Q2 2021, UKSA has awarded 161 TIA contracts worth €118 million. As shown in Table 15, UKSA has awarded the vast majority of contracts, both in terms of contract value and the number of contracts to private companies, accounting for 95% of the total contract value, and 56% of the total number of contracts. While educational establishments account for a small proportion of the total contract value, they do account for a large number of contracts, demonstrating that while educational establishments tend to have many small value roles in TIA projects.

Table 15 TIA contracts (to date) breakdown by entity type 2020-Q2 2021

Entity Type	Value of Contracts (M€)	% of total	Number of Contracts	% of total
Company	€112.76	96%	137	85%
Research organization (academic and RTO)	€5.25	4%	24	15%

ESA geo-return datasheet

As demonstrated in Table 16 below, to date, TIA funding has tended to be concentrated within a small number of contractors. Ten contractors account for nearly three quarters of the total TIA contract value, while the top five contractors account for 61%. There is a certain level of diversity however, in these top five contractors. Satixfy and Isotropic are small organisations that have only recently established UK-based operations, while Inmarsat and Airbus are large multinationals with a long-standing presence in the UK space industry. There is also geographic diversity with the top five contractors, with organisations being based in Reading, Portsmouth, Farnborough, London and Glasgow.

Table 16   Top 10 TIA contract recipients by value 2020-Q2 2021

Entity Name	Total Contract Value (M€)	% of total value of TIA funding	Cumulative % total of TIA funding	Number of contracts
SATIXFY SPACE SYSTEMS	€23.40	20%	20%	1
AIRBUS GB (ADS GB)	€14.01	12%	32%	3
ISOTROPIC SYSTEMS	€12.91	11%	43%	1
INMARSAT NAVIGATION VENTURES	€10.14	9%	52%	1
CLYDE SPACE LTD	€9.87	9%	61%	1
CELESTIA TECHNOLOGIES GROUP (UK)	€5.15	4%	65%	1
ASTROSCALE LTD	€2.90	3%	68%	1
NETWORK ACCESS ASSOCIATES	€2.70	2%	70%	1
UK RESEARCH AND INNOVATION	€2.33	2%	72%	3
URA THRUSTERS	€2.12	2%	74%	1

ESA geo-return datasheet

While not necessarily representative of all TIA contractors, survey evidence suggests that a large proportion of TIA contractors are SMEs with 58% of the 38 TIA contractor survey respondents indicating that they had 111 to 250 employees. Theses SMEs include those in the 'upstream' segment part of the space industry (supplier, manufacturers and operators of space infrastructure) and in the 'downstream' applications segment. For applications only, we would expect the proportion of SMEs to be higher, with ESA figures indicating it is closer to 75%.

Interview evidence revealed that there was roughly an even split between contractors that received their first TIA contract during CMIN19, and those that had received TIA funding prior to it. Contractor survey evidence confirmed this with 45% (17) of respondents having secured ESA TIA contracts before 2020. With applications representing a rapidly growing market, it is expected that TIA will continue to extend its reach to new companies and part of the economy that may not have considered space derived solutions in the past. In most cases where contractors had had TIA funding before CMIN19, they had used the subsequent funding to further develop technologies and solutions. Some for instance looked to produce next generation models of their technologies, while others turned to TIA again to find ways to commercialise or scale up their operations.

A study of TIA applications projects which have a UK prime (as listed on the ESA website) show that nearly two-thirds of projects (64%, 38 of 59) have drawn on ESA EO assets while another 20% (12) have utilised satcom assets.

5.4 Outputs

The main outputs to date, highlighted by interviewed contractors, has been technological progress. At a minimum, contractors have spoken of how TIA-funded RDI activity has helped develop knowledge and capabilities needed to further develop their technology or solution. The types of technology developed have varied greatly but range from improved antennas and terminals for satellite devices, the development of algorithms to facilitate use of satellite data, producing constellation services, and developing 3D imaging solutions. The length and start date of contracts has varied greatly but some interviewed contractors spoke of how they had already been able to produce prototypes or demonstrators of their products, and were on course to have a commercial product within 12 to 18 months. Others, such as D-CAT's Fusion Platform and Airbus' OneSat have progressed further still, resulting in products that have reached market and started generating sales.

Survey evidence supports the idea that TIA supported projects have made technological progress. A total of 30 respondents detailed the technology readiness level (TRL) of their project at the start of the ESA contact. The mean TRL at this point was 3.4. Twenty-nine also provided their TRL now, with the mean being 5.3; while 29 also stated their expected TRL at the end of the contract, with the mean being 6.3.

Alongside the technological outputs, there is also evidence of TIA-supported projects having generated outputs in terms of commercial income. As noted above, some interviewed contractors have already generated sales from products and services developed through TIA-funded contracts. In other instances, contractors have generated sales from demonstrators or early iterations of their final product. In all cases where sales have already been generated, contractors expect total sales value to steadily increase further over the next 12 to 18 months. Interviewees were also clear that TIA enabled an acceleration in the technological and commercial progress made, allowing them to achieve sales quicker than they would have done otherwise. Even those who had not yet generated sales, there was confidence that they could achieve sales within the next 12-24 months and in some cases, within the lifetime of the TIA contract. There were a number of cases where contractors anticipated significant commercial impacts, including markets that could be worth hundreds of millions of pounds.

Through our interview programme, we found two cases where the main output generated was process innovation rather than product innovation. In both instances, TIA had helped fund work that looked to facilitate the production scale-up of existing technologies. AAC Clyde for instance, had a contract to improve their capability to deliver constellations at volume, while Aavid Thermacore receiving funding to investigate the use of 3D printing to produce gravity friendly heat pipes for satellites. Both organisations have made good progress in their respective projects – AAC Clyde expects to be able to fly its more efficiently produced constellation installations by 2023, while Aavid Thermacore now they have a commercially viable solution.

Very few of the interviewed TIA contractors, in either satcoms or applications, spoke of having produced any scientific publications as result of their TIA projects. Their priority was instead to bring products to market as quickly as possible. As BASS is a commercially focused programme this is understandable. Nevertheless, there was some interest amongst some contractors to produce scientific publications at a later stage, drawing on their TIA work. While interviewees didn't report any patenting activity from their contracts, the survey evidence includes two patents granted (the only one reported across all ESA programmes). Two interviewed contractors (Aavid Thermacore and Isotropic) are using TIA to further develop technologies and solutions that they had patented prior to their programme involvement.

5.5 Outcomes and impacts

5.5.1 Telecoms

5.5.1.1 Outcomes and impacts for contractors

Most of the direct benefits for contractors themselves have been either commercial or technological, as outlined above. Some, although certainly not all, the interviewed contractors indicated that they planned to take the knowledge gained from their TIA projects into future product lines and RDI activity. For those that did not plan to do so, reasons included wanting to sell the business after the current research had completed, or that it was too early to tell what future products might like.

5.5.1.2 Benefits to the wider UK space sector

Satcom technologies developed via TIA are likely to have a variety of different end-users in the wider space sector including telecom satellite operators, telecom providers, and users of constellation services. These groups are likely to benefit from the technologies developed via TIA. TIA satcoms projects have in the main focused on improving the productivity and efficiency of satcom and telecom activity – mainly by finding ways of lowering the manufacturing costs of satellites, or by improving their operational efficiency. This will help make satellite operations more profitable, either by reducing production costs, or by enabling satellites to handle more data or generate greater output. Some end-users have already benefited from the technological benefits that TIA projects have generated:

- Celestia has developed solutions that enables OneWeb to have cheaper and smaller solutions for receiving multiple satellite signals
- Airbus has already sold its OneSat satellites, which enables customers to change to reconfigure satellite usage in orbit. This is particularly helpful for clients who currently use satellites for live television broadcast, a market that will ultimately diminish with the rise of on-demand television. Satellite operators can now reconfigure their satellites if demand for television broadcast falls, ensuring their satellite does not become obsolete
- Lacuna Space has already launched some of its IoT constellations, providing new data services to end users. It has also produced some open source sensors, enabling other IoT data providers to improve their own systems

For other TIA satcom contractors, it will take another 18 to 24 months for products to reach market and therefore for end users in the space sector to start seeing benefits. Such benefits are likely to include more affordable and timely access to satellite services (e.g. as AAC Clyde Space increases throughput of its constellations, and Aavid Thermacore's gravity friendly heat pipes lowers the running costs of satellite operations), and more stable connectivity to satellites (e.g. through Satixfy's satellite modems, and Isotropic's satellite ground terminals).

Feedback from contractor interviews has shown how telecoms projects have generated wider economic benefits for those beyond the contractor and their immediate supply chain. In two cases, TIA has been an important driver of foreign direct investment (FDI) into the UK. Consultees at Satixfy and Isotropic spoke of availability of TIA funding was a major driver for them increasing their UK operations. Representatives from Satixfy, an Israeli headquartered company, opted to build a new base in the UK because it enabled them to access substantial TIA funding to continue R&D activity. In the case of Isotropic, the firm already had bases in Reading and the United States. However, being able to secure TIA funding was a strong driver in Isotropic expanding their UK operations (which also entailed the building of new UK premises) rather than doing so in the US.

A number of consultees also spoke of the centrality of TIA in helping build up the UK space sector, with the programme having supported the development of many of the UK's fast developing satellite communications firms such as AAC Clyde Space, Lacuna Space, Satixfy and Isotropic. Consultees spoke of how the UK space economy would not be as extensive as were it not for TIA. The programme has also led to some important knowledge spillovers which has benefited the wider UK space economy. One interviewed contractor spoke of how many people had come to their organisation to work on TIA projects. Their experience on these projects encouraged some of them to form their own space start-ups. According to the consultee, this has been an especially important development as the UK space sector often lacks such an entrepreneurial culture.

5.5.1.3 Wider benefits to the UK

In the case of the TIA satcoms activity, the main benefit that the UK will see beyond the space sector will be improved connectivity and data access. The technologies developed via TIA will provide more stable connections to satellites, even for instance in remote areas, or when on the move. In the longer run, it is possible that consumers will also benefit from either more or cheaper satellite services. As satellite capabilities improve, some providers may exploit this to offer new data or connectivity services to consumers. If satellite operation costs also fall, these may be passed onto the consumer, providing them with more cost effective satellite-based services.

5.5.2 Applications

Considering applications more broadly, not just satcoms, the TIA BASS programme supports the development of a wide range of space powered products, applications and services. ESA's website provides a series of case studies of TIA projects it funds. Of these, 59 applications projects during the CMIN19 period are led by a UK organisation (a UK organisation is the 'prime' in ESA terminology). As shown in Table 17below, half of these projects (30, 51%) have been demonstration projects looking to develop commercially ready solutions, with approximately a quarter (22%) being focused earlier in the technological, and business development process via feasibility studies. Another 19% of the projects have been 'kick-start activities', exploring how space technology can be developed more quickly to introduce new features and innovative services to end users.[40] The majority of the applications projects (65%) are based on utilisation of data from EO satellites, followed by satcom capabilities (22%) and satnav (position, timing, navigation data) (7%). A very small number (just two projects) are based on technologies developed for human spaceflight.

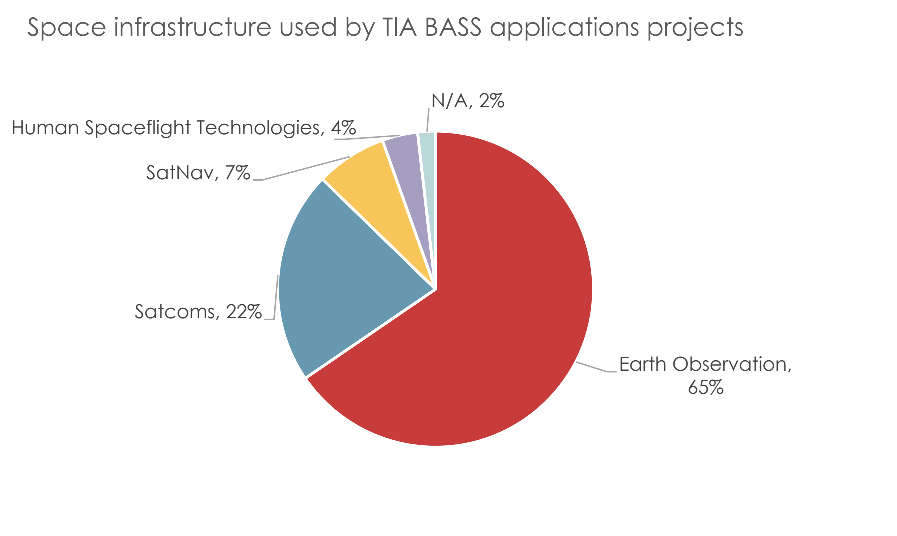
Table 17 Types of TIA applications activity with a UK prime during CMIN19 period

Type of Activity	No. of projects	%
Demonstration project	30	51%
Feasibility study	13	22%
Kick-start activity	11	19%
Feasibility study and demonstration project	1	2%
Other/NA	4	7%
Total	**59**	**100%**

Technopolis (2022): Analysis of ESA website TIA applications case studies

[40] https://business.esa.int/taxonomy/term/91

Figure 32 Space infrastructure utilised in TIA BASS projects (2020-2021)



Technopolis (2022): Analysis of ESA website TIA applications case studies

The TIA projects have covered a wide variety of different thematic areas, with many projects covering multiple themes. As shown in Table 18, over a quarter (29%) of the TIA application projects funded during CMIN19 (to date) centred on infrastructure and smart cities, with another quarter with a focus on environment, wildlife and natural resources. Collectively though, the TIA projects have covered a diverse range of themes, including aviation, sport, finance, and maritime.

Table 18 Thematic areas covered by TIA applications projects during CMIN19

Thematic Area	No. of projects in thematic area	% of all TIA applications projects
Infrastructure and smart cities	17	29%
Environment, wildlife and natural resources	15	25%
Health	9	15%
Energy	8	14%
Food and agriculture	6	10%
Safety and security	5	9%
Transport and logistics	5	9%
Media, culture and sport	5	9%
Finance, investment and insurance	4	7%
Education and training	3	5%
Maritime and aquatic	3	5%
Aviation	2	3%
Na	4	7%
Other	1	2%

Technopolis (2022): Analysis of ESA website TIA applications case studies (n=59 projects)

5.5.2.1 Outcomes and impacts for contractors

We have reviewed and categorised the information available for each of the 59 TIA applications projects with a UK prime that were funded during CMIN19, examining the types of outcomes and impact that they have generated to date. Three-quarters of the projects (44) have to date generated some form of impact for the contractor themselves. In total these 44 projects have produced 62 different instances of impact based on the categories used.

As shown in Table 19, 40 projects (68% of the total number of projects) have produced innovative products and processes through their projects, be they the development of new technologies or new production methods. Eleven projects (19% of the 59 projects) have already been able to generate some commercial income from their work, be it through the sale of prototype or demonstrator products and services, or through their finished solutions having come to market.

Table 19 Generated outcomes and impacts for contractors

Area of Impact	Total no. of projects generating impact	Share of projects generating impact
Innovative products and processes	40	68%
Commercial income	11	19%
Skills and capabilities	6	10%
Export/ export potential	5	9%

Technopolis (2022): Analysis of ESA website TIA applications case studies (n=59 projects). Projects can generate more than one type of impact so columns will not necessarily add to 100%.

5.5.2.2 Benefits to the wider UK space sector

Given the focus of TIA applications in addressing wider societal concerns beyond the space sector, it is unsurprising that so far they have not generated many benefits for the wider UK space sector. Between them, the 59 projects only generated 17 instances of outcomes or impacts for the UK space sector. Furthermore, only 13 projects generated benefits for this stakeholder group.

As shown in **Error! Reference source not found.**, where impacts were seen they tended to be in t erms of supply chain development - ten projects (17% of the total) generated impacts in this area. Space sector supply chain benefits have tended to occur when contractors have drawn on space experts to help understand better ways of using and running the planned technologies and solutions. For instance, D-CAT in developing the agricultural monitoring tool, Fusion Platform, worked with AAC Clyde Space to help their offer to satellite data mangers, while for its deforestation tool, Forest Mind, the Satellite Applications Catapult has worked with a wide range of UK-based space technology specialists like Telespazio UK to help define the tool's potential capabilities.

Table 20 Generated outcomes and impacts for the UK space sector (for current TIA BASS projects)

Area of Impact	Total no. of projects generating impact	Share of projects generating impact
Supply chain development	10	17%
Knowledge spillovers to space sector	4	7%
New products and services for space sector	3	5%
Increased employment	0	0%

Technopolis (2022): Analysis of ESA website TIA applications case studies (n=59)

5.5.2.3 Wider benefits to the UK

It is perhaps unsurprising that the greatest number of impacts seen from TIA applications projects has been outside the space sector. Our analysis of TIA funded projects with a UK prime found 225 instances of UK-wide outcomes and impacts (beyond the space sector), accounting for 74% of all outcomes seen across all stakeholders. Indeed, there was only one applications project that did not achieve an outcome or impact to the wider UK, and each project generating benefits on average in four different impact areas.

As shown in Table 21, the TIA applications projects have tended to generate impacts in two areas. Some 85% of projects (50 of the 59 total projects) have created knowledge spillovers to non-space sectors. The types of knowledge spillover have varied considerably. In some cases, as with Bennamann's CRESS project, this has centred on being able to provide new or more accurate data to customers, giving them the tools to undertake their work more effectively and efficiently. CRESS is helping grassland owners better monitor methane production for instance. In other cases, such as Adaptix's TransDIm, the project has produced new physical products which help give users the knowledge to perform their jobs more effectively. In the case of TransDIm, this has focused on providing more effective and accessible x-ray imaging tools, which in turns gives healthcare providers the knowledge to deliver more effective healthcare.

Table 21 Generated UK-wide (non-space sector) outcomes and impacts

Area of Impact	Total no. of projects generating impact	Share of projects generating impact
Knowledge spillovers to non-space sector	50	85%
Consumer/end-user benefits	48	81%
New terrestrial products and services	39	66%
Improved public services	23	39%
Other social benefits	22	37%
Environmental protection (e.g. pollution)	19	32%
Improved healthcare and healthcare services	10	17%
Addressing climate change (e.g. reducing greenhouse gas emissions)	8	14%
Crisis/disaster resilience	5	8%
Development of UK sovereign capabilities	1	2%
Enhanced international reputation for the UK	0	0%

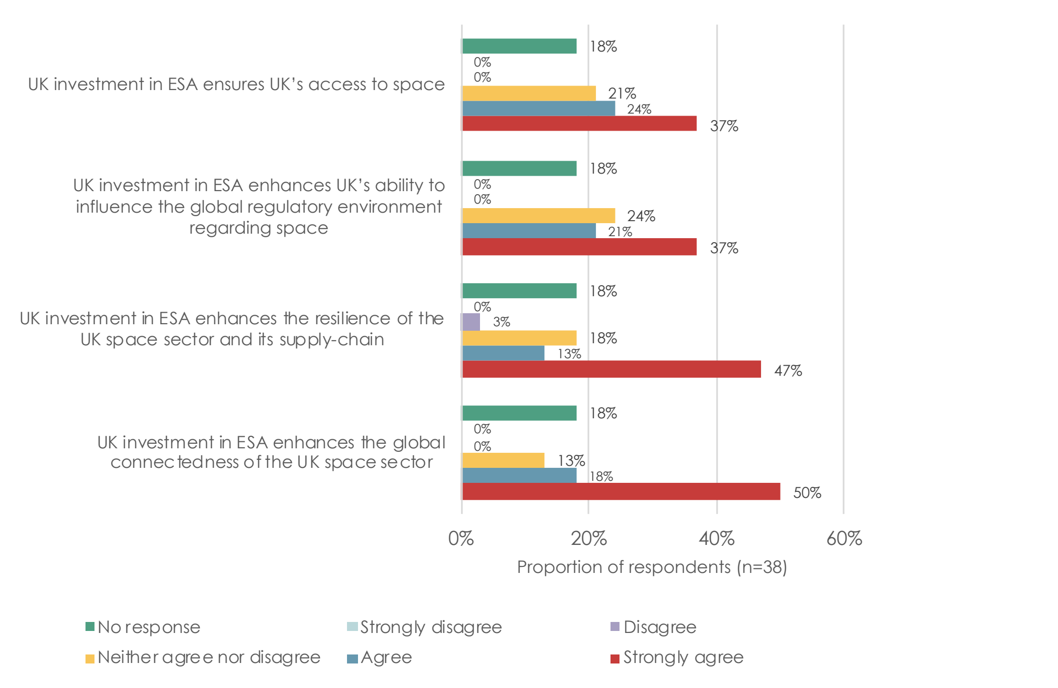
Technopolis (2022): Analysis of ESA website TIA applications case studies (n=59 projects)

The second area to have experienced a large number of impacts is consumer/end-user benefits. As shown above, 81% of TIA applications projects have generated impacts which have benefited the contractors' customers or the general population more widely. The specific end users from TIA applications projects have varied considerably. For 19% of projects (11 of all 59 projects), end-users were those working in natural resources, covering actors like forestry companies, conservation organisations and the quarrying industry. The next most frequently seen end users were those in health and wellbeing (e.g. medical industry, mental healthcare providers), and energy and utility companies (e.g. utility providers, photovoltaic plant operators) – each one being the end-user for 15% of projects (9). Potential end-users in agriculture and transportation each account for 8.5% of the possible end-user group. Agriculture and transport companies provide the end-users for 9% of projects (5) each.

5.5.3 *Cross-programme outcomes*

Survey evidence provides some further indications on broader more strategic outcomes and impacts that UKSA's participation in TIA may have facilitated. The TIA survey respondents as provided some feedback on the ways that the UK may have benefited from TIA participation outside of specific project activity. As shown in Figure 33 below, large proportions of respondents indicated that that they agreed or strongly agreed with the notion that the UK's participation had helped enhance the global connectedness of the UK space sector (68%) and ensure the UK's access to space (61%). There also appears to be strong belief in participation having helped give the UK space sector greater regulatory influence, as well as helping improve the resilience if the UK space supply chain.

Figure 33 Extent to which TIA survey respondents agreed with the following statements



ESA contractor survey

5.6 Attribution and additionality

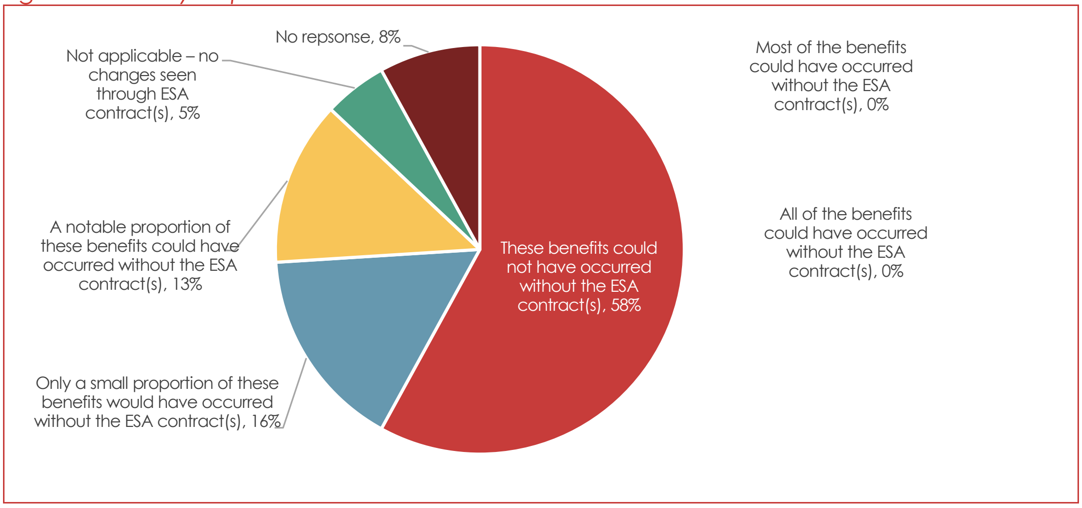
All of the interviewed contractors spoke of how TIA had played a central role in the development of their projects/technologies, and in some cases, the development of their business. A handful of contractors highlighted that their projects could have continued in some form in the absence of TIA funding – alternative public funding opportunities could have existed through Innovate UK, contractors could have raised finance through capital markets, and in one or two cases the contractors could have funded the activity by relocating to other parts of the world (e.g. the USA) that could provide the required amount of grant funding. However, for another handful, alternative funding streams were unviable because they involved giving up equity in their business. Furthermore, consultees consistently spoke of how other funding avenues could not provide the scale of funding that TIA offered.

While some interviewed contractors spoke of having used other funding sources alongside TIA (e.g. internal R&D budgets, funding from private backers) some spoke of the role that TIA played in helping leverage the additional funding. Of the 38 respondents to the ESA contractor survey, 58% (22) indicated that having an ESA contract had a significant influence on the amount of internal investment provided to R&D activity. In one case, a contractor provided some of their R&D budget to the TIA project because ESA funding helped reduce the overall amount the contractor themselves had to commit. In other cases, having ESA backing helped give financiers greater confidence to invest in the contractor.

While most interviewed contractors spoke of how some project activity could have taken place in the absence of TIA, they were clear that the size of the investment provided by the programme enabled them to accelerate the progress made. In one case, a consultee spoke of how TIA had helped them get their product to market much earlier than anticipated in their business plan, and consequently, helped give them first mover advantage in a market that is now becoming more competitive. Indeed, a consultee speculated that competitors would need to start undercutting the TIA contractor to gain a meaningful foothold in the market.

Survey evidence confirmed the centrality of ESA in enabling the benefits seen through TIA funded projects. Of the 38 respondents, 87% said that ESA had contributed in some way to the benefits seen, with 58% going so far as to say that the benefits could not have occurred at all without the ESA contracts (see Figure 34).

Figure 34 Survey respondents' views on the link between benefits and ESA contracts



ESA contractor survey

5.6.1 ESA-added value

There are a number of ways that TIA funding appears to have added value relative to other support packages available. For many interviewed contractors, the biggest benefit that TIA offered was the nature of the funding available. The amount of funding available through TIA is substantially higher than what is available through other public programmes, including those run by Innovate UK. This increased level of funding enabled contractors to undertake much more extensive R&D activity than might have bene possible through other means. Another advantage stated by some contractors was that TIA provided grant funding. Several contractors spoke of the only real alternative to TIA to fund their projects would have been going to capital markets. However, this would have meant giving up equity in their business, something which interviewees were reluctant to do. TIA therefore was unique in offering a large amount of funding without the contractor having to give up equity in the business.

Another commonly cited area of ESA-added value was the reputational benefits that came from being ESA backed. Interviewees spoke of how ESA has a strong international reputation. According to interviewees, having TIA funding allows them to demonstrate that they are backed by ESA, and therefore that their technology and/or business is credible. This has help give greater confidence to potential investors, as well to prospective clients and partners. In addition, 69% (26) stating that the ESA contract had helped improve their reputation.

To a lesser degree, some interviewed contractors spoke of other ways that ESA provided added value in a way that other funding sources could not have done. For instance, some reported how TIA contracts had helped provide access to ESA's wider international networks, helping give UK contractors access to experts and organisations in other Member States. Other interviewees reported the benefits in terms of providing access to ESA's expert technical staff as ESTEC – who are able to provide supportive and robust challenge and valuable inputs to their TIA project activities.

6 Telecommunications and Integrated Applications: case studies

6.1 Sunrise Programme / OneWeb consortium

Title	**Sunrise Programme / OneWeb consortium**
Summary	The Sunrise Programme aims to organise and cluster industry partners around large-scale programmes to achieve 'competitive leaps forward', as well as associated economic impacts. The current programme of work is led by OneWeb, supported by a consortium of companies in the development of a new beam-hopping satellite ('joey-sat'), including the digital payload, user terminal, and ground antenna. The programme of work also includes the development of space debris retrieval capabilities, and will also develop 5G capabilities. It is expected that this programme of work will directly benefit the consortium companies in terms of business growth, as well as delivering positive impacts for the UK space industry in terms of reputation and market positioning.
Type of impact	Technology development New skills and capabilities Size/growth of UK space industry Increased employment and skills Supply of products and services based on space infrastructure Usage benefits
ESA contractor(s)	OneWeb (Prime), plus Celestia, SatixFy, and Astroscale
ESA contracts	This programme of work is being led by satellite / telecommunications company OneWeb, supported by a consortium of UK-based companies. The consortium comprises Astroscale, Celestia UK, and SatixFy. The consortium has received £34m from the European Space Agency's Sunrise Programme to date.[41]
Complementary activities	ARTES TIA has been the main driving force behind the programme, though it is possible that delegations may invest in complementary activities.
Activities	
Sunrise[42] is an ESA Partnership Project, backed by the UK Space Agency, that aims to organise and cluster industry partners around large-scale programmes to achieve 'competitive leaps forward', as well as the economic impacts associated with these leaps. The current programme of work is being carried out by a group of UK space tech companies (referred to as the 'OneWeb[43] consortium') to develop a new satellite, nicknamed 'joey-sat' for its beam-hopping abilities.[44] The 'joey-sat' beam-hopping technology will allow satellites to remotely switch and direct beams to boost	

[41] The sum of £34m was given in interview, but differs slightly from what is available online ('over £32m'). See: https://www.gov.uk/government/news/uk-companies-join-forces-to-build-revolutionary-beam-hopping-satellite

[42] The term Space for 5G is also evident in reviewed data and documents

[43] See: https://oneweb.net

[44] Beam-hopping satellites can switch which region of the world they cover – and vary the data volume and rates for each region – according to demand (see: https://www.esa.int/Applications/Telecommunications_Integrated_Applications/First_leap_for_beam-hopping_constellation)

coverage in certain locations,[45] changing which part of the world they cover. This aids the management of real-time surges in commercial demand (e.g. areas of high usage where the network is struggling to cope with demand) or the ability to respond to emergencies such as natural disasters. The work will demonstrate this technology for OneWeb's second-generation constellation of satellites.

The £34m of ESA funding awarded to the OneWeb consortium has leveraged a further £16m of private funding to date from the consortium partners, meaning that the entire current programme of work is worth around £50m. This new funding building on previous investments.

The programme comprises four current projects. These include first and second the manufacture of the digital payload and development of the user terminal based on state-of-the-art application-specific integrated circuit components, funded at £25m and delivered by British company SatixFy.[46] The payload will be delivered on the first generation joey-sat and tested twice in orbit before potential use in OneWeb's second generation satellites. The third project in the programme is the development of a low cost ground gateway antenna, funded at £4.4m and delivered by Edinburgh-based Celestia UK.[47] This third project focuses on the development and trial of smart ground-station technology to reduce the footprint and costs of each ground station and increase the efficiency of the whole ground network. The fourth current project is the development of debris removal technologies by Astroscale[48] (also based in the UK) that aim to aid the removal of failed satellites from orbit. Astroscale's involvement in the Sunrise programme will further mature its debris removal technology and capabilities, ready for a commercial service launch by 2024. The first development will relate to a magnetic fixture, with secondary potential to develop a grappling robotic arm fixture. Funding for this element is estimated to be up to £14m.

A fifth project, currently under development, focuses on the 5G component. This work will be undertaken in partnership with the University of Surrey,[49] CGI,[50] Airbus (unfunded),[51] and SatixFy.

Impact*

The types of impact expected to be generated by this programme of work are broad ranging, though the timetable for realisation is also varied. The programme of work remains at an early stage, with several phases still to be undertaken: the current scope of the contract runs to 2023 with future phases potentially to follow.

It is expected that the earliest impact of this programme of work will be on the companies involved in the consortium, including both direct business growth (revenue and employment) and opportunity (e.g. continued participation in OneWeb supply chains and as providers of technologies, products, and components for OneWeb's subsequent second generation of satellites, as well as other constellations). This potential growth has not yet been quantified, though projections may be included in business cases or other project documentation.

Another area of anticipated impact is industry-level growth in the UK. This encompasses both the reputation of the UK space industry and its position to participate in global supply chains due to the development and evidence of capabilities in specific technology areas. It is believed that the programme of work should result in significant boosts for the UK space industry, with the development of a UK version of this technology providing an opportunity for first-mover advantage. There is potential for constellations other than OneWeb's to make use of the technology, as well as other broader use cases too.

Further in the future, impacts may include consumer benefits (e.g., 5G impacts for air passengers such as broadband on aeroplanes),[52] socio-economic benefits (e.g., demonstration of how next-generation 5G connectivity can benefit life on Earth such as support and real-time monitoring during disaster events), and environmental benefits (e.g., development of space debris removal technologies).

[45] See: https://www.gov.uk/government/news/uk-companies-join-forces-to-build-revolutionary-beam-hopping-satellite

[46] See: https://www.satixfy.com

[47] See: https://www.celestia-uk.com/about

[48] See: https://astroscale.com/about-astroscale/about/

[49] See: https://www.surrey.ac.uk/institute-communication-systems/5g-6g-innovation-centre

[50] See: https://www.cgi.com/uk/en-gb

[51] See: https://www.airbus.com/en/products-services/space

[52] See: https://www.gov.uk/government/news/uk-companies-join-forces-to-build-revolutionary-beam-hopping-satellite

In terms of timescales for impact, it has been suggested that the foreseen direct business growth may already be evident to the consortium companies already, with further growth seen over the next 5-10 years dependant on the success of the work programme and technologies. For example, if the development of the technologies is successful, the consortium companies will gain significant market position.

For impact to be generated and realised, timing is crucial. Many components of the work programme are on a tight timescale, and the critical path for the testing of the payload technology concludes with the launch of the first generation OneWeb satellite in July 2022. Any delays will mean that the payload cannot be tested at this time, potentially resulting in lost opportunities. However, there is some flexibility to launch dates with final manifests yet to be confirmed, and potential back-up opportunities already foreseen.

Additionality and ESA-added value

While OneWeb's reputation and reach means that they are already able to identify and reach suppliers and partners, ESA have played an important role in approaching and working with delegations. While the space industry was described as 'small' in the sense that actors regularly know one another, the role that ESA played was key to developing joint propositions, and strengthening the position of OneWeb and the relevant delegations. This was achieved by facilitating communications (i.e., informing delegations of OneWeb's vision and objectives), which is seen as key to the successful development of financing.

ESA's role offers additional benefits, too. ESA offers a great deal of guidance in the development of plans, and examines all propositions in great technical detail. OneWeb and other consortium members have benefitted from ESA's panel of experts, which have been made available for partners to draw on for help in shaping plans. This was described as a constructive challenge over and above internal expertise that improves the chance of developing suitable, sustainable solutions. The type of expertise available via ESA's panel was described as applicable to each facet of the work programme.

While external influences are hard to gauge, challenges in current global supply chains were discussed in consultation. These primarily include the availability of some components, exacerbated by the COVID-19 pandemic and other interrelated issues. This may affect the delivery of the aspects of the project due to be included in the first generation launch in July 2022.

6.2 Adaptix and TransDIm solution for 3D x-ray imaging

Title	**Adaptix and TransDIm solution for 3D x-ray imaging (BASS project)**
Summary	Adaptix has used ARTES to develop TransDIm, a 3D medical imaging device that is cheap to use, mobile, and reduces exposure to radiation relative to traditional CT scanner. This in turn will reduce the chances of misdiafanoses, or of health conditions being missed. The technology has a shared heritage with miniature electron emitters used previously in space missions such as Rosetta. Adaptix has used ARTES to accelerate the technological progression of TransDIm. It has already generated sales for use in veterinary settings, and is working towards approval for live human testing in healthcare settings.
Type of impact	• Technology Development • New products and services • Supply of products and services based on space infrastructure • Increased knowledge and innovation • Usage benefits • Innovation benefits (and spillovers) • Efficient service delivery
ESA contractor(s)	Adaptix (sole contractor)
ESA contracts	TransDIm has been Adaptix's only ESA contract. It has centred on the development of a new 3D imaging unit which is cheap to run, does not involve radiation exposure, and is easily transportable.
Complementary activities	Some additional funding received from UK security agencies but ARTES has been the main driving force behind the project's activity.

Activities

The initial idea for TransDIm came following discussions with the ESA Incubation Centre at Harwell. The centre facilitated meetings between an STFC scientist and Adaptix staff which in turn led to a sharing of ideas on the potential medical use of technologies derived from those initially used for space missions. Adaptix was looking to develop an imaging system that generated X-rays by using emitters and sharp tips to pull electrons onto a target. This has shared heritage with miniature space field emitters which have previously been used to land spacecraft onto a comet in the Rosetta mission. Discussions at the ESA Incubation Centre helped show Adaptix staff of the potential that X-ray emitters could play in developing miniaturised X-ray scanning.

The technology forms the cornerstone of Adaptix's business and was something that they would have looked to have developed even without ARTES support. What the programme has done however, is enabled an acceleration of technological progress, providing the capital needed to allow further R&D activity.

Through the ARTES project, Adaptix has looked to further develop and demonstrate their solution, aiming to reach a point where they have a market ready product that can be used on humans in a healthcare setting. To date, work on the contract has centred on imaging in labs, and of cadavers in a London hospital. At the time of interview, Adaptix was working towards gaining regulatory approval to undertake live imaging of humans, and also working towards multiple cadaver imaging.

In addition to the human healthcare work, Adaptix has also developed a version of TransDIm which can provide 3D imaging in a veterinary setting.

Impact

Adaptix's solution has the potential to deliver a range of important benefits to human healthcare, by helping improve access to 3D imaging. In relation to 2D X-rays, 3D imaging provides much more detailed images and in turn, gives a much better idea of the state of a patent's body. However, there are several barriers to the more widespread use of 3D imaging. Currently, this is done through CT scanners which are expensive, immobile, and involve high levels of radiation exposure. TransDIm will provide a new 3D imaging unit which is cheap to run, does not involve radiation exposure, and is easily transportable. Having such improved equipment will enable better treatment of patients, reducing the chances of missing serious conditions, or misdiagnosis (both of which can also create litigation risks for healthcare providers). Adaptix already envisages TransDIm helping serve hospital outpatient radiology departments (through more sensitive detection of fractures and ailments), intensive care wards (through more confidence positioning of tubes in ventilated patients), podiatrists and orthopaedic surgeons (who can handle more cases without having to send patients to other sites for a CT scan), and those delivering primary care in remote settings.

The project has made notable progress to date, having passed a Factory Acceptance Test milestone in May 2021. This involved testing equipment at the site of manufacture to confirm that TransDIm could satisfy its performance and function requirements. Adaptix also demonstrated its imaging system in March 2021 at the European Congress of Radiology, receiving positive feedback on the system's capabilities in hand imaging, and weight-bearing imaging of feet. At the time of interview, Adaptix was working towards gaining regulatory approval to undertake live human imaging. In parallel to this work, a veterinary imaging system also using TransDIm has already been used in multiple UK veterinary practices.

The firm has already generated some sales from TransDIm through animal imaging. At the time of interview, Adaptix representatives were confident of being able to generate sales through the imaging of humans in a matter of months. They foresee the market as being potentially being worth £ billions. Their solution will help tackle common ailments such as hand, foot, and leg injuries, while company representatives also believe that Adaptix will also be ablet o provide components for use in other organisation's solutions.

Adaptix has also held discussions with ESA technical experts about the potential use of TransDIm in the human space travel market too. Space travel leads to an increased risk of osteoporosis so there is an increased need to monitor the bone density of astronauts. With astronauts already receiving lots of radiation exposure in space, it is preferable to avoid providing astronauts to further radiation through continual use of CT scans. TransDIm however, will enable monthly radiation-free bone health checks of astronauts. Going forward, TransDIm could potentially be viable devices on space stations. Space stations can currently only use ultrasound systems on board as CT scanners are too heavy and rotate frequently – TransDIm would not have these drawbacks.

Additionality and ESA-added value

ARTES funding has been central to the project being able to make the progress it has. The size of the funding available has been especially helpful, allowing Adaptix to accelerate its work on TransDIm, enabling it to move further along the TRL scale and at a quicker rate than might otherwise have been possible. While alternative funding through Innovate UK might have been available, it could not have provided the level of investment that ARTES could. Furthermore, Adaptix has not always been successful in securing funding from other public sources. While they have received funding from UK security agencies, they have previously struggled to secure European funding. To that end, ARTES has been an unparalleled funding source, both in terms of the amount of money available, and the relative ease of accessibility. Interviewees added that it has been helpful having a funding source dedicated to the use of space heritage technologies.

Adaptix representatives also spoke of how they had only really considered taking the TransDIm technology into the human spaceflight sector following discussions with ESA technical experts. Were it not for their interactions with them, the opportunity to expand into a completely different market might not have been as clearly visible.

6.3 D-CAT's Fusion Platform

Title	**D-CAT's Fusion Platform (BASS project)**
Summary	Through ARTES, D-CAT has developed the Fusion Platform, a platform which provides the agriculture sector with processed and easy to handle data from Sentinel satellites. With this data, end-users are able to monitor frost damage, identify weeds within crops, remotely predict crop yields months before harvest, and estimate biomass on demand. D-CAT also already generated its first sales of Fusion Platform services. ARTES has played an particularly important role in funding the development of a demonstrator, allowing D-Cat to present an end-product rather just an abstract idea to their clients.
Type of impact	• Technology development • New products and services • New skills and capabilities • Increased employment and skills • Usage benefits (commercial and consumer benefits) • Efficient service delivery
ESA contractor(s)	Digital Content Analysis Technology (D-CAT) (Prime)
ESA contracts	ARTES has funded D-CAT's work on the Fusion Platform. This takes data collected from multiple sources in ESA's Sentinel satellite programme, and incorporates artificial intelligence (AI) to bring some automation to data processing. This processed data is then used to track changes in agricultural patterns such as yields and frost damage.
Complementary activities	Prior to receiving ARTES funding, D-CAT has examined the potential of using satellite data for agricultural decision-making. However, they had no end-product to demonstrate, and therefore nothing to show potential customers.

Activities

The project has centred on developing an automated solution that provides different price and performance options to agricultural firms for weed detection, frost damage detection, yield prediction and biomass estimation, varying their offer based on the imagery, data and algorithms used. The work stems from some initial ideas developed in the preceding years. The firms co-founders all came from a defence background but could see the agricultural market as one that could benefit from the use of satellite data, and also a market that was not well developed to date. The company thought that by enabling better processing of existing data, they could help the agricultural sector optimise their use of satellite data.

Initially, D-CAT had planned to provide end user software packages to help access satellite data. They have subsequently pivoted to providing APIs and other services to help interpret the numbers produced by satellites such as Sentinel. This ARTES contract has focused on enabling D-CAT to further develop this offering via the Fusion Platform.

Through the project, D-CAT has looked to produce solutions for two user types. Firstly, it has worked with the Australian agricultural corporate, Elders, to produce a demonstrator which can help monitor frost damage, identify weeds, and estimate crop yields and biomass. The focus has been on developing a demonstrator for Australian clients – the level of cloud cover across Europe meaning that data will not really be usable there.

Secondly, their demonstrator has looked to provide a platform through which algorithm and data providers can sell their expertise to potential end-users, using the data service provided by the Fusion Platform. D-CAT has developed an algorithms marketplace, as well as a reverse auction capability where providers offer end users with different price and performance options to meet an identified need.

Fusion Platform has also moved away from a server-based architecture, seeking instead to develop a cloud-based system. This will enable D-CAT to scale up operations in the future and serve end-users across the world.

Impact

The Fusion Platform has generated a number of benefits for end users in the agricultural sector. A traditional barrier to the usage of earth observation data in agriculture has been commercial operators selling data in too large a quantity to make them easy for end users to use. The Fusion Platform on the other hand uses algorithms which help extract smaller amounts of data which end users feel more comfortable using.

In addition, the work on the contract is now complete, with the Fusion Platform having been demonstrated as being suitable for use in four different agricultural service settings: weed detection, frost damage detection, yield prediction, and biomass estimation. Over the course of ARTES contract, D-CAT worked with the leading Australian agribusiness, Elders, to improve their productivity and profitability. Specifically, Fusion Platform is helping them to:

- Monitoring frost damage to lessen the financial impact of crop losses
- Identify weeds within crops to help improve yields
- Remotely predict crop yields before harvest and estimate biomass on demand, to enable more accurate forecasting and more timely crop management support

Going forward, company representatives also believe that the Fusion Platform will help with environmental monitoring, particularly monitoring levels of nitrogen dioxide, a common pollutant from fossil fuel consumption, in the air over time.

Work on the ARTES contract has also led to some important commercial benefits for D-CAT itself . Prior to ESA engagement, the company had a turnover of £300k to £400k a year. By the end of 2021, this had increased to approximately £1 million with D-CAT having generated its first commercial sales of the Fusion Platform, as well as securing a contract for the development of an API. Since commencing their ARTES project, the firm has employed a small handful of additional staff and expects to add another one or two in the near future.

The firm is also confident of generating yet further commercial impacts in the short to medium term future. D-CAT is already in discussions with approximately a dozen companies in relation to selling the Fusion Platform. D-CAT is also looking into repackaging and/or building upon the work done via ARTES to help enter new markets. For instance, D-CAT is working with a global commodity company to develop a crop categorisation model – this will repurpose the Fusion Platform algorithms so they can monitor and detect crops at smaller spatial scales. D-CAT is also in advanced discussions with a water company with a view to using the Fusion Platform to help study blockages in the water network (e.g. from fallen trees). Based on this, the company is hopeful of having a turnover in excess of £2 million a year within the next to three years.

D-CAT's work on the Fusion Platform also involved working with different algorithm providers and data providers, with both groups confirming that the Fusion Platform provided a commercial opportunity for them too. By selling their services to Fusion Platform, algorithm and data providers are now able to reach end users and markets that previously would have been difficult to secure. This therefore represents an important economic spillover to the wider UK space sector.

Additionality and ESA-added value

ARTES has been central to the development of the Fusion Platform and therefore the impacts derived from it. D-CAT representatives spoke of how they needed further funding to be able to bring their business idea to life. There were very few alternative grant programmes available. While an alternative might have been to go to capital markets, the company directors were reluctant to give up equity at this stage. To that end, without ESA funding, it would have been difficult for D-CAT to get Fusion Platform off the ground at all.

ESA funding has also enabled D-CAT to take the Fusion Platform further down the development chain than might otherwise have been possible. Prior to receiving the ARTES contract, the Fusion Platform was at TRL2/3. Without ESA funding, it would have been difficult to progress up the TRLs as they would not have had the means to develop a demonstrator. With ESA funding, Fusion Platform is now at TRL 6 and is commercially ready. Indeed, it has helped develop a cloud-based system which is ultimately globally scalable, meaning that end users around the world will be able to benefit. ESA funding therefore has helped develop the technology much further and much more quickly than might have been possible otherwise.

According to company representatives engagement with ESA has brought some added value in terms of the management practices with D-CAT. Representatives spoke of how the thoroughness of the ESA application process forced a culture change within D-CAT to ensure they could meet the requirements of the process. They added that the contract itself has been a transformative experience for the company, with ESA management processes having helped drive discipline into D-CAT's own processes.

6.4 Isotropic Systems and the Development of a Low-Profile End-User Terminal for Ka-Band Mobility Applications

Title	**Isotropic Systems and the Development of a Low-Profile End-User Terminal for Ka-Band Mobility Applications**
Summary	Isotropic is a developer of satellite terminals operating from the UK and from the USA. ARTES funding for this project has been instrumental in Isotropic's decision to expand its operations in the UK. Following the ARTES award, Isotropic has expanded its UK workforce approximately twenty-fold and while not all of these are directly attributable to ARTES funding, availability of ESA funding has been a major contributing factor in Isotropic's decision to expand operations in the UK rather than in the USA. Having ESA validation of their project has also helped give greater confidence to potential investors in the company.
Type of impact	• New skills and capabilities • Size/growth of UK space industry • Increased employment and skills • Trade and Investment
ESA contractor(s)	Isotropic Systems (Prime)
ESA contracts	As part of this contract, Isotropic is developing an electronically steered antenna with a multi-beam terminal which is able to access both the more established Ku-Band and newer Ka-Band frequencies which are typically used in high speed satellite communications. The technology will enable improved and more cost-effective access to multi-orbit and multi-band satellite constellations. This contract has centred on the performance validation and real-world demonstration of a first generation product, using this to complete product design ahead of the launch of a final second generation model.
Complementary activities	The contract builds on work already undertaken by Isotropic into multi-service, high-bandwidth and low power fully integrated terminals. It provides Isotropic with funding to ensure they can reach their first product launch in Q2 2022, while also enabling them to develop a second generation product in 2023.

Activities

The contract has three central elements[53]:

- Deliver a production-ready, multi-beam, low-profile, all-electronic scanning, Ka band satellite suitable for land and maritime mobility
- Complete product design and industrialisation-readiness, in preparation for commercial exploitation
- To validate performance and demonstrate functionality in a real-world, use-case scenario to confirm the product's suitability for the target markets.

The contract builds on work that Isotropic conducted in relation to a first generation model, set for launch in 2022. ARTES support, will fund the development of a second generation model which will be Isotropic's main product, and one that they aim to bring to market in 2023.

Under this contract, Isotropic's work involved two phases. The first, a technology phase, involve three separate test builds as way of better understanding the fundamental aspects of the technology and de-risking their use. The second phase, the product phase, will take the results from the technology phase and implement the first full product build. ESA funding will allow an acceleration of the development of the second generation model.

The work is focusing on providing solutions to global connectivity challenges, turning what are currently disruptive technologies into fully fledged products for the satcom market. It is hoped that the technologies being developed will help support emerging technologies too such as driverless cars.

[53] https://artes.esa.int/projects/development-lowprofile-enduser-terminal-kaband-mobility-applications

Impact

Some important impacts have already been realised through Isotropic's ARTES contract. Most notably, the contract has been a major driver for an expansion in the firm's UK operations. The confirmation of funding in 2021 gave the firm the confidence to invest in a 20,000 sq ft technology and testing centre in Reading, and according to the company, could add over 150 highly skilled engineering roles in the UK by 2023. Already, Isotropic has an 80-strong team in the UK, having only had 4-5 prior to securing the ARTES contract. While company representatives said that not all of these were attributable to their involvement in ARTES but the contract did nevertheless provide a major influence in their decision to increase headcount.

As Isotropic has expanded its work in the UK through the ARTES contract, the wider UK space industry has also seen some benefits. The company is now undertaking ground-breaking research on terminals and antennas which is helping to draw further private investment into the UK. Furthermore, the company's work has helped expand the UK space supply chain, working with new partners that have not previously been involved in UK space, or in the space industry at all.

Once fully developed, Isotropic's product will bring a range of benefits to end users and those reliant on satellite activity. Current satellite terminals cannot easily switch between different satellites using different frequency types. This makes it difficult to maintain stable connections to satellite services, particularly in remote areas or when on the move. The rise of constellation satellite networks is likely to exacerbate this issue. Satellites will not be based in a single point of space which will it harder to maintain stable connections with them. There will also be a need for end users to be able to continuously switch between different satellites in the constellation to ensure there is no interruption in service. Isotropic's technology will help tackle these problems, developing terminals with antennas which can seamlessly switch between different satellites. It will therefore offer improved and more stable performance for its users. With the terminal not having to use lots of power to try and connect onto a satellite, Isotropic's solution will also enable more affordable satellite activity. Currently, Isotropic is targeting the product at non-price sensitive customers such as governments (who could use the terminals for defence purposes), or high-end users within the aviation and maritime industries.

While Isotropic remains a pre-revenue company, they expect this ARTES contract to help them achieve commercial benefits in the future too. A first generation product will reach market in Q2 2022 with the second generation product, drawing more heavily on ARTES funding, reaching market in 2023. Major aerospace companies have already expressed interest in Isotropic's work and have invested in the company.

Additionality and ESA-added value

ESA funding has provided a large degree of added value to Isotropic. As noted previously, ESA funding has given the firm far greater impetus to scale its UK operations. While Isotropic has secured over $40 million worth of investment via a successful funding round with specialised space investors, the ARTES contract has ensured that Isotropic's work on their final product has been fully funded. In the absence of ESA funding, Isotropic representatives spoke of how they may well have had to locate closer to some of their other US-based investors to ensure that they could have greater visibility over Isotropic.

Company representatives also highlighted that there was very little in the way of alternative funding sources in the UK which could have enabled Isotropic to generate the UK-based benefits it has. While some grant programmes were available in the USA, accessing these would have required the firm to redomicile and would have left little scope to expand UK-based operations. Isotropic could have sought further private investment as an alternative to ARTES but would in all likelihood have involved the company's directors giving up equity in the business, something they were reluctant to do. To that end, ARTES funding has provided a route to expand UK operations in a manner that would have been far less likely otherwise.

It is also clear that receiving ESA funding has brought reputational benefits to Isotropic too. According to company representatives, having support from ARTES helps validate that the technology and the business is worth investing, in turn providing greater confidence to potential investors. This is especially important for Isotropic as investors in their field tend to be quite niche. With there not being a surfeit of potential investors, anything can that help boost appeal amongst investors who are interested in the business is especially welcome.

Aside from financial support, Isotropic has benefited in other ways from ESA support. The company has welcomed having access to ESA's technical experts, who can provide oversight over the technical integrity of the final product. Company representatives also added that ESA has played a role in securing access to UK government customers, and to wider contacts – as described by one consultee, *"ESA has helped plug the firm into a wider network."*

7 Human and Robotic Exploration

7.1 ESA's Human and Robotic Exploration programme

The high-level goal of ESA's Human & Robotic Exploration (HRE) programme is to lead Europe's contribution to the human journey into the Solar System. The programme's robotic element centres around the utilisation of robotic missions as precursors or so-called 'scout' missions and, while the horizon goal is human presence on the Moon and Mars, the programme's human element focuses on laying the groundwork for future human missions through scientific advancements and space-based infrastructure.[54]

Space exploration is focused on Solar System destinations where humans will someday live and work, concentrating on the Moon, Mars, and building on our continuous 20-year presence on the International Space Station. ESA's plan for CMIN19 investments was to ensure Europe's central role in the new era of global space exploration, strengthening European scientific excellence, boosting the competitiveness and growth of the European economy, encouraging international collaboration, and inspiring the future generation. These aspirations are articulated in specific longer-term goals of the Exploration programme outlined during CMIN19. They include achieving:[55]

The first Europeans to travel beyond Earth orbit, and potentially the first European on the Moon

The first European commercial services for Moon exploration, stimulating the lunar economy

The first test of the feasibility of using space resources to enable sustainable space exploration

The first round-trip to Mars to return samples to be analysed in European laboratories for decades to come

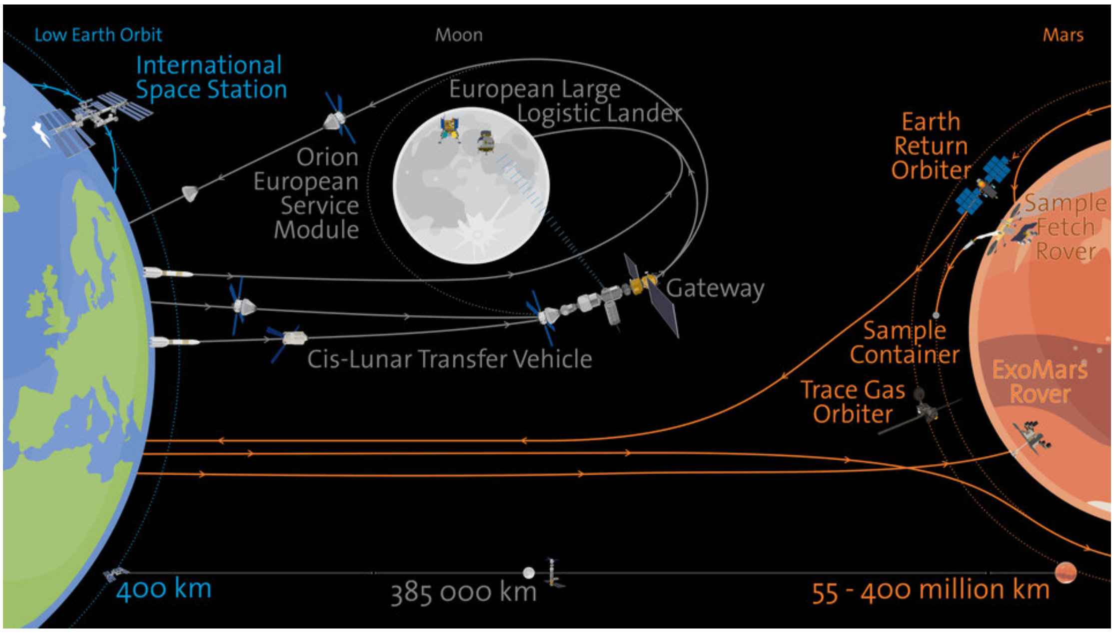
Since 2014, the European Exploration Envelope Programme (E3P) encompasses the three ESA exploration destinations – the International Space Station (ISS), Moon and Mars – into a single exploration process. E3P comprises six key sub-programmes:

- Humans in Low Earth Orbit (LEO)
- Humans beyond Low Earth Orbit (Cislunar)
- Lunar Robotic (Lunar surface)
- Mars Robotic (Mars)
- Scispace: Science in Space Environment (ground-based research, ISS science experiments, science on and near the moon, Mars sample analysis)
- ExPeRT: Developing underpinning technology for all space exploration

[54] https://www.belspo.be/belspo/space/esa_exploration_en.stm and https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/European_vision_of_exploration

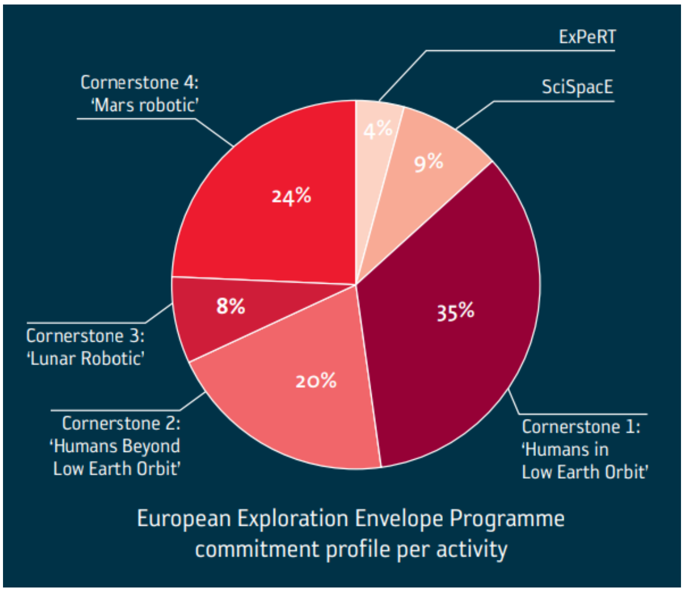
[55] See e.g.: https://esamultimedia.esa.int/docs/corporate/Space19+flyers_HRE_LR.pdf

Figure 35 Overview of ESA Human & Robotic Exploration destinations



ESA

Figure 36 Split of European Exploration Envelope Programme: ESA-wide commitment profile per activity in CMIN19



ESA

7.1.1 UKSA in the ESA Human & Robotic Exploration programme

HRE is an optional ESA programme that the UK joined relatively recently, joining robotic exploration activities in 2005 and human exploration in 2012. The purpose behind joining HRE was to enable the UK to play a role in the international endeavour for humans to explore and utilise space. Through participating in HRE, the UK aims to:[56]

Deliver important world leading science

Gain new technological capabilities that have commercial applications

Inspire the next generation of engineers and scientists

The UKSA CMIN19 Business Case noted that CMIN19 heralded a new age in space exploration and represented an important point at which to decide how Europe should cooperate with NASA on their ambitious plans to have a sustainable presence on the moon fifty years after the Apollo landings and to go on to Mars. With global efforts in space exploration centring on the ISS for the last 20 years, CMIN19 thus represented a key opportunity to put the UK at the heart of new global exploration efforts at a time when plans are being drawn up from first principles.

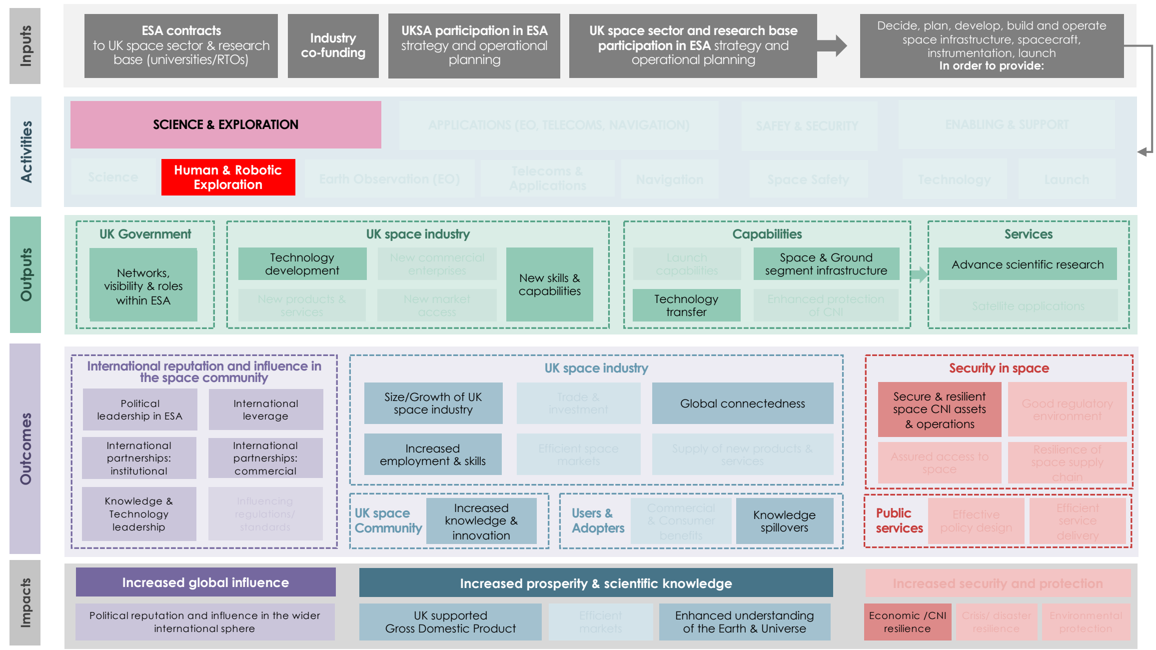
Investing in the HRE programme at CMIN19 was seen as enabling the UK to be a key participant in technology development for the global exploration endeavour. It secured the UK a critical role in Mars Sample Return (MSR), which is the highest priority planetary science mission in the last 40 years, a key involvement in supplying the ESPRIT element of the Lunar Gateway, and in the development of commercial lunar communication/navigation services.

Another aim of the programme is to give UK researchers access to unique facilities on the ISS and Moon and Mars satellites, rovers, and landers. The completion and launch of ExoMars, Lunar landers, and other future exploration missions will provide UK scientists with important scientific data to understand the evolution of Mars and the Moon, address the question of whether life could have evolved on Mars and potentially find evidence of past life in our solar system. The CMIN19 Business Case also noted that not investing in this programme would have meant that contracts worth up to €125M will be placed elsewhere in Europe, undermining the UK domestic space industry and its leading expertise in space robotics and artificial intelligence. There is a common theme here with other areas of ESA investment: capabilities can take decades to establish but can be lost quickly if the activity and funding to support them dries up.

In Figure 37 we present the logic model for the UK's CMIN19 investment in HRE, which shows the routes to impact for the programme. Many of the activities are focused on technology development and the development of new capabilities and infrastructure, in turn enabling new scientific advances and an expansion in the frontiers of what is possible in exploration. Pushing at the boundaries of technical capabilities, HRE can also generate new knowledge that can be applied elsewhere (i.e. spillover benefits) either in other areas of the space sector or in the wider economy. Human and robotic exploration is very high profile and the programme also helps improve UK standing internationally, reinforcing the country's influence, catalysing new partnerships and improving the UK's reputation. In the following sections we assess the evidence for these claimed routes to impact.

[56] UKSA CMIN19 business case

Figure 37 Logic model for ESA Human & Robotic Exploration programme



7.2 Inputs and activities

At the 2019 ESA Ministerial Council the UK subscribed €218.3m into HRE, representing a 11% share of the programme, with the majority prioritised for the Mars element and smaller amounts earmarked for the other elements. This funding level is an increase of 41% from UK subscriptions in CMIN16 (€155M), with CMIN16 also presenting a significant increase from previous subscriptions ranging from €70M to €100M at the ESA Ministerials between 2005 and 2014 - demonstrating the UK's increasing role in HRE over time.

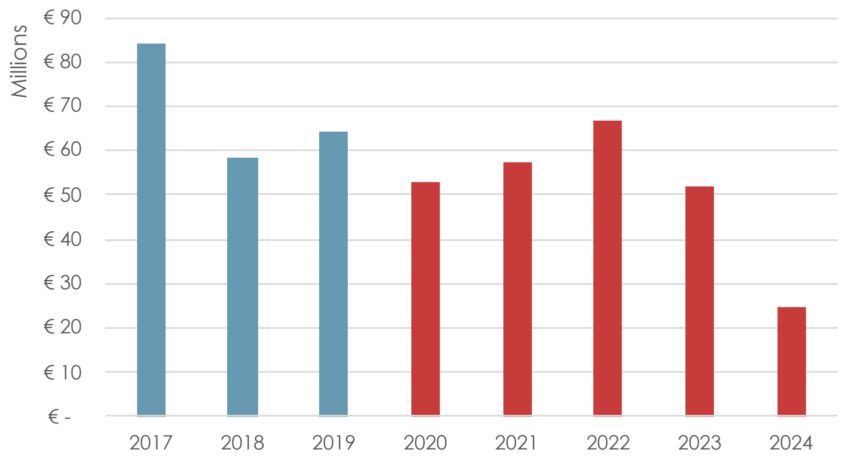
Table 22 and Figure 38 present the total financial obligations over the CMIN19 period (which includes 'carry-over' budgets agreed under the previous CMIN in 2016). Table 22 provides the breakdown of the budget within HRE. 99% of the HRE funding is for E3P activities, with the remaining 1% comprising of relatively small amounts of follow-on funding for investments in previous Ministerials, such as the final stages of ExoMars.

Table 22 UK HRE financial obligations to ESA (€m)

	CMIN16 Period			CMIN19 Period				
Programme	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Aurora ExoMars	€33.84	€9.04	€0.92	€1.87	€0.04	€0.02	-	
Aurora MREP 2 Sub-element 2	€5.42	€4.57	€1.08	€0.43	€0.12	€0.24	-	-
European Exploration Envelope Programme (E3P) Period 1	€4.90	€44.80	€62.40	€24.82	€10.85	€6.16	€4.27	€2.75
European Exploration Envelope Programme (E3P) Period 2	-	-	-	€25.77	€46.34	€60.51	€47.52	€21.81
ISS Expl. Phase 2 - 3rd B.F.C.	€39.68	-	-	€0.19	€0.01	€0.01	-	-
TOTAL HRE budget	€83.84	€58.41	€64.39	€53.08	€57.35	€66.94	€51.79	€24.56

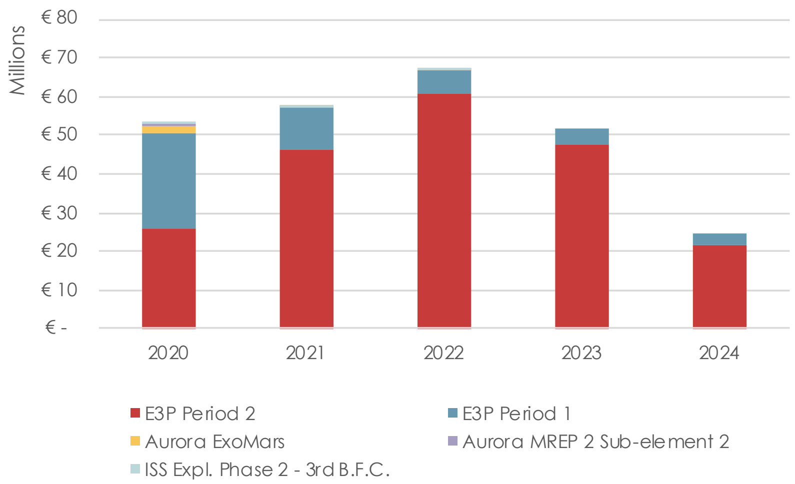
ESA datasheet on national obligations

Figure 38 UK commitments to the HRE Programme 2017-2024



ESA datasheet on national obligations

Figure 39 UK commitments to optional HRE programmes 2020-2024



ESA datasheet on national obligations

The following table summarises key anticipated UK activities in HRE during the CMIN19 period, with the subsequent analysis in the chapter focusing on key contracts that have been awarded or that are expected.

Table 23 Key UK activities in ESA HRE programme areas

Destination	Key UK activities via ESA
LEO (ISS and SciSpace)	Tim Peake flight to ISS sometime in period 2023-2024 Virtualisation of ISS hardware & software More than 30 research projects, including fire safety in space, astrobiology, and quantum entanglement Accompanying national outreach programme by UKSA education team
Beyond LEO / Moon (Lunar Gateway)	UK responsible for the refuelling element on the Lunar Gateway

(Moonlight initiative: Lunar Pathfinder*)*	UK lead studies on Moon-orbiting satellites providing communication and navigation for future missions. UK providing instruments for Russian and American Lunar Landers to study Moon volatiles
Mars (ExoMars 2022) (Mars Sample Return) (Mars Return Orbiter)	UK-led ExoMars rover will land on Mars 2022. (ExoMars budget allocated at CMIN16 and no new budget requested under CMIN19.) Mars Sample Return (new mission) where UK will play leading role in the development of the Sample Fetch rover and retain leadership in rover autonomous navigation and guidance. UK also to supply the chemical propulsion for the Mars Return Orbiter. Accompanying national activities: - Inspiration: a national outreach programme undertaken during launch, cruise and operation of ExoMars - Exploiting data arising from ESA through the National Programme for Mars elsewhere through UKRI funding
Exploration	Across all Exploration programmes, UK companies will have major roles in providing communication navigation sub-systems, equipment, and services on missions. Outside specific missions, the UK is also involved in activities in the ExPeRT element of the programme ('Exploration Preparation, Research and Technology'), for example to study the use of nuclear fuel for future missions, mission simulation software, radiation research, and in-situ resource utilization.

UKSA documentation, geo-return sheet, interviews, survey

From 1 Jan 2020 to the end of Q2 2021, ESA geo-return documents indicate 43 contracts, valued at a total of €37.7m, have been let to UK firms. It is important to note that this geo-return data only covers contracts awarded in the relatively early stage of the CMIN19 investment period, and therefore many more contracts are yet to put in place.

We discuss some of these already-awarded 43 contracts in the 17 interviews we held for HRE with industry, UKSA, other UK public organisations, and ESA and present information on these in the subsequent sections – though again they will only represent a subset of total contracts that will be awarded to UK organisations during this Ministerial period.

Table 24 HRE contracts breakdown by entity type 2020-Q2 2021

Entity Type	Value of Contracts (M€)	% of total	Number of Contracts	% of total
Company	€37.69	93%	38	76%
Research organization	€2.38	6%	5	10%
Secondary or higher education establishment	€0.42	1%		14%

ESA geo-return datasheet

The majority of UK contracts to date have been let to companies (76%). The 10 largest contracts awarded up to Q2 2021 are listed below. Airbus Defence and Space (GB) have five contracts, accounting for 43% of the total, with other key UK companies such as QinetiQ, SSTL, Vorticity and MDA UK accounting for a further 39% between them.

Table 25 Top 10 HRE contract recipients 2020-Q2 2021

Entity Name	Total Contract Value (M€)	% of total value of HRE funding	Number of contracts
AIRBUS GB (ADS GB)	€16.34	40%	5
QINETIQ LTD.	€4.48	11%	2
SURREY SATELLITE TECHNOLOGY LIMITED	€4.27	11%	2
VORTICITY LTD	€3.37	8%	1
MDA SPACE AND ROBOTICS LIMITED	€2.47	6%	3
Nammo (U.K.) Limited	€1.59	4%	1
STFC RUTHERFORD APPLETON LABORATORY (RAL)	€1.55	4%	1
THALES ALENIA SPACE GB (TAS GB)	€1.51	4%	3
NATIONAL NUCLEAR LABORATORY LTD (NNL)	€0.90	2%	1
UK Research and Innovation	€0.63	2%	1

ESA geo-return datasheet

With more than half of UK funding in CMIN19 for HRE going towards the Mars Robotic Exploration (Mars) programme, it was unsurprising that our interviews focused on significant contracts awarded here.

So far, we note two major contracts for Airbus UK under Mars Robotic Exploration:

- €7.8m for supplying the chemical propulsion to the Earth Return Orbiter (ERO) mission, currently in phase B2. The company are also conducting mission analysis and developing battery capabilities.57
- €8.5m for the phase B2 study of the Mars Sample Return rover ("Sample Fetch Rover", SFR), focused on key technological components, such as algorithms for the navigation and the robotic arm. The company have already completed two preliminary studies here. See the case study at the end of this chapter for a more in-depth exploration of the SFR and impact of the CMIN19 funding (see 8.1).

Airbus UK is well positioned as the prime contractor on the fetch rover and are in direct negotiation with ESA on future contracts.

A significant contract of €3.9m has also been let to QinetiQ UK (who built the thrusters for BepiColombo) under the Mars element.

Vorticity also continued a run of ESA contracts to win a €3.4m to continue their testing of lander parachutes that will feature on the ExoMars 2022 lander and the future Sample Fetch Rover lander.[58] So far this is under the Mars programme, but with potential to expand to Moon missions.

The set of noteworthy smaller CMIN19 UK Mars contracts revolve around studying and developing sophisticated algorithms for autonomous guidance, navigation, and control

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[57] https://www.airbus.com/en/newsroom/press-releases/2021-06-earth-return-orbiters-first-step-to-mars

[58] https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/Double_drop_test_success_for_ExoMars_parachutes#:~:text=The%20largest%20parachute%20set%20to,track%20for%20launch%20in%202022.&text=The%2035%20m%20wide%20subsonic,focus%20of%20the%20latest%20campaign

(GNC), mainly for use on rovers and other vehicles, but with applications for launchers and satellites too. Of note is GMV UK's contract worth €426k to build the framework to validate and verify complex autonomous systems for rovers and landers.

For Moon Robotic Exploration (Moon), the UK is heavily involved in ESA's Moonlight initiative, an ambition to provide a satellite-based communication and navigation service on the Moon.[59] ESA aims to kick off its initiative by launching the Lunar Pathfinder satellite. As part of Moonlight:

- ESA will launch the Lunar Pathfinder spacecraft, a Moon-orbit relay satellite, which will enable missions on the polar and far-sides of the Moon. SSTL was selected as the prime for the spacecraft winning a €3.1m contract. SSTL will also invest in the spacecraft themselves. This is part of a non-traditional procurement contract where ESA will act as an anchor customer for the relay services, worth a planned €10m with CMIN19 funding, and an additional planned €10m with CMIN22 funding.
- MDA UK won a €2.3m contract to analyse the business case and commercial potential of lunar navigation and communication services (including Moonlight in general, Pathfinder, and the Lunar Gateway) for future buyers around the world. Based on findings, they will deliver a systems concept that could support the communications requirements identified in their analysis.
- SSTL also won a general Moonlight contract worth €1.2m to put in place all specifications and requirements and overall design of a satellite network orbiting the Moon. The current phase is choosing a baseline for the infrastructure and generating the business case for a tailored solution. SSTL report being on track to finish on time for Sep 2022, i.e. phase AB/1 finished on time for the 2022 Ministerial.

In addition to Moonlight, the UK is also involved in the ESA/NASA/JAXA/CSA joint Lunar Gateway mission, which will put a space station in orbit around the Moon. This lunar space station will serve as a hub for science, function as a refuelling station for missions and will provide communications and navigation services (effectively contributing to the Moonlight initiative as well). ESA is responsible for the ESPRIT module, 'European System Providing Refuelling, Infrastructure and Telecommunications.[60] The UK's involvement in the refueling element is covered in detail in the ESPRIT case study at the end of this chapter (2.3). UKSA explained that the UK was specifically targeting both the refuelling and communications elements of the module for UK contracts and under CMIN19, Thales Alenia Space (TAS) (global) won the contract to build the module, with TAS UK responsible for the refuelling element with a current contract worth €1.3m.

UK organisations are also playing a role in the ExPeRT element of the programme, which aims to build up supporting technology that are destination-agnostic. A noteworthy UK contract is

[59] "Apollo-era missions only had line-of-sight communications with Earth, which restricted landings to the equatorial to mid-latitudes on the lunar nearside. But now ESA has announced its "Moonlight" initiative, in which two consortia of companies — led by Surrey Satellite Technology and Telespazio — will explore the concept of placing a permanent satellite network around the Moon. The network would provide an independent navigation system, giving rovers and crewed missions alike more autonomy to access the Moon's entire surface, including the polar regions and the lunar farside." (From https://skyandtelescope.org/astronomy-news/moonlight-europe-constellation-lunar-satellites/)

[60] ESPRIT comprises two main elements: HLCS (Halo Lunar Communication System), which ensures communications between Gateway and the Moon; and ERM (ESPRIT Refueling Module), which will provide the Gateway with xenon and chemical propellants, extending Gateway's service life and paving the way for a reusable lunar lander and refueling for deep space transport to Mars and beyond. Delivery is planned for 2026, with launch the following year. (From https://www.thalesgroup.com/en/worldwide/space/news/thales-alenia-space-heart-lunar-industrial-challenges)

Metalysis' In-Situ Research Utilisation (ISRU) contract worth €210k to produce oxygen from planetary materials for human exploration missions. This is analysed in more depth in a case study at the end of this chapter (see 0).

7.3 Outputs

The UK's investments and activities within HRE during CMIN19 need to be seen in the context of a longer-term programme of activity both in the past and the future. For example, the significant focus on Mars Robotic Exploration builds off the UK's large prior involvement in ExoMars. The programme is also focused on the bigger picture of enabling human missions to the Moon and Mars, which naturally is a longer-term effort that spans many CMIN investment periods**.** Work on the parachute for the ExoMars mission, for example, began in 2004, and has spanned six Ministerial periods so far. Many of the current projects and investments are stepping-stones that are part of a wider multinational cooperative endeavour that will take many years (decades in fact) and therefore the outputs (and outcomes and impacts) discussed here need to be interpreted accordingly. Interviewees were keen to stress that in many cases, new HRE projects signed under CMIN19 will not deliver their 'final' outputs until at least another CMIN period has been completed, reflecting the inherently long-term nature of exploration activities.

It is also important to note that, while the programme has distinctions in terms of the human or robotic nature of the exploration or the intended mission destination, many new skills, capabilities, and technologies will apply to our exploration capabilities more broadly. For example: advancements in In-Situ Resource Utilisation and orbital refuelling will apply to all future exploration missions; future Moon rovers will draw on technology from previously built Mars rovers; the Lunar Gateway will serve both Moon and Mars robotic and human missions. The outputs of contracts should therefore be seen as contributing both to a specific mission and to exploration capabilities more generally.

Perhaps more than in other programme areas, there was also a clear trend in that key companies (Airbus, Vorticity, TAS, SSTL, QinetiQ, etc.) often had previous related contracts with ESA, and that current activity often builds on previous work, either on missions proposed before CMIN19 or building on technology from past missions and CMIN periods. In the Moonlight initiative and elsewhere, there are also links to ESA support from multiple programme areas (e.g. TIA for communications and GSTP for technology development). These two factors mean that, in some cases, it was challenging for interviewees to identify what outputs and achievements were specifically attributable to CMIN19 funding for HRE.

However, we found good evidence of progress in terms of expected milestones being met and exploration activities being on track, with many examples of technical and scientific progress, skills development, and commercial benefits, among others.

7.3.1 Technology development

While still in the early stages, CMIN19 contracts have led to significant technology development in the various mission areas.

Much of this work is technological progress on autonomous guidance navigation and control systems for use on planetary exploration missions (e.g. Airbus' rover autonomous software, Scisys's Vislock navigation technology), but also includes instrumentation and other hardware development (e.g. Open University's Exospheric Mass Spectrometer, Open University and TAS UK's study of refuelling on the Lunar Gateway, SSTL's progress on the Lunar Pathfinder spacecraft and Moonlight infrastructure) as well as exploratory fuel innovation by NNL and University of Leicester.

In our interviews, we found many examples of organisations reporting significant TRL advancement due to CMIN19 funding. For example:

- Oxygen generation technology was reported to have increased from TRL3 to TRL5-6, with the potential to move to TRL6+ by late 2022.
- Key ISS software products have gone from TRL6 to TRL9 and that the technology is now ready to be deployed elsewhere too. Modernisation in software architecture technology could help extend the lifetime of the ISS by 10 years. While CMIN19 funding is only part of a wider story here, it is nevertheless playing an important role.
- Parachute technology was reported to have gone from TRL 5 to 8 since CMIN19 contracts were awarded.

More broadly, there is a general picture of continued progression towards mission readiness due to CMIN19 contracts. For example, the initial design of the Lunar Pathfinder spacecraft has finished, and the craft is expected to be built before the 2022 ESA Ministerial. The specifications, requirements and design of a broader Moonlight service have also been produced. Other organisations report moving through quality testing steps of their software solutions as a result of their CMIN19 contracts, progressing to the maintenance phase for both visual software and autonomous GNC technology.

A good example of this is CMIN19 contracts leading to innovative outcomes is in the study of radioisotope fuel, which is expected to enter early-stage mission readiness, with the fuel expected to be ready by Feb 2023. This is profiled in a case study at the end of this chapter (see 0), which details the realised and expected routes to impact. CMIN19 funding also had a role in solving a problem related to a wear mechanism issue on the BepiColombo mission, developing a novel technique using a different fuel approach to enhance the thruster for the Earth Return Orbiter (ERO).

CMIN19 funding has also led to the development of algorithms to enhance automation of the Sample Fetch Rover (SFR) and allowed for testing of whether ExoMars rover autonomy systems would work on the SFR. The use of a robotic arm for the SFR has also been studied, which will aim to fetch the samples from the Perseverance rover. For more details on the specifics of the SFR, see the case study at the end of this chapter (2.1).

7.3.2 New products and services

Companies we spoke to reported that their CMIN19 contracts had developed conceptualisation, knowledge, and capabilities needed to produce a commercial product.

Most industry interviewees noted a positive effect of CMIN19 contracts on their commercial opportunities, although most expected commercial activity to likely still be some years away. For example, while there is commercial potential in ISRU/oxygen creation, the earliest this could be realised is well into 2030. We explore these potential commercial outcomes in more detail in the 'outcomes and impact' section below.

Companies often reported that CMIN19 HRE contracts help 'maintain' or 'build upon' existing growth. Examples of reported growth were 3 to 17 in 2020, 12 to 25 in 2021, and several companies expected to grow from less than 20 employees to 50-100. There was a clear theme around dozens of jobs (total) created and maintained at key UK space organisations, and that while all growth cannot be attributed to single CMIN19 contracts, they play an important role.

7.3.3 *New capabilities*

CMIN19 contracts are helping lead to new facilities and assets. For example, the refueling component of ESPRIT is being developed in the UK: a test rig to test the refueling is being built in Harwell, which is expected to be finished in Q2 2022. For more detail on the refueling element of ESPRIT, see the case study at the end of this chapter (2.3). New types of processors have also been developed that will change future payload processor architectures and will most likely be used on the Lagrange L5 mission (now known as Vigil).

7.3.4 *Publications and patents*

Many companies we spoke to reported that they either have already published papers as a result of CMIN19 funding or that they expect to do so in future. Interviewees reported a handful of papers published already, with 5-10 expected the next few years. Examples of published papers include a research paper on the science and potential use of radioisotope power for satellites and spacecraft.

Naturally, many of the papers associated with exploration missions – like the advances in scientific understanding – will come after launch and operation of the different missions, and so is a longer term game. Most stakeholders expect the bulk of scientific papers from their current CMIN19 activity to arrive by 2030 (in line with timelines to publications for previous missions).

No companies or academic institutions we spoke to reported having yet filed for any patents. Some companies could imagine patents in the future, but had nothing specific planned. A few interviewees flagged that this should not be a surprise, given that their contracts typically concern highly specific procurement requirements from ESA revolving around specific missions. They noted that patents (like spin-outs, discussed later) typically occur not with the major contractors who are - for example - building a rover or a refueling element, to which ESA will hold the IPR, but often with companies elsewhere in the supply chain. There was noted to also be potentially much greater scope for patents and spinouts in the longer term, when the commercial potential in LEO / beyond LEO / Moon / Mars begins to realise.

7.4 Outcomes and impacts

Again, it is important to keep a long term perspective when considering the outcomes and impacts arising from CMIN19 investments, given that they are typically part of missions that can take many years – or even decades – to develop from initial idea to completion, involving investments over several CMIN periods. Interviewees, particularly those with a history of ESA contracts, reported that it can be difficult to isolate outcomes stemming from one or two specific contracts. In the words of one interviewee, ESA HRE contracts are "more likely to extend or maintain benefits than establish them".

Ultimately, as discussed above, the goals of the HRE programme are to ensure Europe's central role in the new era of global space exploration, strengthening European scientific excellence, boosting the competitiveness and growth of the European economy, encouraging international collaboration, and inspiring the future generation. This aligns with the UK's goals in the National Space Strategy to build one of the most innovative and attractive space economies in the world and grow the UK as a space nation.[61]

Many of the outcomes and impacts discussed in this section are part of this wider, longer term thrust towards these goals, and should be seen in that context. Growing UK influence, leading

[61] https://www.gov.uk/government/publications/national-space-strategy

scientific discovery, inspiring the next generation, and growing longer term capabilities are all linked to CMIN19 funding, but also more fundamentally to the holistic endeavour, for example through the vision of building a complete space economy on the Moon, which could offer major opportunities for UK organisations.

For estimations of the expected economic impact of CMIN19 investments into HRE, we can gain some insight by looking at previous studies of HRE impact. For example, a 2018 evaluation of the Aurora programme (which precedes current exploration programmes) estimated the value of economic impact that Aurora had achieved at that point to be £369m, with a predicted potential of at least £1.0bn and potentially as high as £3.0bn over the 2018-28 period (benefits depending on ExoMars success) compared to a UK cost at the time of the evaluation of £262m.[62] The evaluation also estimated a total of at least 2,207 person-years of full-time employment had been generated by 2018.

Previous investment into HRE has also led to spillover benefits and spin-offs, with the ESA Technology Brokers estimating that 20% of spin-offs recorded from 1997 to 2008 from ESA space investments originated in space exploration, spilling over into the transport and logistics industry, manufacturing, and materials.[63] Open University sensor technology originally developed for the Rosetta mission has been spun-off to support the UK's Ministry of Defence to develop an air monitoring system for submarines, and the OU team subsequently led an international consortium that studied the use of the sensors for a diagnostic test for tuberculosis.[64]

Other types of impact from past HRE activities have also been studied. A UKSA impact assessment of the Principia Campaign[65] surrounding Tim Peake's flight to the ISS between December 2015 and June 2016 showed that more than 33 million people engaged with the mission. The UK public perception of space changed, with a 6 percentage point increase in the proportion of people recognising that space plays a vital role in the UK's economy. The changes in attitude were not just in terms of human spaceflight, but in areas such as satellites and space science as the mission was used to highlight the whole space sector and the importance of space to our everyday lives. By the end of 2016, at least 1.6 million young people had taken part in one or more of the 34 education projects across approximately 10,000 schools - equivalent to around 15% of all school children and one in three schools in the UK.

7.4.1 Commercial opportunities

Part of the wider context for commercial opportunities within the programme is the development of a lunar economy. CMIN19 contracts – as part of wider activity – can help position UK organisations well in potentially lucrative future markets. For example, an analysis by PwC predicts a potential future economy on the Moon surpassing €142bn by 2040 and identified three key areas of activity:

- Transportation of humans and resources between Moon and Earth, as well as potential applications of projects in the lunar orbit

[62] Aurora Interim Evaluation Report, Winning Moves, November 2018

[63] https://ec.europa.eu/docsroom/documents/1042/attachments/1/translations/en/renditions/native

[64] https://www.ukspace.org/wp-content/uploads/2019/04/Spillovers-in-the-space-sector_March2019.pdf

[65] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764882/Impact_Assessment_Principia_Campaign.pdf

- Exploitation of Moon data on Earth, covering technical data for mission preparation and research, as well as entertainment data for leisure usage on Earth
- Resource utilisation which stretches from mining, over manufacturing, to exports and infrastructure projects[66]

Several interviewees reported commercial benefits from CMIN19 contracts. For example, CMIN19 contract activity has helped establish a key company in communications markets, enabling them to position themselves as the 'New Space' provider of both commercial and exploration communications systems. This contract helped build on the credibility and standing of this company established during past contracts and has since allowed them to look at other business opportunities across the wider space sector. Again, this should be seen within a wider context where past investment in human exploration has provided anchor contracts to companies establishing themselves and expanding within the UK.

Another key company also reported discussions with institutional and private customers as a result of CMIN19 contracts and activity, with potential follow-on business (though they flagged it is too early to say whether these discussions will bear fruit). Sales of Moon satellite communication services were reported to have the potential for follow-on sales of more than £50m in the next 8 years, with key interest from the US, Japan, Australia, and others. Here, the role of ESA as an anchor customer was noted as important in the realisation of these sales. Oxygen production was reported to have the potential to produce £100m per annum in sales to space agencies in 10 years, lasting 10 years (if not more).

Other areas of UK activity has also seen international interest, for example the use of innovative fuels, where the potential for a commercial spin-off was reported.

We found a belief in the potential for a satellite refuelling market in our consultations, and confidence of a key company in the UK's competencies and capabilities in the field. Key skills, capabilities, and technology in in-orbit refuelling are expected to be developed as part of CMIN19 contract activity, which will help the UK build leadership in this growing area. For example, NSR estimate the In-Orbit Servicing and Manufacturing market may reach $4.7bn cumulative revenue by 2031, mainly driven by Life Extension of satellites (which includes repair and refueling).[67] The UK's capture of the refueling market will depend on the development of UK refueling (and other in-orbit servicing) capabilities.

While only a relatively small number of companies responded to the survey for HRE (N=10, with not all answering all questions), some companies pointed towards new capabilities in robotics and propulsion systems, which have the potential to be exploited externally, with associated follow-on sales and revenue.

7.4.2 Increased employment and skills

The general theme from our interviews and other evidence-collection was that CMIN19 contracts – as part of a bigger picture – have an important role in boosting skills within organisations and both sustaining and creating new jobs.

Companies told us that their work on CMIN19 contracts made employees more competent in the space sector and that newly gained capabilities transferred to their terrestrial work too. In our consultations, we found evidence of CMIN19 contract activity enhancing skills in system engineering, propulsion, software development, thermal engineering, computer vision, the

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[66] https://www.pwc.com.au/industry/space-industry/lunar-market-assessment-2021.pdf

[67] https://www.nsr.com/?research=in-orbit-services-satellite-servicing-adr-and-ssa-5th-edition

handling of nuclear materials, and more. One company told us they created new roles for mechanical engineers and established a cross-discipline robotics team, bringing lots of internal staff together and recruiting several people.

This was particularly emphasised by companies that had previously little exposure to the space industry, with relevant companies noting that these skills also transferred to their operations in non-space areas.

Much like the commercial opportunities discussed above, many companies and organisations we spoke to were also keen to point out that this is a longer term game, and that the effect of the CMIN19 contracts in terms of longer term skills and employment impacts need to be seen within the wider context of HRE aims and goals.

There was also a theme from some interviews around inward investment and FDI. One company noted that without ESA contracts, they would not be in the UK and would have conducted activity in their overseas offices instead. CMIN19 contracts were noted as "continuing the story" of FDI into the UK.

7.4.3 Relationship and network development

We found good evidence for CMIN19 contracts leading to significant new relationships. One company new to the space industry reported strong new relationships within space industry, particularly with the UKSA, ESA, other primes and subs, and academia. International relationships were also strengthened, with companies reporting various new beneficial and improved relationships, for example with US and Japanese organisations and security departments around Europe.

Interviewees (both industry and academic) also reported significant reputational gains through their new work with ESA, which lead to benefits like easier outreach, hiring, heightened employee motivation, and retention. One company saw a stark increase in media interest in the company, while academic institutions reported that participation in ESA contracts give a significant reputational boost to their universities.

A key point made by UKSA and others is that having a presence in exploration is more effective in terms of reputation building than in other areas of space investment. A visible investment in exploration shows that the UK is a serious space faring nation, and that exploration is rising up the agenda. The UK was often seen by our interviewees as performing fairly well in a comparative context here (with for example one interviewee opining that "we're not at the top of the table, but near the top").

UKSA noted that the UK has done well in terms of getting into and is well-represented on appropriate working groups, such as for the ExoMars landing site selection. Those we spoke to in UKSA, ESA and industry who discussed the topic all noted that on exploration the UK is seen as having a well-respected, knowledgeable team on the ESA Human Spaceflight, Microgravity and Exploration (PB-HME) programme board. Another natural example of UK influence is the presence of Dr David Parker, former UKSA CEO, as ESA's Director of HRE.

A clear theme from both our interviews and the survey was that HRE naturally lends itself to international coordination and relationship-building, with endeavours such as the ISS leading to direct cooperation with countries such as Russia where relations are otherwise fraught, as well as with key future Global Britain partners, not least the USA. Some stakeholders therefore raised the wider geopolitical benefits of UK HRE involvement that go far beyond the direct return from projects and missions. UK CMIN19 contracts are already contributing to coordination: for example, the Open University (OU) is delivering a key component to the Russian Lunar lander mission, leading to the OU signing an Institutional collaboration agreement with the Russian Academy of Sciences which gives the OU co-investigator status on the Russian atmospheric analysis instrument on the ExoMars 2020 surface platform.[68]

7.4.4 *Knowledge and technology transfers*

Stakeholders frequently noted that technologies being developed for one purpose will be able to be used in other missions in the future. For example, Moonlight launch and navigation technology could potentially be used to replenish and enhance future constellations, while presenting the opportunity for 'communication and navigation as a service' rather than requiring space agencies to have their own data relays for future missions. This offers the potential for missions to be lighter, more cost-effective, and focused.

Space exploration missions often operate at the forefront of technical capabilities, generating knowledge and know-how that can be applied elsewhere, both within the wider space sector and indeed the wider economy. For example, Systems engineering and systems architecture capabilities developed for the ISS would be directly applicable to the Lunar Gateway, capable of being used as a template for building future payload support software while (as a generic solution) creating new potential applications in non-space sectors such as insurance, manufacturing, banking. Some companies reported that there have already been (confidential) applications of their CMIN19-funded technologies to the defence sector, while there were numerous examples of spillovers both within and beyond the space sector, such as:

- Titanium powders for 3D printing on Earth
- Applicability of parachute technology to any parachute missions
- Reduced cost of space communications designs and sensors by up to 30% due to studies on radiation dosage design
- New in-orbit servicing and manufacturing and active debris removal applications for robotic arms and automation of agricultural rovers
- Wider applicability of radioisotope power research to future space missions that cannot easily harness solar power, as well as terrestrial applications, e.g. submarines, mine safety systems, oil wells, nuclear medicine
- Tunnel inspection in GPS-blocked areas
- Biomedical applications for compliant mechanisms research e.g. prosthetics

While we did not identify any spin-outs already resulting from CMIN19 funding, there were some expectations for spin-outs from current missions on both Moon and Mars missions – though there were suggestions that spinout potential is typically lower for the prime contractor, and is more likely at lower levels in the supply chain. As discussed above for patents, there is also a longer-term story here.

7.4.5 *Wider, longer-term benefits*

Again, the purpose of missions and the longer-term nature of HRE endeavours should not be overlooked, and the role of CMIN19 funding should be contextualised accordingly.

For lunar activity, the longer-term benefits will come from new capabilities and cost reductions for future space activities developed through this decade's missions. These will be enabled by new communication and navigation infrastructure around the Moon and an increased understanding of in-situ resource utilisation (ISRU). While key UK companies are advancing Moon orbital infrastructure through Moonlight (mainly the Lunar Pathfinder) and the Lunar

[68] Open University ProSPA document (via UKSA HRE business case)

Gateway, the UK has also played a key role in realising the long term benefits of ISRU (which is crucial for the success of human settlements). To study lunar volatiles (material that can eventually be used for rocket fuel, producing air, or industrial operations)[69], the Open University developed the Exospheric Mass Spectrometer (ESM), which will be part of the OU-led ProSPA miniature analytical laboratory, whin in turn will be part of ESA's PROSPECT (**P**ackage for **R**esource **O**bservation and in-**S**itu **P**rospecting for **E**xploration, **C**ommercial exploitation and **T**ransportation). This package will be on the Russian Luna-27 lander, set for launch in 2025, and will also be an integral part of the Peregrine Ion Trap Mass Spectrometer (PITMS) instrument launching on NASA's Artemis missions.[70] Prospecting for lunar volatiles, especially at the poles where temperatures are cold enough to trap ice, is seen internationally as a first step in realising the benefits of a future sustainable space exploration economy.[71] This instrument builds on decades of developing expertise at the Open University through OU-developed instruments on the Rosetta lander and the Beagle 2 and represents the UK's first instrument on the Moon.

Activity in PROSPECT has also positioned the UK well to participate in future Lunar Surface Volatile science and exploration. This is a very rapidly growing field, fuelled by the recent tentative discoveries of water ice and other useful resources at the Moon especially near the poles.[72]

For Mars, the wider, longer term benefits are in part around the ability to achieve the long-term ESA exploration goal – and indeed goal of humanity – of sending humans to Mars. Many of the activities funded through CMIN19 concern fundamental precursory capabilities, and are part of this longer term thrust of activity. In the longer view, human settlement on Mars has many longer term benefits ranging from human resilience to existential threats ('not having all our eggs in one basket') to the intrinsic value of enhancing our understanding of the bodies in our solar system. Contracts awarded during a single ministerial will be part of realising these long term benefits. Because the impacts of single contracts are hard to isolate, expected long term benefits of CMIN19 activity is best understood through already-published studies on the return and impacts of previous exploration missions (often on a by-mission basis), some of which are referred to in the beginning of this section.

HRE activities have a well-recognised inspiration effect as discussed earlier in this section, and many interviewees commented on the importance of future exploration missions in terms of driving STEM uptake (which in turn is linked to higher career earnings and wider economic benefit to the UK), noting the impact that the next UK astronaut flight could have in inspiring the next generation. One example is ExoMars-related outreach activities developing coding skills, potentially helping to reduce skills gaps.

As noted above, knowledge transfers from HRE missions can also benefit missions in other areas – both within and outside exploration – in turn helping to unlock wider benefits. In our interviews, desk-based research and survey, we found numerous examples of technologies being used and developed in HRE missions that are expected to be used elsewhere. For example, more effective / cheaper / resilient navigation and control systems or fuel systems can enable greater efficiency or cost savings for other missions, in turn leading to cheaper data for use on

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[69] https://core.ac.uk/download/pdf/323104236.pdf

[70] https://www.ukri.org/news/uk-scientists-join-nasas-first-steps-back-to-the-moon/

[71] UKSA HRE business case for CMIN19

[72] https://www.esa.int/ESA_Multimedia/Images/2021/07/The_heart_of_a_lunar_sensor, https://www.esa.int/ESA_Multimedia/Images/2020/08/Sensing_the_Moon#:~:text=Its%20name%20is%20the%20Exospheric,set%20for%20launch%20in%202025, https://www.ralspace.stfc.ac.uk/Pages/UK-scientists-join-NASA%E2%80%99s-first-steps-back-to-the-Moon-.aspx

the ground for myriad purposes – whether for socio-economic benefit or 'pure knowledge' benefits. Through robotic arms and other technologies, HRE can also provide ways in to new, potentially lucrative markets such as In-Orbit Servicing, Assembly and Manufacturing (IOSM) and Active Debris Removal (ADR) that are expected to be worth billions in coming years and decades.[73]

CMIN19 contracts also have a role in delivering national security and resilience benefits, through developing UK capabilities and reducing reliance on other countries. An example is in new fuels for propulsion systems and, while the nature of follow-on work was often confidential, some interviewees spoke of new defence applications for their technologies.

As new CMIN19-funded technologies are developed for use in other purposes, interviewees also spoke of potential wider economic, social and environmental benefits, ranging from energy sustainability and climate change (e.g. clean nuclear power), to sustainability benefits stemming from reduced launch requirements (IOSM, e.g. satellite refuelling) and reduced operational risk in space from debris (ADR).

Finally, HRE is a basis for scientific research about the Solar System and how to support humans in space and, while relatively early days, UKSA noted that the science return from the CMIN19 investments has been good so far. For example:

- ESA released an Announcement of Opportunity (AO) in 2021 soliciting human research proposals for biomedical experiments to be implemented on the Concordia Antarctic station, that address human research questions that are relevant to ESA's overarching goal to enable a human mission to the Moon, Mars or beyond. The statistics on proposal selection show that while only 14 of 50 submitted proposals were selected, 3 of the 4 the proposals submitted by UK researchers were selected[74]
- In order to maintain an up-to-date SciSpacE research pool of projects that would have realistic perspectives for implementation, ESA's European Programme for LIfe and Physical Sciences in Space (ELIPS) carry out a three-yearly review process. As of the latest review, 61 unique UK researchers were involved in 60 projects that the review proposed for re-confirmation, a relatively high proportion of the 98 total proposed projects.
- UK researchers are involved in 34 SciSpacE projects, including research in fire safety in space, geodesy clocks and time transfer, quantum entanglement, relativity, thermophysical properties, astrobiology, spaceflight nutrition, and more.[75]

While the bulk of science return from CMIN19 investments will not occur until missions are launched and operational, which can take many years, interviewees noted that the UK is in a strong place to take advantage of data when it is released, reflecting broader UK strengths in skills, infrastructure, and data exploitation.

One industry interviewee also noted that over the longer term, the Lunar Pathfinder will allow for lower cost lunar science.

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[73] https://space-economy.esa.int/article/68/value-created-by-esas-clean-space-initiative
Estimated at $14.4bn worldwide with UK able to capture $1bn, UK In-orbit Servicing Capability, A Platform for Growth, Satellite Applications Catapult, Astroscale, FairSpace, May 2021 https://sa.catapult.org.uk/wp-content/uploads/2021/05/Catapult-Astroscale-Fairspace-Platform-for-Growth-report-final-27-05-21.pdf

[74] ESA, Selection of Proposals Submitted to AO-2021-Concordia – Stats, November 2021

[75] ESA, List of Topical teams funded through SciSpaceE – updated Q4 2019

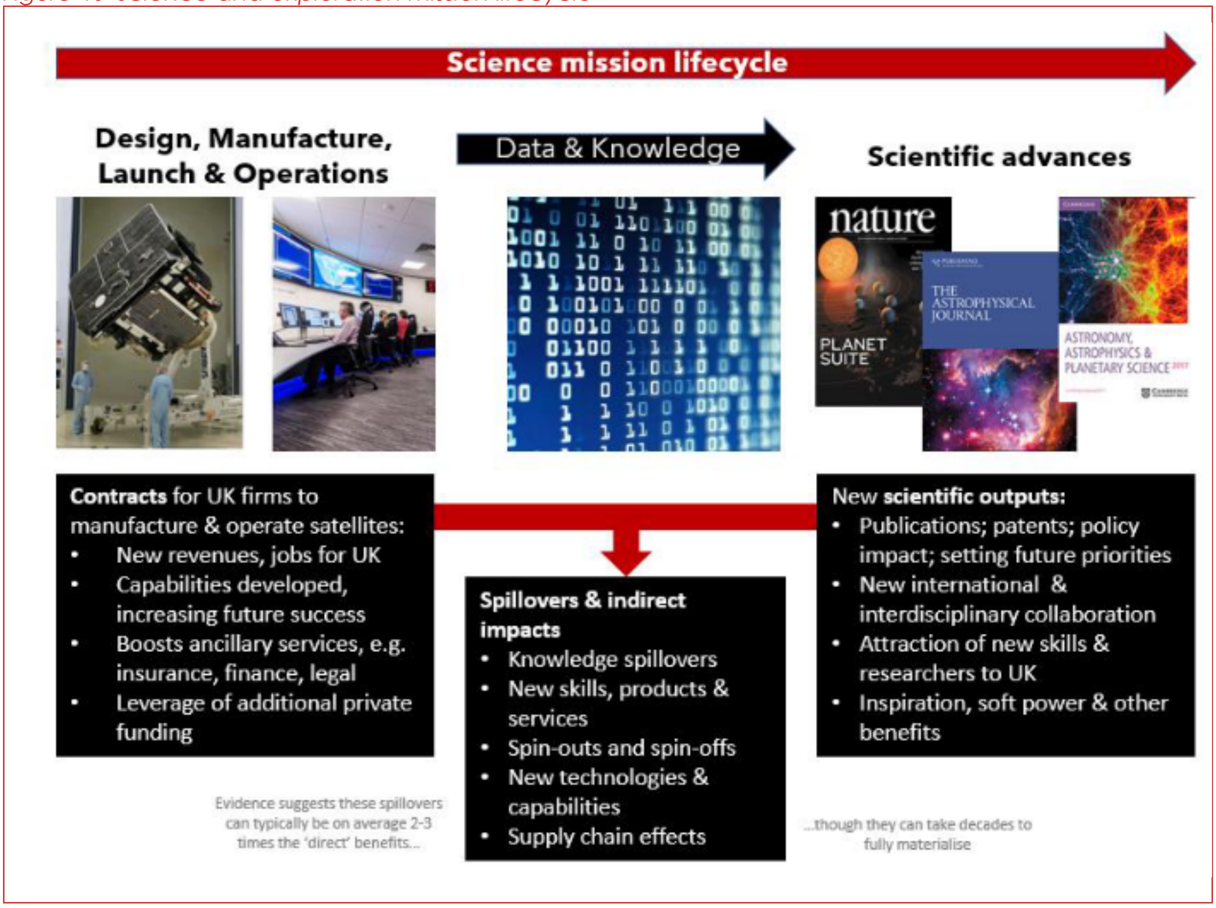
7.4.6 *Outcome and impact timescales*

As E3P is an envelope programme, the new activities signed up to in 2019 will not start to be fully developed until at least after one more CMIN period. This is a common theme across exploration activities, with for example activities funded in previous Ministerials such as ExoMars still receiving (limited) funding in CMIN19 for the final activities.

Ultimately, the timescales to impact will depend on which outcomes and impacts are being discussed. For the commercial impacts, there can be a real and shorter-term boost to R&D, investment and revenue that can happen within a few years of a contract being awarded. However, for other types of impact – particularly on scientific return – the impacts can take much longer to fully materialise.

An example is Mars Sample Return, where the return of the samples themselves is not envisaged to happen until 2031, meaning that the bulk of the scientific return will not occur until then. While the various socio-economic benefits associated with the design, manufacture and operation of a mission are very real, and the technology transfer and 'spillover' impacts can lead to major impacts in many different areas of the economy, the scientific advances and new knowledge generated (arguably the 'point' of the mission) can take years if not decades to fully materialise. This is illustrated in Figure 40.

Figure 40 Science and exploration mission lifecycle



know.space (2021), *UK Space Science: a summary of the research community and its benefits*, for SPAN

7.5 Attribution and additionality

Fundamentally, HRE is an area where activity is driven by public funding rather than the private sector acting in isolation. In the absence of the UK's HRE investments, therefore, it is unlikely that any of the outputs, outcomes and impacts discussed above would have been realised.

New capabilities in exploration (both Moon and Mars) should be seen in the wider context of a combination of agencies (notably NASA through its Artemis programme) pushing the frontier of human exploration. While ESA involvement is central to certain missions, like the Lunar Gateway[76], examples such as China's launch of their own space station and Moon rover show that the story is not only one of ESA's role in realising HRE goals, but of ESA as an enabler to represent UK exploration interests and values in the growing international exploration activity.

In this chapter, a core theme has been that perhaps more so than in other ESA programme areas (with the possible exception of space science), CMIN19 investments are typically part of a longer-term multi-Ministerial process. Indeed, it is the nature of an envelope programme such as E3P that the new activities agreed upon at CMIN19 will take further investments at future CMIN periods to realise. Any discussion of the potential future benefits that a mission may lead to, if successful, should be considered in this context. This is not necessarily a bad thing, with one interviewer calling the ESA HRE and Science programmes (where missions and projects tend to span longer than in other programmes) 'more coordinated and with a clearer long term focus'.

A clear conclusion for our stakeholders was that without the CMIN19 investments, for the most part, we would not see the benefits discussed above. It is likely that in the absence of UK investment we would still (via ESA, NASA and other international activity) see many of the outcomes from the lunar and Mars exploration, though the UK would not be involved and we would only gain the knowledge benefits and a portion of the various socio-economic in an indirect way.

Interviewees were unanimous in their views that while some of the activities could be taken forward nationally, HRE is (again perhaps more so than any other area) a naturally internationally collaborative endeavour and the UK would not be able to achieve the same outcomes by 'going it alone' – at least unless there was an order-of-magnitude increase in budgets. Even then, the scale and range of knowledge and skills that would need to be developed in the UK would take many years, if not decades to develop. A potential counterfactual scenario of national investments to secure UK roles within larger (e.g. NASA-led) missions for specific purposes was raised by a few interviewees, though they were not able to say whether this would have led to better outcomes than investing through ESA. This scenario also requires that NASA would be willing to work with the UK not only as an exploration partner but as an equal partner in order that the UK could maximise capture of the same level of benefits as working via ESA. This is considered further below.

7.5.1 ESA-added value

As noted in above in *Attribution*, our consultations featured frequent discussions around bilateral and even national opportunities in exploration. However, these opportunities were often caveated with the view that the scope of activities the UK could participate in would be much different. Big science and exploration missions such as the Mars Sample Return have multiple constituent parts – the NASA Perseverance rover that has collected the samples, the fetch rover that will collect them, the launcher, and the Mars Return Orbiter that will return them

[76] https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/Gateway

to Earth. There might be opportunities for UK industry to be involved in some of these parts, but the overall mission itself would have been impossible for the UK unilaterally, due in part to the prohibitive cost but also the necessary mix of skills and capabilities needed to deliver a complete mission.

In the same vein, it was noted that through this sharing of cost of the big missions, the UK (and UK organisations) are able to secure involvement (often in priority areas) and stay part of the bigger picture programme ambitions. The continued leadership in HRE was noted to be extremely important for companies who rely on the UK taking a strong role and actively seeking to prime ESA missions. With leadership and commitment comes influence, capabilities, and negotiation-power, which in turn leads to more prime contracts.

In the context of ESA funding vs national or bilateral funding, two models were repeatedly alluded to: the Canadian model, with their own astronaut corps and missions, and the Italian model, where they have ESA membership, and then use bilaterals to get more out of their membership (as is the case in the UK, albeit with more limited national budgets). Any conclusions on what is the 'best' model for the UK context goes beyond the scope of this study, however.

Two specific and important value-adds of investing via ESA were reported as: the access to ESA facilities and ESA expertise – which would be extremely costly to build up at a national level; and the benefits of participating in a collective organisation in terms of helping to make links between different areas of capability, enabling technology transfer both for the exploration activity itself and wider links and transfers in areas as diverse as medical applications and tunnel inspection.

From a UKSA perspective, investing through ESA enables the UK to "get geo-return in areas we are more interested in" and build capabilities for the future. There was a noted element of being able to prioritise in areas of national focus, while remaining part of the wider high-profile exploration endeavour.

Examples of companies coming to the UK as a result of HRE contracts also present a clear story around ESA-added value to UK capabilities, inward investment, and economic benefits. Additionally, the stamp of approval effect (as reported in other programmes), also helps unlock wider commercial benefits in HRE through reputational improvements and network-building, particularly in the US market.

8 Human and Robotic Exploration: case studies

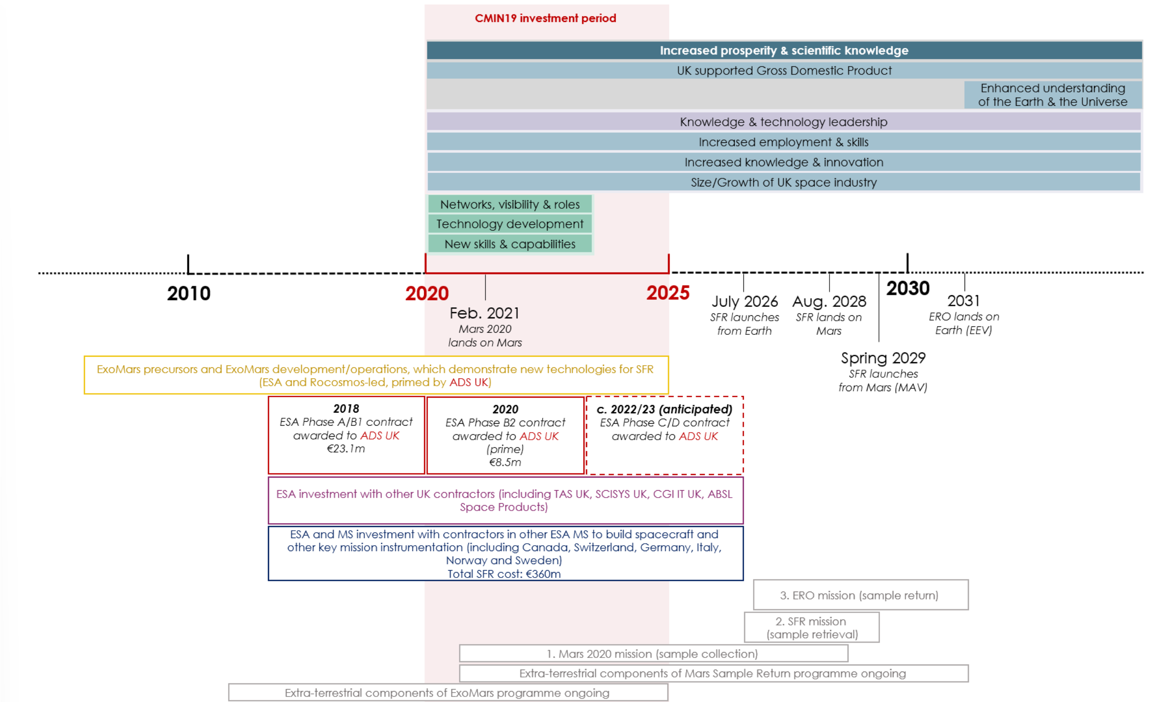
8.1 Mars Sample Return – Sample Fetch Rover

Title	**Mars Sample Return – Sample Fetch Rover**
Summary	The Sample Fetch Rover (SFR) is one of three steps in the NASA-ESA Mars Sample Return mission, which aims to enable the analysis of Martian rocks on Earth. Airbus Defence and Space UK secured the leadership role in SFR and was awarded funding to conduct phase B2 (detailed design and technology development of the mission), building on its feasibility and preliminary work in phase A/B1 and the work it led on the ESA and Roscosmos' ExoMars programme. CMIN19 contracts helped Airbus UK and UK stakeholders develop critical skills and capabilities, notably in human-robot interactions and autonomous guidance, navigation and control (GNC) systems. The innovations will eventually lead to new space assets (the SFR and autonomous GNC), but they could also have applications for lunar exploration and wide-ranging terrestrial industries. Overall, this upskilling has strengthened the UK space supply chain, providing it with a competitive advantage to secure further institutional and commercial contracts. The UK's leadership in SFR provides it with international visibility and credibility and enabled Airbus UK to develop and strengthen relationships with key actors. The high-profile nature of the activities is also expected to inspire individuals to pursue careers in STEM and the space sector, as Mars exploration programmes have in the past. Overall, the UK's work in SFR is integral to developing scientific knowledge to better understand Mars, and thus our Universe. SFR and its associated benefits for the UK would not have occurred without ESA investments during CMIN19 and previous CMIN periods dating back decades.
Type of impact	Main: • Networks, visibility & roles within ESA • Technology development • New skills and capabilities • Knowledge & technology leadership • Increased employment & skills • Increased knowledge & innovation • Size & growth of the UK space industry Other: • Technology transfer • International partnerships: institutional • International partnerships: commercial • International leverage • Commercial & consumer benefits (potential spillover) • Knowledge spillovers Resilience of space supply-chain
ESA contractor(s)	Prime contractor: Airbus Defence and Space Ltd UK (Airbus UK)Awarded to Airbus UK as prime contractor: Phase B2 of the MSR Sample Fetch Rover: €8.5m (2021)
ESA contracts	Awarded to Airbus UK as prime contractor: Phase B2 of the MSR Sample Fetch Rover: €8.5m (2021)
Complementary activities	The Sample Fetch rover is part of the sample retrieval mission, which is only one part of the Mars Sample Return mission. The Mars Sample Return mission consists of the sample collection mission (NASA's Perseverance, launched in 2020), the sample retrieval mission (present case study, planned launch in 2026), and the return mission (launching from Mars in 2029, landing on Earth in 2031).

ESA and Rocosmos' ExoMars programme is also complementary to the Mars Sample Return mission. It investigates the Martian environment and demonstrates new technologies, paving the way for the Mars Sample Return mission. The ExoMars' rover, Rosalind Franklin, was also developed by Airbus UK

Activities

Timeline of the SFR CMIN19 impacts

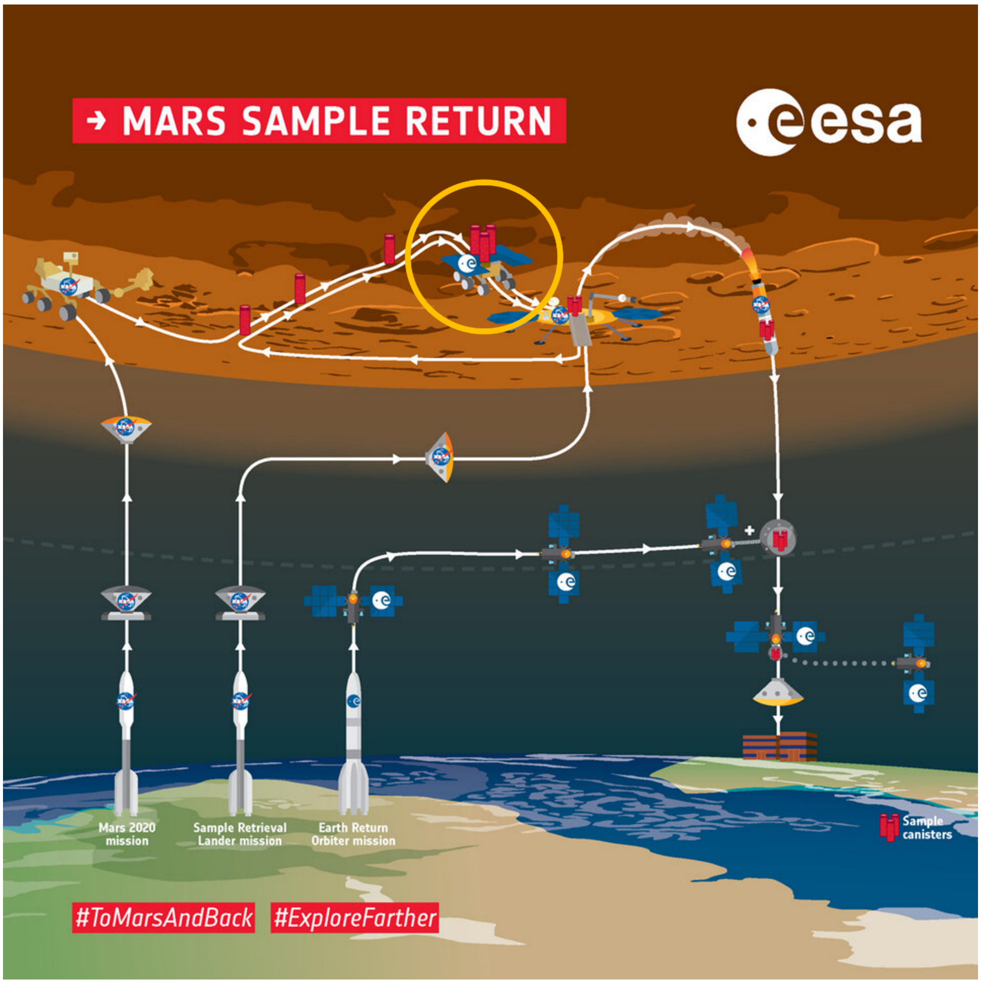


While missions to return samples from Mars have been studied for decades but never implemented, NASA and ESA have embarked on a joint campaign to achieve this by the early 2030s (Mars Sample Return mission, MSR). MSR is composed of three steps (c.f. figure below):

- *Sample collection*, which is currently being undertaken by the Perseverance rover, which landed in the Jezero crater in February 2021 through the 'Mars 2020' mission.
- *Sample retrieval*, which consists of landing a sample fetch rover (SFR) on Mars to collect the samples from Perseverance with a robotic arm. These samples are then transported to the lander and loaded into the Sample Return Capsule in the Mars Ascent Vehicle (MAV). SFR could also deliver new sample tubes for Perseverance, should the sample collector rover still be operational by the end of the decade. The mission is expected to be launched from Earth in July 2026, land on Mars in August 2028, and launch into low Martian orbit (through the MAV) in the spring of 2029.
- *Sample return*, which involves the Earth Return Orbiter (ERO) retrieving the samples from MAV and place them in the Earth-entry capsule, which is scheduled to land on Earth in 2031 on the Earth Entry Vehicle (EEV).

Returned samples will then be exploited by the global science community to better understand Mars' climate and geology, determine whether life ever arose on the planet, ultimately preparing for human exploration of and settlement on Mars. Returning Martian samples to Earth would allow for more extensive analysis than enabled by onboard sensors (like those of ExoMars' Rosalind Franklin Rover), notably by storing and reanalysing them in the future with new innovative instruments.

The three steps of the Mars Sample Return mission and the Agencies in charge of the different components

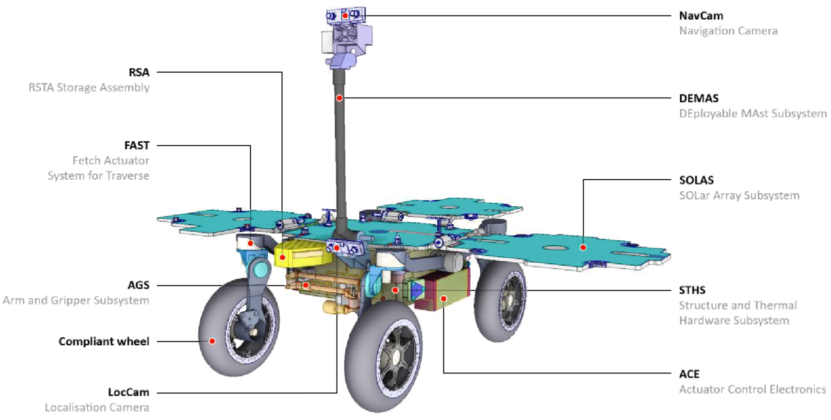


Source: ESA

SFR is one of the main elements of the European contribution to MSR. UK stakeholders play at major role in SFR, with Airbus UK leading the project. The company is priming a €8.5m contract, funded with CMIN19 investments, which consists in carrying out phase B2 of SFR, i.e. the detailed design and technology development of the mission (e.g. TRL-raising, de-risking).

SFR heavily draws from work done in other missions, most notably in the ExoMars programme, which demonstrated new technologies. As a prime contractor for the ExoMars rover, Airbus UK developed strong capabilities, notably in Martian surface operations, the development and breadboarding of complex Martian rovers, miniature electro-mechanical systems, and sample handling systems. However, SFR's objectives and design (c.f. figure below) are unique and thus present new challenges. While ExoMars' rover technology was already tested for use on the SFR, the Rosalind Franklin rover does not involve a robotic arm but focused on drilling in position to collect samples. SFR is also designed to collect up to 30 sample tubes, far beyond the capacity of previous robotic arms, for example on Beagle 2. Additionally, SFR needs to operate autonomously for as long as possible during a single sol (a Martian day), which is significantly different than other Martian rovers, which only drive for short distances around sol midday. This means it must travel much faster than its predecessors, with autonomous navigation algorithms required to be 10 times faster.

Preliminary design of SFR



Source: NASA JPL

Therefore, innovative technologies still need to be developed and tested to enable SFR to meet its considerably ambitious mission objectives. The emphasis is on the rover's increased autonomy, as teleoperations cannot be relied upon due to the time delay between Earth and Mars. Airbus UK's phase B2 contract builds on Phase A/B1, i.e. feasibility and preliminary work conducted in 2018/19, involving many UK stakeholders such as TAS UK, SCISYS UK and CGI IT UK. Phase B2 consists in further developing the algorithms, paperwork and breadboard of the enhanced autonomous guidance, navigation and control (GNC) system, with tests taking place in 2022. The rover's speed will be significantly increased by using LEON4 processor core, an enhanced vision system, and innovative locomotion.

While Airbus UK is the prime on this contract and leading the project, other countries are also involved in the development of SFR, with participating stakeholders from Canada, Switzerland, Germany, Italy, Norway and Sweden. The UK is in charge of the overall system design, assembly, integration and test, developing key subsystems around navigation and operational software, including autonomy and communications.

Subsequent phases for SFR will be awarded in future CMIN periods (CMIN22/25), with a total mission award anticipated at ~€360m. SFR is expected to be delivered to NASA in 2026.

Impact

Our consultation with Airbus UK highlighted that work around SFR phase B2 has already led to numerous benefits, with many more anticipated in the next few years.

<u>For contractors</u>

CMIN19-funded contracts are resulting in skills, technical capability development, and new beneficial relationships for Airbus UK and the UK supply chain:

- Airbus UK is building new skills in human-robot interaction and thermal engineering, as SFR requires much more complex mechanisms and technologies due to the particularities of the Martian atmosphere. This led the company to formally establish a robotics team, a cross-cutting discipline, by bringing internal staff together and recruiting several new employees.
- Airbus UK is also enhancing its software development skills, doing most of the work in-house, starting from scratch with a whole new system.
- Overall, there is a general upskilling across the stakeholders involved in the development of SFR. The UK's prime role in SFR not only helps it build skills and capabilities, it ensures that key subsystems and equipment are retained in the country, avoiding weakening the supply chain.
- As SFR is a high-profile mission, Airbus UK is receiving significant attention from industry, academia, space agencies, policy-makers and the public, notably accessing forums like the International Astronautical Congress to present the design of the rover.
- Airbus UK has also developed its relationship with various laboratories and companies across Europe, strengthened its R&D links with UK academics (including the Open University and the University of Leicester), and reinforced its partnerships with US actors, especially JPL.

For the wider UK space industry

UK leadership on SFR stimulates international collaborations and provides the country and its stakeholders with considerable international visibility, overall enhancing the connectedness of the UK space industry, which could lead to further international work down the line.

CMIN19 activities also contribute to setting up building blocks in robotics and autonomous space exploration through the development of new space assets, i.e. the sample fetch rover and the autonomous GNC. These technologies for extra-terrestrial surface mobility will not only enable breakthroughs in Martian exploration, they could also be useful in lunar exploration, leading to commercial opportunities and follow-on contracts:

- This is particularly relevant as ESA is preparing for sustainable activities on the Moon, meaning a lunar locomotion system will be required. There could therefore be opportunities to supply rovers of various sizes, which Airbus UK is in a good position to compete for due to the skills and capabilities it developed in the SFR project.
- More generally, the enhanced autonomy in human-robotic systems expected to be achieved from CMIN19 SFR contracts is anticipated to be a major enabler in future space exploration activities, and could be applicable in wide-ranging terrestrial industries (e.g. nuclear decommissioning, agriculture, defence, biomedical). Again, Airbus UK and other SFR contractors will possess a competitive advantage to secure new contracts, as they are at the forefront of innovation in this field.
- Some UK subcontractors are also participating in a deep space mission for the first time, enhancing their experience and, thus competitiveness for future commercial and institutional contracts.

For UK government

Participation in SFR, for Airbus and for the UK more widely, maintains and enhances the global reputation of the country as a technologically advanced and highly capable space-faring nation, reinforcing that already acquired through the central role played in ExoMars. This helps build UK credibility and prestige by widely demonstrating that the country is a leader in knowledge and technology in the field, and secured ESA and NASA's trust in building this complex and highly ambitious mission. Various stakeholders discussed how the UK's enhanced reputation is expected to:

- Increase the country's leverage within ESA to secure key roles on future exploration missions for UK stakeholders;
- Lead to further international collaborations with national space agencies such as NASA; and
- Inspire students to pursue careers in STEM and attract graduates to the space sector (through internships, apprenticeships and/or jobs). UK stakeholders are actively seeking to achieve this, notably through extensive outreach efforts, such as Airbus and the Hertfordshire Local Partnership's STEM Discovery Centre. Airbus UK expects this to have a positive impact on recruitment.

For wider society

Overall, UK leadership in SFR will contribute to more extensive analysis of Martian samples both with current tools and technologies yet to be developed. UK stakeholders are thus playing a critical part in the quest for knowledge on the development and environments of planets, potential extra-terrestrial life, and preparing for eventual human Martian exploration and settlement.

Additionality and ESA-added value

As noted when covering other big, internationally-collaborative missions in this evaluation, the MSR mission and the benefits from the phase B2 activities on the SFR would not have occurred without ESA funding. This applies to previous and future exploration missions, most notably ExoMars, which could not have happened unilaterally by the UK. Therefore, the decades of ESA investments and collaboration with NASA and Roscosmos on exploration have been critical to building UK skills, capabilities, and ground infrastructure, which allowed the country to play a central role in this high-profile mission. The realisation of expected benefits is also contingent on ESA (and therefore UK) funding subsequent mission phases.

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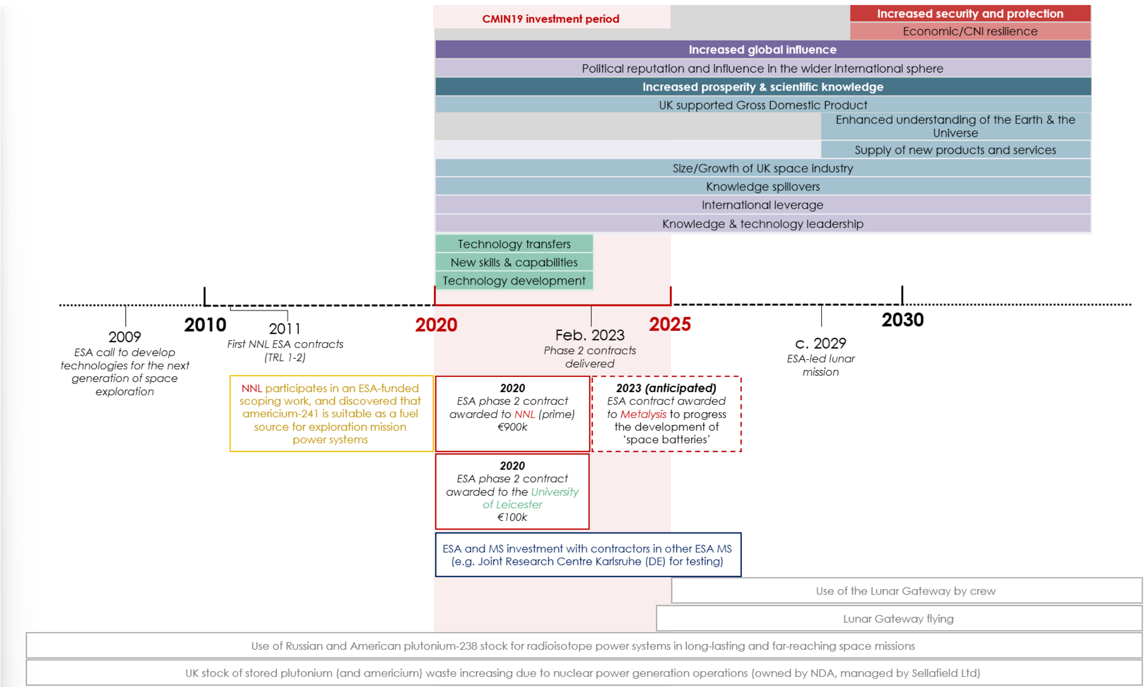
8.2 Americium Fuel

Title	**Americium Fuel**
Summary	The National Nuclear Laboratory (NNL) is developing a new innovative fuel for nuclear power to support future human and robotic missions, using Americium-241, a radioactive isotope cleaned and refined from plutonium nuclear waste. Future missions to the Moon and Mars will require a nuclear power solution to keep systems active and provide electricity to survive the long night. This is new, innovative fuel that is expected to deliver ESA its first native nuclear power source. CMIN19-funded activities are bringing ESA closer to its objective by maturing the technology. They have also contributed to economic growth in the UK through the creation of jobs, the acquisition of key new skills and technical capabilities, and the generation of commercialisation opportunities. The UK is in a unique position to secure future commercial and institutional contracts due to its 140 tonnes of plutonium waste and the leadership it is developing in the domain through this ESA-funded work. These CMIN19-funded activities have also led to new and strengthened relationships with key players and knowledge transfers to other industries. Overall, the activities undertaken since 2020 increase national resilience by developing a process to recycle nuclear waste and enhancing UK's capabilities necessary to autonomously work with nuclear power (for space and in general). By being at the forefront of this work and possessing a significant stock of americium, the UK is well-positioned to reap the benefits and is securing itself a substantial role in space exploration going forward.
Type of impact	Main: • Technology development • New skills & capabilities • Technology transfers • International leverage • Knowledge & technology leadership • Size/growth of UK space industry • Supply of products and services • Knowledge spillovers Other: • Networks, visibility & roles within ESA • Increased employment & skills • Increased knowledge & innovation • Commercial & consumer benefits
ESA contractor(s)	Prime contractor: National Nuclear Laboratory Sub-contractor: University of Leicester
ESA contracts	Awarded to NNL as prime contractor: • Americium Fuel Pellet Development, Phase 2: €900k (2020) Awarded to the University of Leicester, as a sub-contractor: • Americium Fuel Pellet Development, Phase 2: €102k (2020)
Complementary activities	Preceding contracts under HRE to develop this technology dating back to 2011.

Timeline of the americium-241 contracts CMIN19 impacts



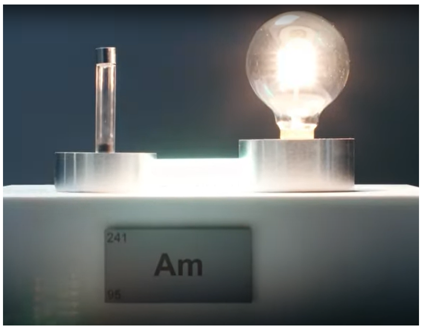
Activities

Nuclear fuel (through radioisotope power systems (RPSs)) is the only long-term power source that supports long distance space missions without relying on the Sun. Russia and the US have historically secured leadership in the development of such a fuel, using Plutonium-238, which is both expensive and difficult to access and make. In that context, ESA sought to identify and develop an alternative to increase independence and ensure mission affordability.

Investments in this field go back to 2009, when ESA put out an international call for stakeholders to develop technologies for the next generation of space exploration. Specifically, as part of the Mars Rover Exploration Preparation (MREP), NNL has been exploring a fuel source for power systems, securing its first ESA contracts in 2011 (TRL 1 or 2).

Through initial ESA-funded scoping studies (in which NNL participated), it was discovered that the decay of plutonium from nuclear fuel waste forms another radioisotope, americium-241, which has similar properties than plutonium-238 and a much longer half-life (430 years vs. 90 years). This preliminary work and demonstration suggested that americium-241 may constitute a viable sustainable nuclear energy source for ESA's exploration activities. This makes americium-241 suitable to power long duration missions. Additionally, the radioisotope is widely available, notably in the UK which possesses over 100 tones of separated civil plutonium, providing a potential role for UK in this technology.

Americium-241-generated electricity lights a lightbulb in Cumbria



Source: NNL

In this context, ESA committed to launching a lunar mission towards the end of the decade (2029), using americium-241 as a fuel source. The UK's NNL (a UK government owned and operated nuclear services technology provider) is participating in that mission, developing a sustainable production process for the supply of americium-241. It is also collaborating with other partners to ensure the highest levels of nuclear safety throughout the project.

NNL received a €900k ESA contract in 2020 to progress the development of americium fuel pellet. The laboratory is focused on increasing the quantity of americium-241 (raw fuel) that it extracts, cleans, and refines from plutonium nuclear waste. This will be done through experimental 'runs' in NNL's Central Laboratory on the Sellafield site, using the UK's stockpile of stored plutonium, which is owned by the Nuclear Decommissioning Authority (NDA) and managed by Sellafield Ltd. The provision of americium-241 is to enable test work on pellet manufacturing to be undertaken at the Joint Research Centre (JRC) Karlsruhe (Germany). The University of Leicester's €102k contract consists of participating in the research work at JRC, further exploring the development of the RPSs, i.e. a system that would use the heat from americium pellets to generate enough electric current to power a spacecraft. Overall, these 2020 ESA contracts are key to increasing the maturity of the technology and achieving operational 'space batteries' by the end of the decade.

This work builds on many years of previous work funded by UK national grants/contracts and ESA contracts, and on NNL's facilities and expertise in handling and processing nuclear material and the University of Leicester's capability in the development of RPSs.

Impact

NNL reported during our consultation that CMIN19-funded activities have already resulted in many benefits, and that future impacts are likely to be significant.

For the contractors

NNL reported that it anticipates commercial opportunities and/or follow-on contracts from this ESA-funded work:

- Americium fuel is very affordable and thus, attractive because it comes from nuclear waste. NNL expects to embark in a commercial agreement to provide it as a commodity to ESA. Indeed, the NDA would lend its plutonium waste to NNL, who would exploit it to provide americium fuel to ESA, returning cleaned plutonium waste for NDA to recycle. In other words, NNL would recycle waste from one industry and turn it into a significant asset in another.
- While NNL is already well positioned to exploit these commercial opportunities due to its existing infrastructure, skills and capabilities, it expects to invest in new equipment (on the chemical processing part) to ensure its ability to produce quantities that ESA would require for space missions.
- NNL is also getting interest from other organisations for the supply of americium fuel, which would be done independently from ESA through direct agreements. NNL's ability to pursue commercial opportunities with third parties will initially be contingent on whether it has the capacity to do so, which will depend on ESA's demand as a 'anchor customer'. In a scenario where this fuel is in high demand by both ESA and third parties, NNL may consider expanding into a bigger factory or creating a commercial spin-off.
- Overall, NNL's commercial opportunities and follow-on contracts are expected by them to lead to the creation of new jobs (~5-10 highly-skilled jobs every year for 10 years, including graduates and apprentices), notably in North West England. This not only participates in achieving the UK Government's Levelling Up objectives, but it also helps train and keep young professionals in the space and nuclear sectors, preventing potential skills gaps

For the UK Government, and the wider space industry

NNL and the University of Leicester's ESA-funded activities since 2020 also contribute to increasing national resilience:

- It further strengthens key skills and capabilities, notably around the handling of plutonium, extracting and refining nuclear waste and developing RPSs, contributing to the UK taking leadership in this cutting-edge field. It also participates in achieving Europe's non-dependence in critical technologies, ultimately enabling stronger leverage and competitiveness.
- It contributes to securing an independent European nuclear power solution and infrastructure for space exploration missions, which is an entirely new capability for Europe, moving away from the reliance on the US and Russia's plutonium 231-based nuclear fuel, which also enables the use of Ariane rockets for launch. Beyond independent production and use of nuclear power for space missions, americium fuel is also a sustainable and dependable alternative, as there are no practical limitations to the amount of americium fuel that can be produced. Each spacecraft could be powered using only 1 to 10kg of americium, which

is negligible when compared to the UK's 4 to 5 tonnes stock of americium (stock which will grow in the UK and Europe due to the continuing exploitation of nuclear power plants).

Overall, this will help keep UK and European space industry actively involved in space exploration, leading to many follow-on contracts:

- While the sustainable production process for the supply of americium-241 developed by NNL and the University of Leicester will initially be used for a Lunar mission launching in 2029, this type of fuel could also be used to power other long-lasting (up to 400 years) and long-distance missions if ESA adopts it. This will help ESA, European and UK stakeholders remain involved, competitive and at the forefront of space exploration by developing more capable spacecraft that can access distant, dark, cold and inhospitable environments. NNL expects to benefit from a competitive advantage to secure strong involvement in high-profile Martian and Lunar missions due to its involvement in the examined ESA contracts.

For wider society

- ESA's independent ability to access far environments with its americium fuel will subsequently enable the increase of science returns, through the generation of valuable images and data for many decades, far longer than would otherwise be possible. This will enhance our understanding of the Earth and the Universe.
- NNL's space batteries work offers the potential to slightly reduce the UK's nuclear waste by exploiting americium-241.
- NNL is leading by example by demonstrating the feasibility of using nuclear waste productively, which is anticipated to catalyse further R&D. If further innovative solutions are identified and realised, this could remove potential threats to the environment and the health and welfare of the population and lead to wide-ranging benefits. For example, working on using nuclear waste to power space missions has triggered a new area of work for NNL by catalysing a new mindset and process around the productive exploitation of waste. Further solutions are currently being explored by the organisation, notably in the field of nuclear medicine. Indeed, the innovative process of using decaying isotopes from nuclear waste is being investigated as a means to treat cancer, meaning that the ESA-funded activities could ultimately contribute to significant health and welfare benefits. Overall, NNL anticipates transfers of the knowledge and technology developed through the examined ESA contracts to other applications, such as a power source for submarines, safety systems in mine and oil wells.

Additionality and ESA-added value

ESA funding was critical in enabling NNL's R&D on americium fuel and the associated potential impacts, as NNL would not have undertaken this work without the 2020 contract. More broadly the various ESA contracts have been described as having catalysed this branch of work at NNL. ESA awards for subsequent phases of the work are also key to the full realisation of the anticipated benefits.

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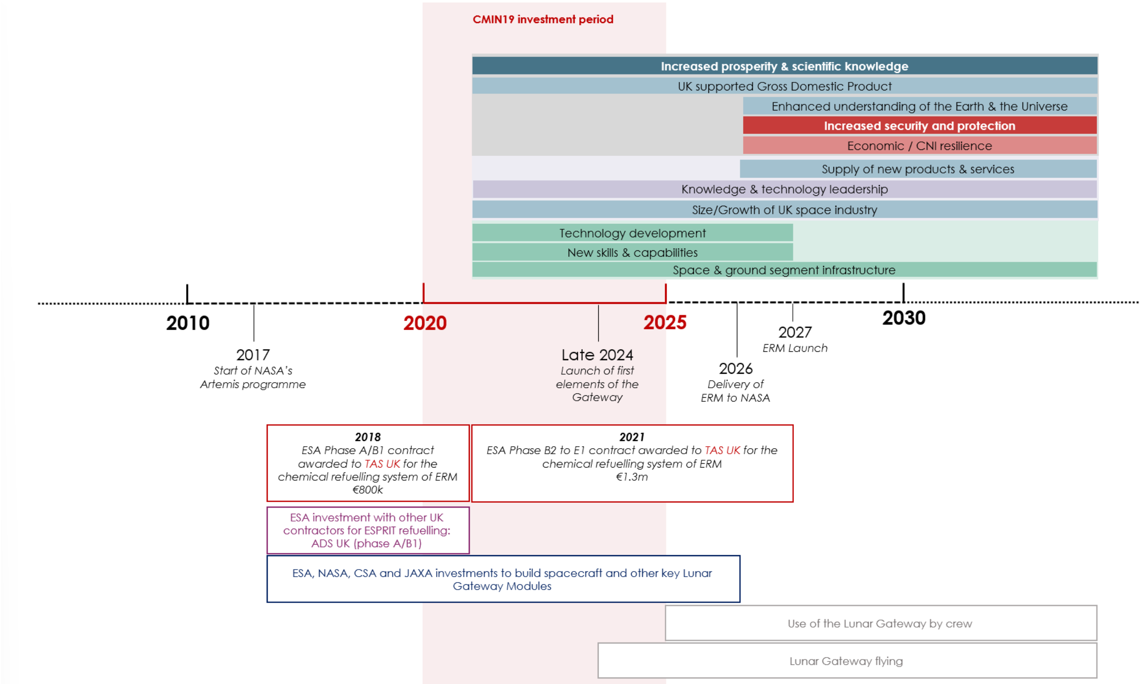
8.3 ESPRIT Refuelling

Title	**European System Providing Refueling, Infrastructure and Telecommunications (ESPRIT) Refuelling**
Summary	The Lunar Gateway is a planned NASA-led international space station orbiting around the Moon and will serve as a communication hub, science laboratory, short-term habitation module, refueling station, and holding area for rovers and robots. TAS UK is leading the development of the chemical refuelling system of the European module of the Gateway and was awarded a €1.3m contract following CMIN19. While these activities have only recently begun, economic benefits are already starting to be realised in the UK, notably through supporting jobs in Harwell and Belfast. Most impacts of the CMIN19 contract are anticipated for the coming years. TAS UK is expected to develop skills, capabilities, and technology in in-orbit refuelling, which will help the UK build leadership in the area and capture future commercial opportunities and securing follow-on refuelling ESA contracts. Ultimately, TAS UK is contributing to a critical part of the Gateway and, thus, helps the bigger picture of Lunar and Martian exploration, which will increase our understanding of our solar system and the Universe.
Type of impact	Main: • Technology development • New skills & capabilities • Space & ground segment infrastructure • Knowledge & technology leadership • Size/growth of UK space industry • Supply of products and services Other: • Networks, visibility & roles within ESA • International partnership: institutional • Increased employment & skills • Increased knowledge & innovation • Commercial & consumer benefits • Secure & resilient space CNI assets & operations • Assured access to space • Efficient service delivery
ESA contractor(s)	Prime contractor: Thales Alenia Space (France) Sub-contractor: Thales Alenia Space UK
ESA contracts	Awarded to TAS UK, as sub-contractor to TAS France: • Phases B2/C/D/E1: €1.3m (2021)
Complementary activities	N/A

Timeline of the ESPRIT Refuelling CMIN19 impacts



Activities

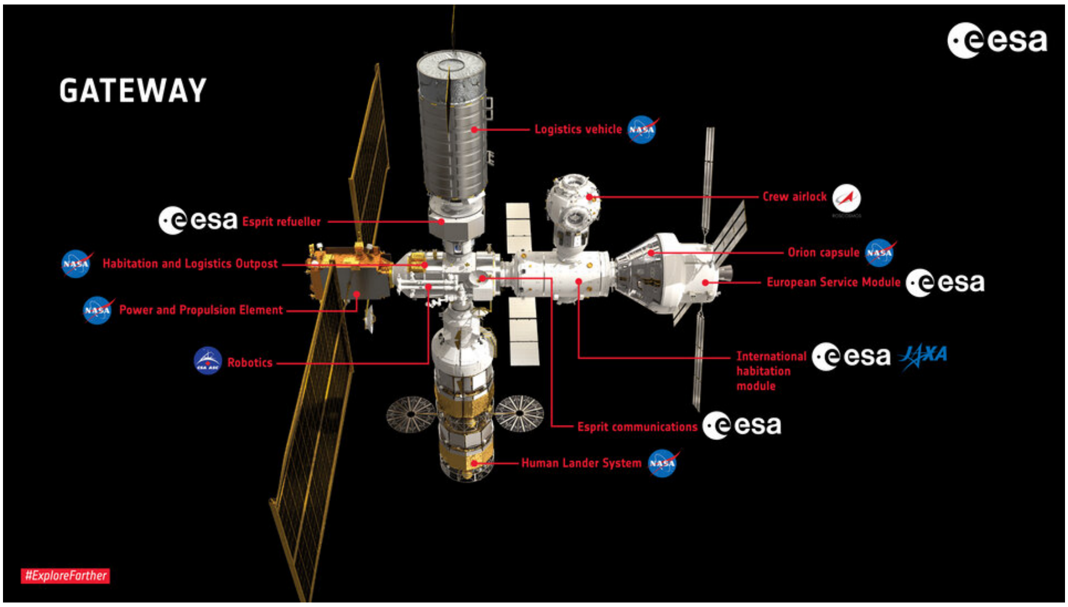
The Lunar Gateway is a planned space station orbiting around the Moon, which is led by NASA and developed in collaboration with ESA, JAXA, CSA and commercial partners. It will play a critical part in NASA's international Artemis programme, which aims to return humans to the Moon by 2025. The Gateway will serve as a communication hub, science laboratory, short-term habitation module, refuelling station, and a holding area for rovers and robots. The first elements of the Gateway will be launched in late 2024, ahead of the first crewed mission to the station (Artemis 3) planned for 2025.

As part of its development, TAS (France) was chosen by ESA in early 2021 to develop ESPRIT (European System Providing Refuelling, Infrastructure and Telecommunications), a service module of the Gateway. ESPRIT comprises 2 elements, HLCS (Halo Lunar Communication System) and ERM (ESPRIT Refuelling Module). ERM will provide the Gateway with xenon and chemical propellants, extending its service life, and paving the way for a reusable lunar lander and deep space transport (e.g. to Mars). It will also contain docking ports and a habitation corridor.

TAS UK plays a vital role by leading the development of the chemical refuelling system (part of ERM). With CMIN19 funding, TAS UK was sub-contracted (€1.3m) to explore the concept definitions for the Hydrazine refuelling element of the Gateway. This contract covers phases B2 through to E1. TAS UK is currently in the design stage and is building the test rig at Harwell, which will be delivered in Q2 2022. The delivery of ERM is planned for 2026 and is anticipated to be launched in 2027.

This work builds on a design study (Phase A/B1) led by TAS (France), prior to consortium selection in late 2020.

Lunar Gateway Concept



Source: ESA

Impact

The benefits of TAS UK's €1.3m contract are anticipated to be realised in the coming years, as the funding was awarded fairly recently (early 2021).

For the contractor & the UK space industry

- TAS UK emphasised the main impact of its work on ERM to be the development of technology leadership. In-orbit servicing is an important topic, increasingly becoming a priority area of interest for government and commercial space actors, notably due to concerns around the financial and environmental sustainability of space activities. Work on this contract enhances TAS UK's competitiveness and helps securing follow-on funding and contracts from ESA for satellite-refuelling activities.
- CMIN19-funded activities around the Gateway are enabling TAS UK to develop skills, capabilities and technologies that will help the UK secure a leadership position in in-orbit servicing.
- TAS UK will be in a good position to offer refuelling services and help adapt telecommunication satellites to in-orbit servicing and is establishing itself as a key player in commercial refuelling. This would result in economic benefits for the UK, through follow-on institutional and potential private sector sales, sustaining and creating highly-skilled jobs, and catalysing internal investments in TAS UK's ground infrastructure.
- The technology surrounding an in-orbit refuelling system for the propellant Hydrazine is completely new. While some work has already been conducted on technologies like pumps and transfer of fuel (i.e. on the ISS), TAS UK's innovative system will be the first that could be used as a 'petrol station in space'.
- In-orbit refuelling technology could change the 'philosophy' of satellites, removing significant mass at launch by planning for subsequent in-space refuelling, aiming, in the long run, to reduce operating costs.

For the UK government & society

- The UK is developing state-of-the-art expertise in refuelling satellites, meaning it could be able to refuel its space-based assets (i.e. satellites providing data for defence, telecommunications, Earth Observation, navigation, science or other purposes), which are essential for service provision on the ground. Through life-extension of these assets – especially for defence satellites such as Skynet-enabled military communications - this would contribute to ensuring the resilience of critical national infrastructure, which is an integral part of the Government's National Security Strategy. CNI protection can also come through reduced orbital congestion from fewer launches, as discussed below.
- TAS UK's work on the refuelling element is expected to contribute to the Government's Levelling-Up Agenda, as the manufacturing will take place in Northern Ireland (Belfast) and the designing and testing

of the chemical refuelling system South East England (Harwell). Current and future contracts help TAS UK sustain jobs in these area, supporting the local economy.

Wider benefits

- Developing in-orbit refuelling capabilities may also lead to environmental benefits. If new and existing satellites can have their lifetime expanded through refuelling, fewer replacement satellites will be required cutting down launch emissions. Additionally, refuelling satellites implies fewer dead orbiting satellites and fewer launches, preventing further congestion in Earth's orbit, thus helping with space traffic management and the problem of space debris. This, in turn, further contributes to ensuring the resilience of space-based critical national infrastructure.
- In the long term view, the refuelling element of Lunar Gateway will be a critical part of the Gateway and is expected to play a key role in future Lunar and Martian exploration, e.g. enabling a reusable Lunar lander, which will increase scientific output of Lunar missions.

Additionality and ESA-added value

UK participation to ERM would have been unlikely without investment via ESA. ESA is one of the main space agencies developing the Gateway, and contracts would have likely gone to other member states if not to TAS UK. Given the main contract for the whole ESPRIT module went to TAS (global), there is also an element of FDI attributable to UK ESA funding. Because of the clear difficulties in de-risking and developing complicated space assets nationally, ESA funding was also essential to get over the entry barriers to the technology and provided a 'stamp of approval', which will subsequently help with the exploitation of commercialisation opportunities at the Gateway and in securing future funding and FDI for the UK. Because of the nature of a complicated, multi-stage, and internationally-collaborative mission like the Gateway, the associated impacts from activity from this contract would be unlikely to have occurred without ESA funding and participation.

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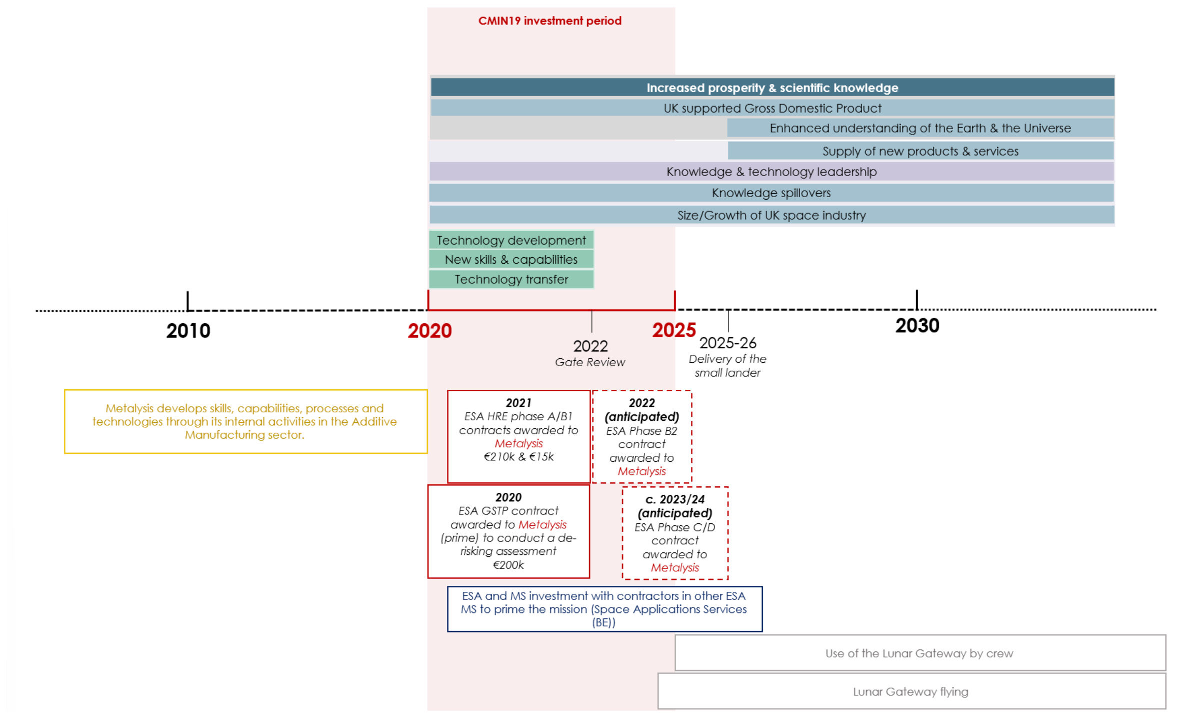
8.4 Metalysis: Producing Oxygen on the Moon through In-Situ Resource Utilisation

Title	**Metalysis: Producing Oxygen on the Moon through In-Situ Resource Utilisation (ISRU)**
Summary	Metalysis is a UK-based company that generates oxygen as a by-product of its activities in the (terrestrial) additive manufacturing sector. This sparked ESA and UKSA's interest, as oxygen is a considerably valuable element that can be used for propellant and habitat support in space. In the context of renewed interest for Lunar (and Martian) exploration, ESA awarded three contracts to Metalysis to adapt its terrestrial processes and technologies for extra-terrestrial oxygen production for in-situ resource utilisation (ISRU). These CMIN19 contracts have enabled Metalysis to advance the technology, enhance its reputation, create new relationships with space actors, create new jobs and develop space-related skills and capabilities. The ESA-funded work has significant commercial potential, with follow-on sales for extra-terrestrial oxygen production expected to reach £100m per annum in 10 years. In the long term, ISRU is expected to facilitate space exploration, contribute to better understanding Earth and the Universe, and enable future Moon and Mars settlement activities. While CMIN19 funding led to Metalysis 'spinning-in' to the space sector, the impact of these contracts spills over to the company's terrestrial activities as well.
Type of impact	Main: • Technology development • New skills and capabilities • Technology transfer • Knowledge & technology leadership • Size/growth of the UK space industry • Supply of products and services based on space infrastructure • Knowledge spillovers Other: • Increased employment & skills • Increased knowledge & innovation • Commercial & consumer benefits
ESA contractor(s)	Prime contractor: Space Applications Services (Belgium, for the 2021 contracts), Metalysis (for the 2020 contract) Sub-contractor: Power Resource Group Ltd. (Metalysis, UK, for the 2021 contracts)
ESA contracts	Awarded to Metalysis as a prime contractor, part of the GSTP programme: • De-risk assessment of the Metalysis process for extra-terrestrial oxygen production from ISRU €200k (2020) Awarded to Metalysis as a subcontractor to SAS, part of the HRE programme: • ISRU ground-based research investment and utilisation: €210k (2021) • ISRU Phase B1 for an oxygen extraction demonstration payload: €15k (2021)
Complementary activities	Metalysis' original focus is on producing metal parts for the additive manufacturing sector. The company developed skills, capabilities and technology through internal investment for these terrestrial activities.

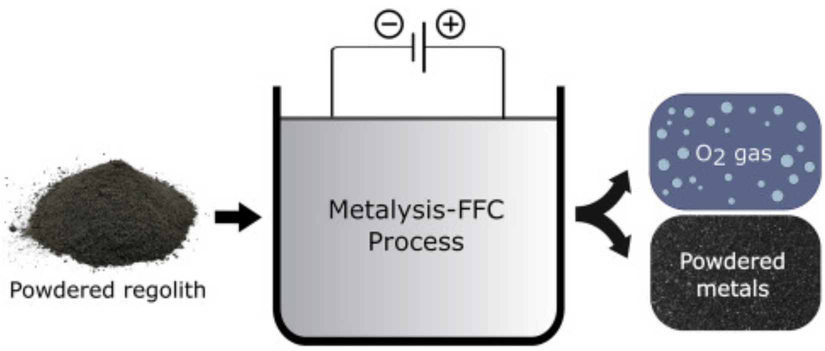
Timeline of Metalysis' ISRU activities CMIN19 impacts



Activities

Metalysis is a UK-based (non-space) company that produces metal parts for the Additive Manufacturing sector. It generates oxygen as a by-product of its activities which is a valuable resource in space as a propellant and for supporting life. Being able to generate oxygen *in situ* would enable longer and further-reaching space exploration, hence ESA and UKSA's interest in exploring the concept.

Oxygen generation from ISRU



Source: Lomax, et al. (2020)

ESA awarded three contracts to Metalysis through CMIN19 funding to develop the technology and adapt the proven terrestrial processes and technologies for extra-terrestrial oxygen production for ISRU using Lunar resources (Lunar regolith). The company was awarded its first ever ESA contract (as the prime) in 2020 under GSTP. Amounting to €200k, it focused on the fundamental process, with Metalysis conducting a de-risking assessment. The next two contracts (€210k and €15k) were awarded to Metalysis in 2021 under HRE as a sub-contractor to Space Applications Services (Belgium). They begin the process of making the technology and processes flight-ready.

As of December 2021, Phase B1 was concluded and Metalysis is awaiting feedback from ESA on whether the consortium has been successful for further developments and funding. If so, the company expects to make a full lunar package ready by the end of Phase B2, which would take 12 months to complete. Ultimately, the project aims to develop a small lander by 2025-2026 that would demonstrate that the technology works in space, before (potentially) being scaled up and used on exploration missions.

The CMIN19 ESA funding is expected to enable TRL advancement from TRL 3 to TRL 6, which is anticipated to be reached by the end of Phase B2 in late 2022. Metalysis' contracts are also expected to de-risk the technology, enabling a scale up of oxygen production from ISRU on the Moon in the future.

Impact

For the contractor & the UK space industry

Broadly, Metalysis exemplifies the case of a spin-in to the UK space sector, bolstering UK industry space capabilities:

- Two-way technology and knowledge transfers have occurred as a result of these ESA contracts, with consortium partners learning about Metalysis' processes and technologies and Metalysis learning how to use them in space.
- These capabilities are expected to have significant commercial opportunities. Once proven through the small lander developed by 2025-2026, the technology and processes could be used by Metalysis to offer an oxygen production service -- in space, it could be used as a 'gas station' on the Moon, and be exploited for propellent or habitat support. Follow-on sales are anticipated to reach £100m per annum in 10 years, lasting at least another 10, with clients envisioned to include governmental space agencies and private ventures.
- Work on these CMIN19 contracts also grow UK leadership in ISRU, which can help the wider UK industry capture some of the significant commercial and follow-on funding potential going forward.

Some of the other main impacts of these contracts for Metalysis are increased reputation and the associated benefits:

- The company's space activities have significantly raised its profile, as space itself, Lunar, and Martian exploration are popular topics with other businesses and the public.
- Holding ESA contracts provides a 'stamp of approval', which is helpful in the space sector and beyond.
- Metalysis reported that it is now broadly seen as a space company as a result of ESA contracts despite being entirely new to space in 2020.
- Metalysis developed new relationships with wide-ranging stakeholders in the space sector, from space agencies like ESA and UKSA to its Belgian prime contractor (Space Applications Services) and other consortium partners (SMEs and academia).

CMIN19 contracts also led to increased R&D activities, hiring, and upskilling:

- Allocating investments from terrestrial activities into space.
- Doubling in size from March 2021 (12 employees) to December 2021 (25 employees). In addition to the 13 jobs already created, a further 25 are anticipated within next 12-18 months.
- Gaining new space-related skills and capabilities and increased cross-sectoral transfers within the company.

For wider society

- CMIN19 contracts have helped Metalysis develop more efficient processes and reduce the carbon footprint of its terrestrial activities (something which was referred to as 'ground-breaking' for the metal sector).
- Metalysis' processes and the end-user adoption of their technology would contribute future lunar and Mars exploration, helping humanity better understand our solar system and Universe, enabling more sophisticated exploration missions and even human settlement on the Moon or Mars.
- On Earth, Metalysis expects terrestrial commercial application of oxygen extraction could bring benefits to wide-ranging sectors (e.g., aerospace, defence, electronics, medical).

Additionality and ESA-added value

As the ISRU activities were fully funded since 2020, Metalysis highlighted that the impacts outlined associated with the ISRU technology are entirely attributable to CMIN19 investments, while advancements in skills and capabilities in the terrestrial application are more difficult to link specifically to the CMIN19 contracts.

ESA not only offered the interest that brought Metalysis into the space sector in the first place, it also provided funding that would have been difficult to secure internally or in the private capital community, considering the uncertain and distant commercial end-point.

This is also an example of the ESA value-add highlighted in this chapter: realising the utility of ISRU oxygen production springs from an expert view of the opportunities and challenges of exploration, and it's uncertain whether the UK would have seen the 'spin-in' potential (or prioritised an investment) on its own.
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9 General Support Technology Programme

9.1 ESA's General Support Technology Programme

The General Support Technology Programme (GSTP) is part of a wider portfolio of ESA programmes across domain areas that supports space-related technology development. GSTP was created in 1993 to ensure the continuity of technology development in critical technology areas, as identified by ESA and its member states. Over time, the programme has changed and developed to meet the ever-changing needs of the European space community, growing significantly in size and scope.

Technology development programmes aim to support hardware and software that will likely be incorporated into future ESA missions. The technology development programmes sit within two complementary elements, mandatory programmes, and optional programmes. Many of the other domain areas, as detailed within this report, have specific technology development components, but GSTP represents the only optional programme that is not domain specific. In this vein, GSTP is designed to support all types of space-related technology development except for telecommunications, which is funded within the much larger ARTES programmes.

Table 26 Overview of Generic technology programmes in ESA

Mandatory	**Optional**
Basic Technology Research Programme (TRP)	General Support Technology Programme (GSTP)
European Components Initiative (ECI)	

ESA's TRP and GSTP Technology Programmes: A General Overview

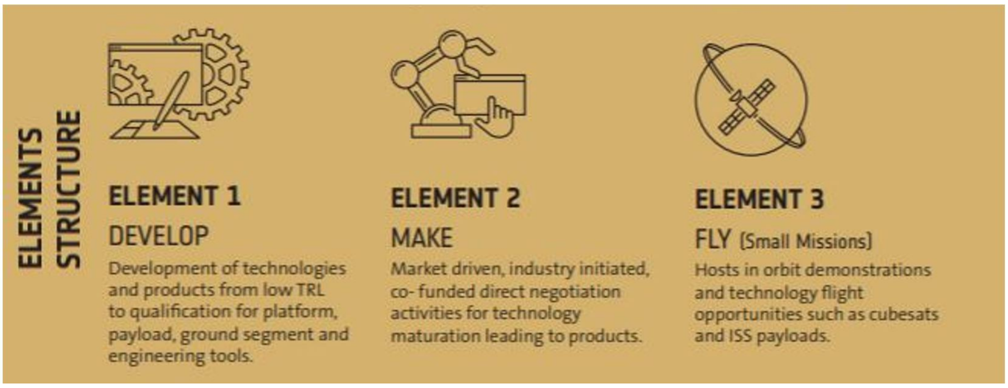
As an optional programme, GSTP requires the voluntary participation of ESA member states. Nearly all countries choose to participate in GSTP to some degree, although each country emphasises different priorities in their investment to GSTP. Participating member states contribute to GSTP and then receive an allocated proportion of those funds minus the ESA overhead, which covers project application and project management. The objectives of GSTP can largely be defined within four areas:

- Enable activities at ESA and National programmes through technology development
- Support the competitiveness of UK and European Industry
- Foster innovation within the space sector, and encourage the uptake on non-space technology for use in the novel space related applications
- Enhance UK and European technology non-dependence

To achieve the objectives of GSTP, the programme is separated into three distinct Elements, Design, Make and Fly. Each Element is funded independently, with each participating member state able to choose the amount of investment into the programme overall and to which elements that investment is allocated. However, at the request of each member state, funds can be moved between Elements at their discretion. The description of each element is as follows:

- Element 1 "Develop": Technology developments for future missions, ground applications and tools
- Element 2 "Make": Development of technology and products for commercial sustainability
- Element 3 "Fly": In-orbit demonstration of new technologies, preparation of future missions and small missions

Figure 41 GSTP Elements



ESA GSTP Elements Graphic[77]

Across the three elements GSTP can support projects from TRL 3 all the way through TRL 8/9. Broadly, each element is focused on a different TRL stage for the projects. Element 1 Develop, is intended for early-stage technology development, generally allowing a technology to progress from TRL 3 through to TRL 5. This is followed by Element 2 Make, which supports projects in TRL 6/7, with Element 3 Fly offering flight testing opportunities at TRL 8/9. If a country chose to fund all elements of GSTP, they could offer commercial support throughout this process, shepherding critical technology from the early design phase all the way through in-situ validation. Although this is possible, it is not something that most participating member states choose to do. The majority of member states focus the majority of their resources on Element 1, with significantly less in both Elements 2 and 3.

GSTP is designed to help leverage private spending in support of technology development through co-funding requirements on commercial applicants. Co-funding rates are not set uniformly across all GSTP Elements, however maximum co-funding rates are set for different types of participants. Within GSTP, Universities and research organisations can receive full funding, SMEs receive up to 80% and Primes receiving up to 50%. In Element 1 Develop projects can be either fully funded or co-funded, in contrast to Element 2 Make and Element 3 Fly, which can only be co-funded. Overall co-funding rates for GSTP are not readily available, as the rate is determined on a project-by-project basis. However, for all projects, the co-funding rate does not exceed 50%.

9.1.1 *Programme Logic Model*

Figure 42 below details the UKSA ESA logic model, highlighting the pathway to impact for GSTP. Broadly speaking, the outputs and impacts of GSTP largely sit with the companies that receive contracts from ESA. However, over time the effects of participation in GSTP have the potential to support future ESA missions, the UK space-sector, more broadly and even to enhance critical manufacturing and infrastructure in the UK.

UK Space Industry

As outlined in the theory of change, the objectives of the GSTP programme from the UK perspective are largely focused on the UK space sector. Support for technological

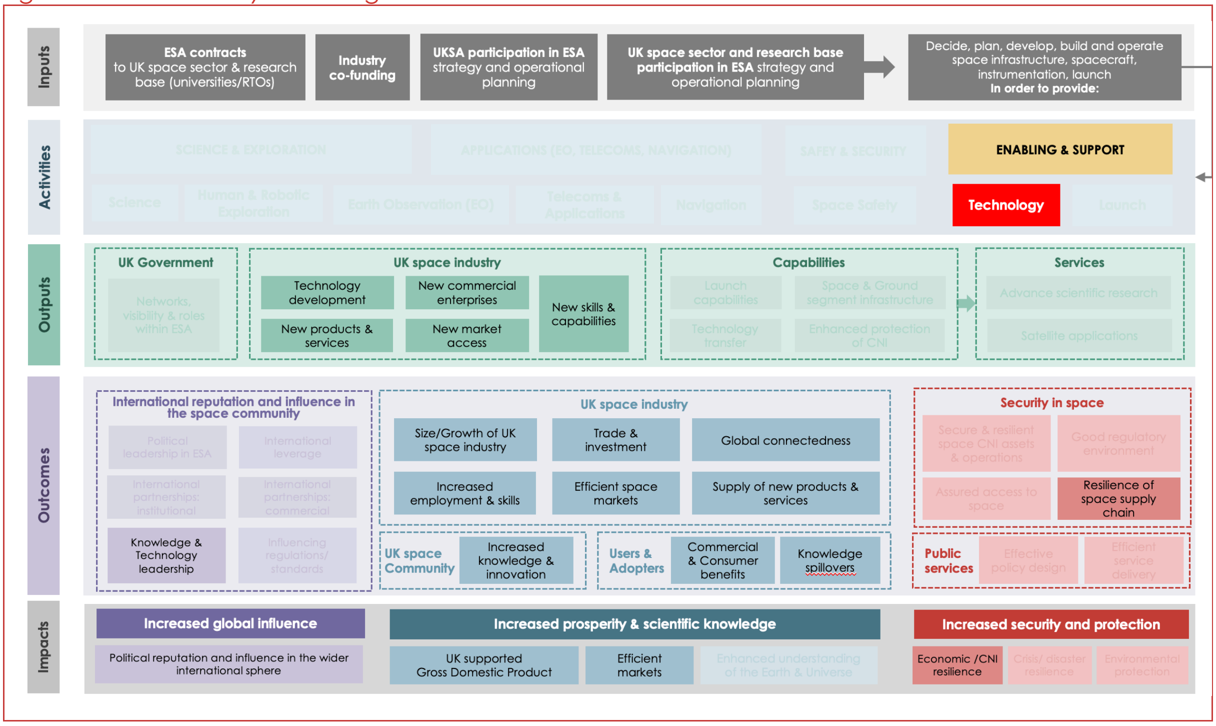
77 https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/About_the_General_Support_Technology_Programme_GSTP

development in the early stages provides a significant boost to the UK space sector, allowing them to progress their technology more rapidly, enter the market more quickly, and ideally beat their competitors while capturing significant market share. The development of technology through GSTP allows for the creation of new markets, as well as the development of technology that will become the lynchpin of future ESA missions, positioning the UK to gain benefits from the GSTP programme for many years after the initial investment.

Security in space

Through GSTP, the UK also has an opportunity to support companies that fill gaps in the UK space sector supply chain. Having a voice in which projects get funded, the UK can choose to fund projects where there are perceived deficiencies in the UK space sector. These choices can also align with UKSA and government priorities, whether that be the recent National Space Strategy[78], or previous iterations of the Industrial strategy[79]. Funding these projects through ESA can improve industrial and commercial outcomes with technical support from ESA staff that is unmatched through domestic pathways. Having discretion over chosen projects can also plug gaps in the UK space sector that would otherwise take many years to fill, with those companies likely to be far behind their international competitors by the time products are ready to come to market through private investment. This in turn can improve outcomes in the UK space sector and make it less reliant on foreign technologies and capabilities.

Figure 42 GSTP Theory of Change



9.2 UKSA's involvement in GSTP

The UK has committed a significant investment in the UK space sector technology development through GSTP, with €56.69M being allocated to the programme prior to 2019. This

[78] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1034313/national-space-strategy.pdf

[79] https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

funding will nearly be matched in the CMIN 19 period, with an additional €40M being allocated to the programme. Over the years, UK spending on GSTP has varied but the consistency of UK contributions has made it the third largest participant of GSTP across ESA member states, accounting for just more than 10% of total cumulative investments in the programme since it began.[80] This places the UK behind only Germany and Belgium, who account for 23.5% and 22% respectively.

GSTP is seen as a critical technology development pathway for UK firms. In the CMIN19 business case, GSTP is described as a pathway to demonstrating the credentials of UK space products which leads to increased opportunities to support all other ESA programmes, as well as national and international programmes. GSTP support is essential in directing the technological development of the space sector, making UK firms more competitive against other ESA member states. Supporting a project in GSTP, at comparatively low cost to other programmes, can lead to much larger contracts in the future and elevate the UK space sector as a reliable and capable partner.

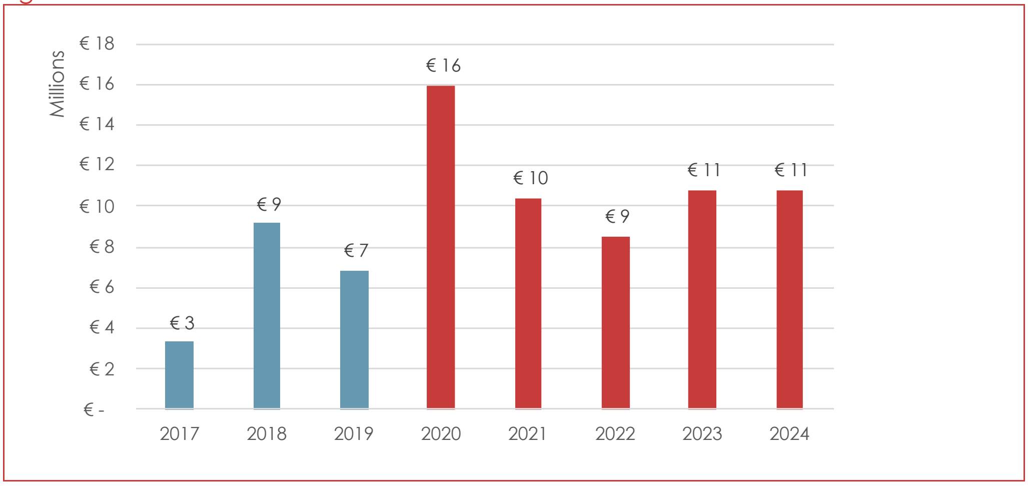
All projects funded within GSTP are assessed by UKSA to determine whether they should be supported through a process detailed on the UKSA GSTP website. If the proposals meet the criteria of the UKSA and are endorsed by the GSTP Review Panel, then the selected projects receive a letter of support, a necessary step before applying to ESA. This ensures that UKSA is both aware of all projects that are funded within the programme but can also ensure that projects meet the needs of the UK space sector in the coming years.

9.3 Inputs and activities

During the CMIN19 period (2020-2024) a total of €56.52m has been allocated to GSTP in ESA financial obligations data, however, only €40m of that is considered new money agreed at CMIN19. The additional funding is a carry-over in spending from the previous CMIN16 period, as the agreements can last longer than the now formalised three-year gap between ministerial meetings. The higher figure for 2020, as seen in Figure 43, is indicative of the overlap between CMIN periods. The indicative yearly allocation of GSTP funding has risen during the CMIN19 period compared to prior years. Despite ESA illustrating the spread of ESA spending through to 2024, the UK can choose to support contracts earlier on in that period than is indicated, therefore the actual spread of spending within the GSTP programme is largely at the discretion of the UKSA and ESA GSTP teams.

[80] This includes both past years, as well as committed spending on GSTP through the year 2026. These numbers will change as future CMIN agreements are signed

Figure 43 UK commitments to GSTP 2017-2024



ESA datasheet on national obligations

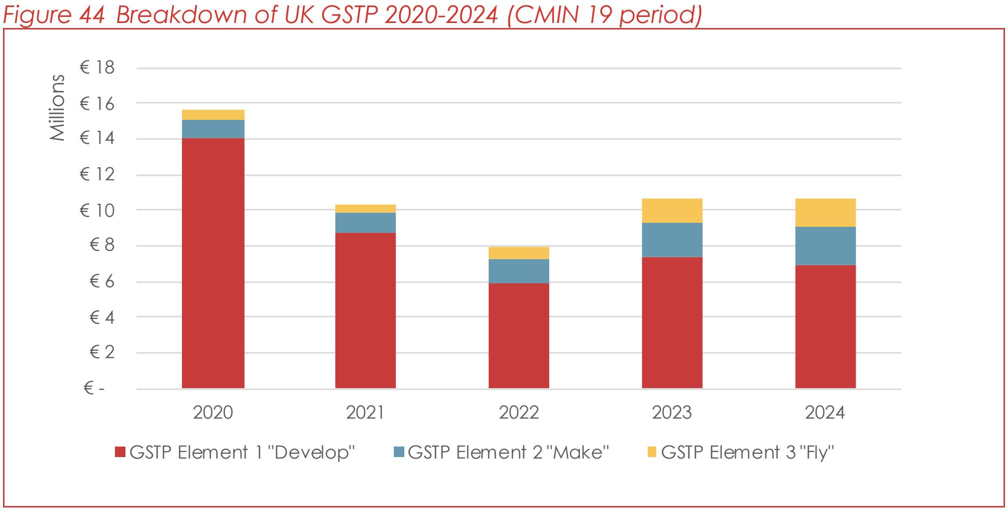
The UKSA has chosen to weight its contribution to GSTP towards the first of the three Elements, focusing on the earliest TRLs proposals. Broken down in Table 27, Element 1 Develop has been allocated €28m, representing 70% of the entire newly allocated funds to the programme. This is significantly larger than the 20% (€8m) allocated to Element 2 Make and 10% (€4m) to Element 3 Fly. As shown in Figure 44, the bulk of spending in each year is in Element 1, with only a small fraction being spent on later TRL Element 2 and Element 3 projects.

Table 27 Element breakdown of GSTP funding

GSTP Element	CMIN19 funding allocation
Element 1 Develop	€28m
Element 2 Make	€8m
Element 3 Fly	€4m

ESA Document 100

Figure 44 Breakdown of UK GSTP 2020-2024 (CMIN 19 period)



ESA datasheet on national obligations

Over the period 2020 to Q2 2021, represent half of the primary spending period for CMIN19, ESA has awarded 69 GSTP contracts, amounting to a total contract value of €25.5m. The value of the contracts represents the total value of the contracts, with actual contract spending likely to be spread out over a wider period. The bulk of the contracts, both in terms of value (84%) and number (81%) have been awarded to companies. Although secondary or higher education establishments only receive a small amount of funding through GSTP, it appears that their research does play a role, with their relative overrepresentation in comparison to their portion of contract values.

Table 28 GSTP contracts breakdown by entity type 2020-Q2 2021

Entity Type	Value of Contracts (M€)	% of total	Number of Contracts	% of total
Company	€21.49	84%	56	81%
Research Organisations (academics and RTOs)	€4.01	15%	13	19%

ESA geo-return datasheet

As shown in Table 29, much of the funding to GSTP remains concentrated in a small number of contractors. The top 10 recipients received two thirds of the contracts by value during this period, with the top 5 recipients awarded just below 50% of the contracts by value. Unlike many other programmes there is a diversity amongst the participants, with large firms, small firms, research organisations, and higher education institutions all included in the top 10.

Table 29 Top 10 GSTP contract recipients 2020-Q2 2021

Entity Name	Total Contract Value (M€)	% of total value of GSTP funding	Number of Contracts
GMV NSL LTD	€4.28	17%	10
THALES ALENIA SPACE GB (TAS GB)	€3.08	12%	3
CGI(GB)	€2.30	9%	1
POWERLINE TECHNOLOGIES LTD	€1.43	6%	1
UK RESEARCH AND INNOVATION	€1.25	5%	4
MARS SPACE LIMITED	€1.20	5%	1
NATIONAL PHYSICAL LABORATORY	€1.05	4%	2
UNIV. BIRMINGHAM	€0.91	4%	2
AIRBUS GB (ADS GB)	€0.73	3%	4
RHEATECH LTD	€0.66	3%	2

ESA geo-return datasheet

9.4 Outputs

After consulting with participating stakeholders and assessing GSTP specific survey responses, there is a view that the GSTP CMIN19 projects have been progressing well and leading to a limited number of outputs to date. Interviews were conducted in the latter half of 2021, with survey responses collected in autumn and into 2022, so there are likely to be additional outputs over time with more projects being completed after that time.

Figure 45 Key outputs from CMIN19 GSTP investments

- Technology development, with notable increases in mid-TRL development (3-5)
- New commercialised products and services
- Access to new markets as a result of GSTP Product development
- Increased employment and retention of employees
- Development of new skills and capabilities, over 90% of survey respondents indicated improved internal capabilities due to ESA projects

9.4.1 *Technology Development*

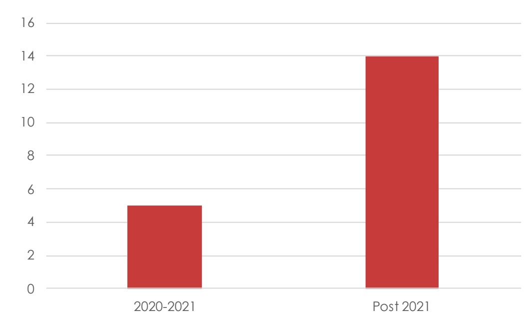
GSTP contracts in CMIN19 have broadly supported advances in space related technologies. Interviewees and survey respondents have indicated that their contracts have progressed at pace and are allowing them to deliver their technologies far more rapidly than they would otherwise. Despite the relatively short nature of GSTP projects, respondents indicate that the TRL of supported technologies improves by more than 2 TRL levels during the duration of a GSTP project. This is particularly important when most GSTP projects develop from TRL 3 to TRL 5, where it has been historically difficult to attract external investment to novel product development. The largest increase seen amongst the survey respondents saw a rise of 4, from TRL 3 to TRL 7.

Interestingly, companies both large and small credit GSTP with supporting critical technology development. Interviewees at large firms have stated that GSTP supports the pursuit of completely new products, particularly those where markets are not yet mature, and companies see little short-term profit in the development. As a large firm, leveraging GSTP funding to support novel technologies can galvanize company funding in ways that would otherwise not occur. In contrast, interviewees from SMEs approach GSTP as an essential pathway to commercialisation, often building upon smaller amounts of national funding (NSTP, IUK) before applying to GSTP. GSTP requires such a high level of technical expertise that at an earlier stage the requirements are too onerous for SMEs to succeed.

9.4.2 *New products and services*

Interviewees and survey respondents affirmed that a wide array of products and services will be launched because of GSTP projects. Although many CMIN19 GSTP projects are still underway, a few have already led to the launch of new products or services. The launch of these products is still expected to come

Figure 46 Products/services commercialised as a result of ESA contract(s)



ESA contractor survey

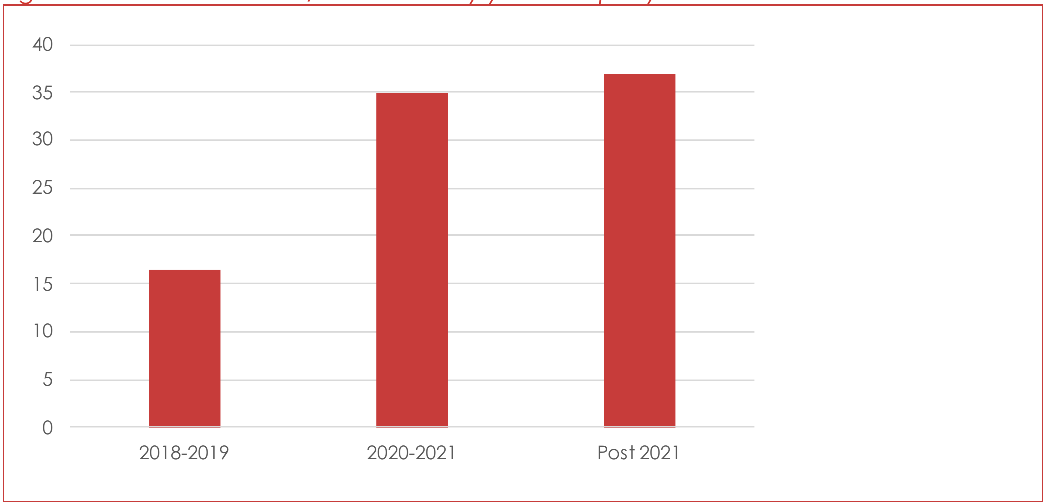
Due to the relatively early and mid-stage TRL for GSTP projects (3-7), the commercial benefits of GSTP from CMIN19 funding remains somewhat limited. With many projects continuing their development after the conclusion of GSTP funding there is likely to be a lag between concluding a GSTP project and garnering additional external funding for programme participants. Interviewees and UKSA staff have highlighted past successes in the commercialisation of GSTP projects, and there is a similar expectation for the current crop of projects that have been undertaken in the CMIN19 funding period.

Despite the limited commercial benefits to date, interviewees have highlighted the decreased time to market that they will be able to achieve because of their participation in GSTP. Interviewees have indicated that this reduction can be as much as half of the expected time to commercialisation, allowing participants to beat competitors to market, both in the UK and overseas. This is particularly critical in areas where unique innovations may have limited markets, so being first to market with a successful product is critical to capturing significant market share. The rationale provided for this reduction is that the funding is earmarked for the projects and entirely ring-fenced, allowing participants to focus their time and resources on project delivery without the distractions that would otherwise draw attention away from R&D.

9.4.3 *Increased employment*

GSTP contractors, both from the survey and interviews detailed the benefits of GSTP on the retention and attraction of staff. Participation in the programme was seen as particularly critical to SMEs in the attraction of new and experienced staff, often creating new jobs as they ramp up their efforts to meet project targets. GSTP has a clear long-term impact on employment with participating firms, with companies hoping to retain new staff for the foreseeable future. Most of the employment gains were seen in the shorter term, with the largest jump in employment related to ESA contracts during 2020-2021, the start of the CMIN19 investment period. The gains in employment appear to stabilise after that point, with only a small number of new hires expected post-2021. However, interviewees and survey respondents indicated that any hires due to GSTP contracts were likely to be retained as the companies grew. The reason behind this tapering of employment gains is not clear, some contractors suggested that the once the R&D was completed, they could re-task their R&D teams to new projects while utilising a lower number of staff in production and sales. A sustained R&D base in the space sector would support longer-term gains in other areas over a prolonged period.

Figure 47 FTE created and/or retained by your company as a result ESA contract income



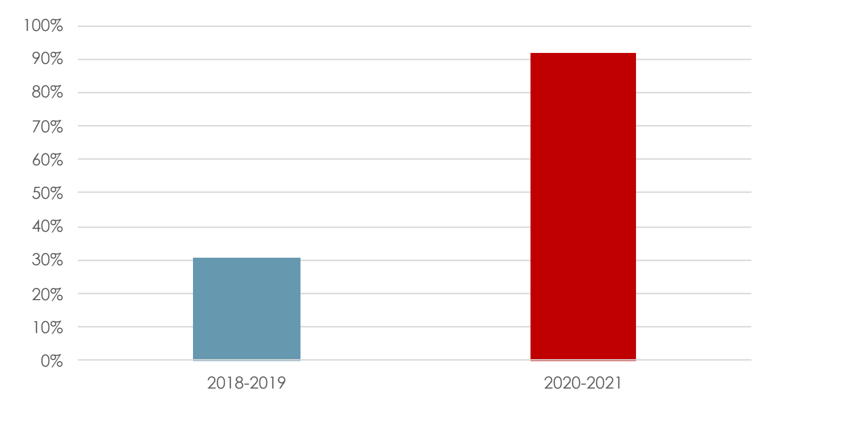
ESA contractor survey n=13

9.4.4 *Skills, capabilities, and competitiveness*

The development of staff has also been highlighted as a key benefit of the participation in GSTP projects. The ability to attract new personnel is critical to the delivery of GSTP projects, particularly for SMEs, where complex project management and niche engineering expertise may be in short supply. Interviewees indicated that the funding from GSTP has allowed them to accelerate the hiring of new staff to deliver these R&D projects, thereby increasing the range and depth of skills they can call on from their own staff. Key

Survey respondents also indicated that improved in-house skills/knowledge was a key output of their participation in GSTP. Critically, 92% of GSTP survey respondents indicated they saw improved internal skills/knowledge after the start of their CMIN19 projects. This represents a dramatic increase, 61%, over the prior period.

Figure 48 New or improved skills / knowledge

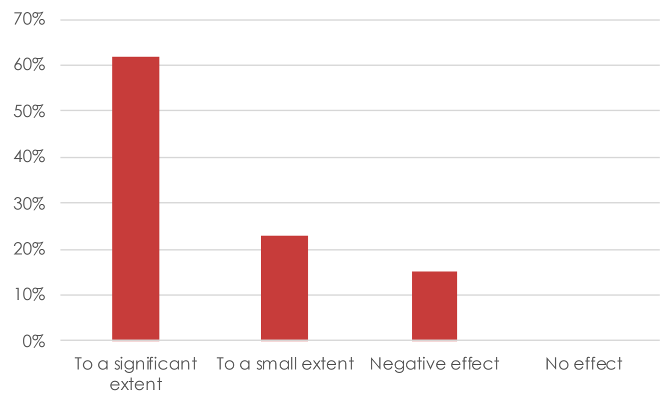


ESA contractor survey n=13

The ability for staff to devote their full efforts to R&D projects in GSTP is essential in the improving of skills and capabilities. Under other circumstances, interviewees have indicated that they would not be able to commit the same level of time and resources to these projects, focusing more on earning income in other areas. The opportunity to run these projects through GSTP allows the companies and staff to enhance their own expertise without undermining the company bottom line.

Improved skills and capabilities through participation in GSTP is also linked to wider company competitiveness. Interviewees have indicated that the success of their GSTP projects has led to follow-on projects, new partnerships, and potentially new ESA contracts. This has been supported by the survey data with 85% of respondents indicating that GSTP had improved their international competitiveness, and 62% indicating it had done so to a significant extent. The ability to prove their technology to ESA at an early stage was seen as essential to winning more advanced and lucrative contracts in the future. New technologies are rarely flown on ESA missions, where reliability and a proven track record are given significant weight. Interviewees and survey respondents have shown that participating in GSTP can alleviate some of those concerns, as GSTP allows for the technology to be developed with ESA oversight.

Figure 49 Increased international competitiveness as a result of ESA contracts (post-2019)



ESA contractor survey

9.4.5 *Papers and publications*

Although there are some advanced technologies being developed within the scope of GSTP, only a limited number of interviewees indicated any push toward scientific publications or patents as part of these projects. However, survey respondents did demonstrate that GSTP is producing advances in knowledge, with 9 papers being published in 2020-2021 because of their GSTP projects. It is likely that further publications and patent applications will materialise once products move out of the design phase and progress to prototyping and in-flight validation.

9.5 Outcomes and impacts

Given the robust evidence of outputs from the first year and a half of the CMIN19 period, we can expect further generation of near-term outputs as further contracts are signed. With many of those early projects coming to an end, we can begin to observe and predict medium and long-term outcomes and impacts generated from the CMIN19 investment. The predicted outcomes and impacts from the CMIN19 investment should only be considered an early look at the much broader impacts that are to be expected over time. The early indications, as summarised in Figure 53, show considerable potential for wide ranging impacts from the CMIN19 GSTP investment.

Figure 50 Key outcomes and impacts from CMIN19 GSTP investments

Increased prosperity and scientific knowledge

- Wide ranging commercial opportunities, with anticipated income and follow-on sales
- Increased reputation amongst programme participants in the UK and abroad
- Leveraging of GSTP to support further R&D investment in the space sector
- Improved supply chain resilience

9.5.1 *Increased prosperity and scientific knowledge*

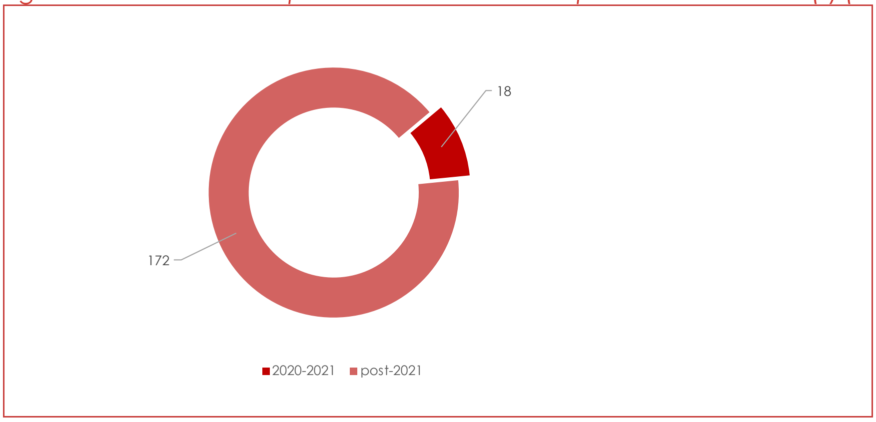
9.5.1.1 Commercial opportunities

Participants in GSTP have reported wide ranging commercial benefits in the medium to long-term. The ability to develop their technologies and bring them to market in a timely fashion is anticipated by both interviewees and survey respondents to improve company bottom lines for years to come. Survey respondents, as seen in Figure 51, have indicated that they have already received income of around £18m pounds due to their GSTP contracts, but expect that to increase by nearly a factor of 10 to £172m pounds in the coming years. These firms had seen no income from ESA contracts prior to 2020, indicating that this is completely new income being generated by UK firms due to their participation in GSTP. This represents an average of over £14m in additional income per GSTP respondent.

The income is expected to be generated by several new products that have already been commercialised or will be soon. As shown previously in Figure 46, survey respondents indicated that 5 products and services have already been launched because of GSTP projects. However, these products and services were concentrated in only 2 (n=9) of the GSTP survey respondents. This is expected to expand to 14 new products and services spread across 8 firms after 2021 (n=9). Interviewees also highlighted that some research being conducted at present is not likely to lead to products in the immediate term but will be further developed in the coming years into novel products, services, and applications.

Current projects will also likely inform other R&D projects currently under way, thereby amplifying the benefits of GSTP to participating firms. Contractors explained that their ability to focus R&D efforts on GSTP projects offered them significant gains outside of the direct project deliverables. Particularly in smaller firms, where R&D teams are limited in size, there were multiple instances of project cross-fertilisation, with ideas and concepts filtering into other existing R&D developments as well as concepts for future work.

Figure 51 Current and Expected Income from outputs of ESA contract(s) (£m)



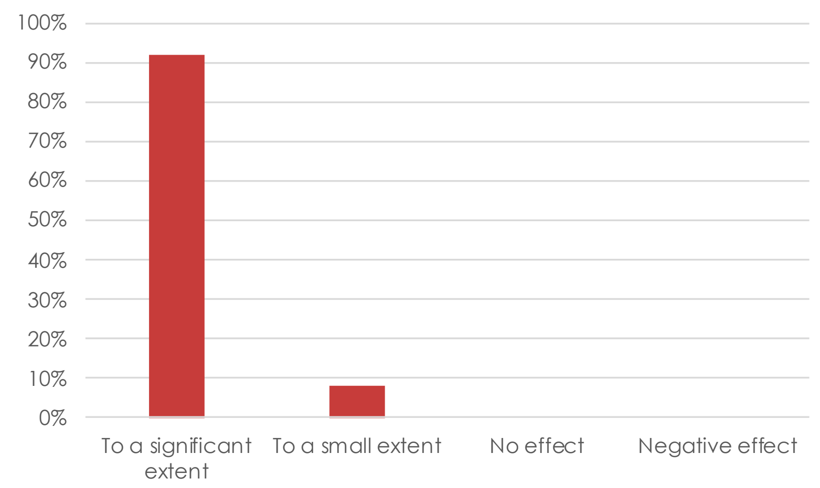
ESA contractor survey n=13

9.5.1.2 Influencing R&D spending in the UK

Investments through GSTP have led to the leveraging of greater amounts of R&D spending at participating firms. Interviewees have highlighted that their companies are often loathed to support projects without clear long-term commercial prospects, however, GSTP support is often able to overcome this internal reticence. Large companies that have applied and won GSTP contracts, have been able to mobilise greater R&D spending than would otherwise have been possible for niche projects. The awarding of a GSTP contract offers a significant incentive to these firms to re-direct R&D spending to the projects when they may not have considered them a priority before. With many GSTP projects leading to future sales, companies are less fearful of investing their own money to match the GSTP funding and leverage the ESA support to achieve greater commercial results.

Survey respondents have also highlighted the influence of GSTP contracts on their internal R&D strategies. All survey respondents (n=12) indicated that winning a GSTP contract had an impact on internal investment in R&D, with a vast majority (92%) indicating that the impact was to a significant extent.

Figure 52 ESA contracts influenced level of internal investment in R&D (industry)

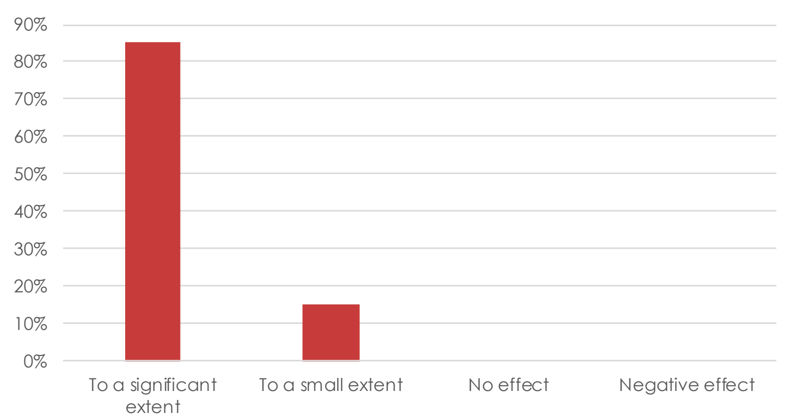


ESA contractor survey, n=12

9.5.2 *Increased reputation*

Interviewees, particularly those with products at early stages of product development, found that working with ESA increased their perceived reputation, opening unique opportunities that would otherwise not be available to them. They often spoke of having received the 'ESA seal of approval', demonstrating the prestige that others saw in the completion of an ESA project. All GSTP survey respondents similarly indicated that they experienced some level of increased reputation, with 85% experiencing a significant increase. They spoke of a perception that is held within the wider community, that ESA projects have been highly scrutinized and once completed have been done so to the highest standard. This has opened companies to new collaborations and other project that would have never materialised without GSTP.

Figure 53 Increased reputation as a result of ESA contract(s)

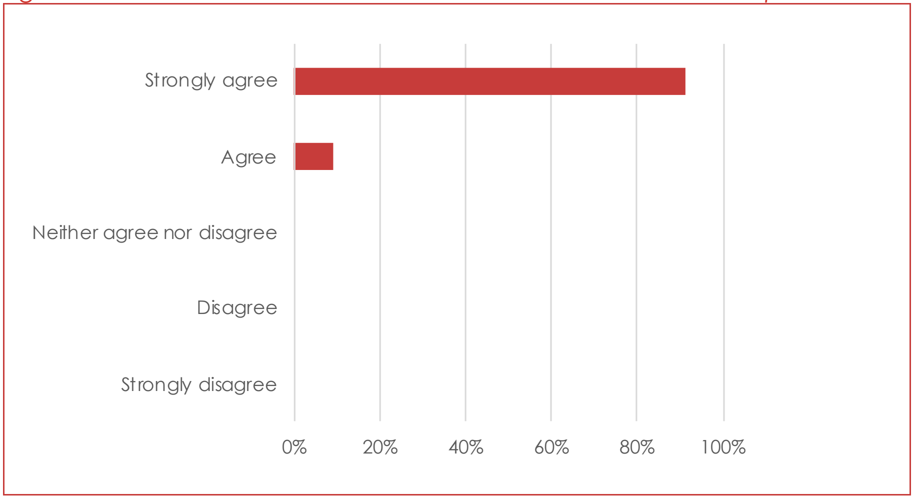


ESA contractor survey n=13

9.5.2.1 Enhanced resilience of the UK space sector

One of the key objectives of GSTP in the UK is to fill gaps in the UK space sector, thereby improving the resilience of the domestic supply-chain. While any one contract is unable to complete this task, the efforts through the GSTP programme do appear to be supporting this mission. While interviewees did not focus on this as a key benefit, a large majority of GSTP survey respondents agreed strongly (91%) that the UK investment in technology development enhanced the resilience of the domestic space sector.

Figure 54 UK investment in ESA enhances the resilience of the UK space sector and its supply-chain



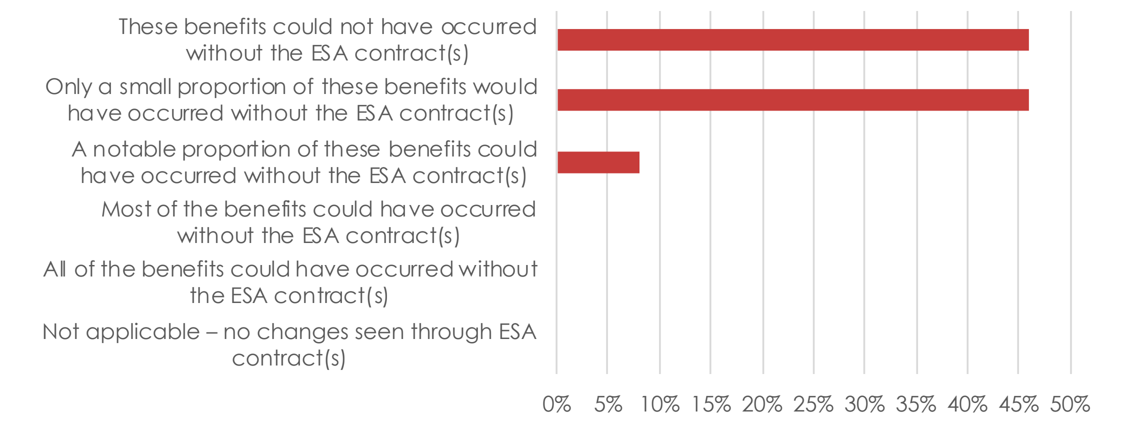
ESA contractor survey n=11

9.6 Attribution and additionality

Across all elements of GSTP, attribution of benefits to a particular project can be difficult. However, there appears to be a consensus among the GSTP interviewees and survey respondents that the benefits they have seen through the programme are largely attributable to their participation in the programme. A substantial majority of survey respondents (92%) indicated that at a minimum, only a small proportion of benefits would have materialised without the ESA contracts, as seen in Figure 55. Attribution of benefits within GSTP is most readily apparent within the SME community, where changes before and after an ESA contract are often clearly visible. Attribution at larger firms is more complex, given that some GSTP funded technologies are then incorporated into larger commercial offerings, making it increasingly difficult to directly link benefits to GSTP.

Interviewed contractors detailed how GSTP was essential in the development of the funded technologies at companies both large and small. There was a clear consensus that the projects would not have progressed at the same speed, and many were unlikely to have been funded privately without GSTP support. This was attributed to the competitiveness of the sector, where being first to market with a new technology is critical to success. Choosing to fund these projects with support from GSTP allowed their firms to advance more quickly, leverage more internal funds, and gain greater market penetration than would otherwise have been possible. While other funding streams do exist, whether that be through national supports, international programmes, or private markets, none offered the same benefits. This meant that while firms were interested in other financial supports for technology development, GSTP remained the pre-eminent space related technology development programme.

Figure 55 Attribution of the benefits to ESA contracts



ESA contractor survey n=13

9.6.1 ESA-added value

For CMIN19 Contractors

While there are funding streams available to support technology development, there are several features of the GSTP programme that make it a critical component for the space sector. The nature of the funding provided by GSTP can be **significantly larger** than on offer through national funding schemes, particularly for very early-stage projects at lower TRL levels. For larger projects, over €500k, if agreement is reached GSTP funding can be increased to beyond what is possible for national programmes (€1m). The increased scale of the funding allows participating firms to complete much more ambitious R&D projects than they would otherwise be able to accomplish.

The flexibility of the funding was also mentioned as a pivotal part of the programme. ESA contracts are not tied to financial years, like most UK programme contracts, allowing GSTP projects to run as needed from when the contract is signed. This allows for the GSTP funds to be rearranged more easily across the project as it evolves, something that interviewees have said is more difficult within national programmes.

Participation in GSTP also provided contractors with access to ESA's wider network of expertise. ESA staff have a long history of managing complex projects and can provide technical and advice but can also refer GSTP participants to ESA and other international experts when required. Access to staff at ESA Estec was highlighted as particularly useful in both overcoming particularly complex challenges as well as pushing the projects to think in ways that they had not previously considered. The expertise of ESA staff is often unique and unlikely to be replicated on a national level even with significant investment in both time and resources. Interviewees have expressed scepticism that such a breadth of expertise could be marshalled nationally, outside of traditional space powers such as the US, Russia, or China.

While developing technology outside of ESA is a possibility, GSTP helped to foster international collaborations that would be unlikely to occur outside of the ESA ecosystem. GSTP survey participants and interviewees explained that by working through ESA they could leverage the spending taking place in other member states, allowing them to pursue larger projects than they could through the UK alone. This type of international collaboration appears to be unique amongst the space related technology development programmes.

For the UK

In the short term, the ESA added value remains somewhat opaque for the CMIN19 investment. Over time, based on past evaluations of GSTP, the contribution to GSTP is expected to bring about benefits to the wider UK space sector. The technologies being developed under GSTP at present are likely to play a significant role in future ESA missions, as proven technologies are more often chosen than novel designs. The spending within GSTP also has the potential to improve UK space sector capabilities in the long term, filling gaps in UK capabilities and supporting domestic space sector supply chains in areas of critical national interest. Although the space sector is growing rapidly, it remains comparatively small to more traditional industries. GSTP helps to maintain the UK at the cutting edge of technological development, while leveraging ESA know how in the process.

The structure of the GSTP programme, being entirely optional at the national level, allows the UK to leverage the spending taking place in other countries to support national priorities. A few interviewees have indicated that when submitting significant proposals, they have been able to work with other GSTP participating national agencies, thereby sharing the cost of critical R&D. Without the structure of GSTP and ESA this type of collaborative funding would require complex bi-lateral agreements for each individual project, thereby adding to the costs and the administrative burden. The long history of ESA international collaboration is a significant benefit to the UK space sector and the UKSA.

10 Navigation Innovation and Support Programme

10.1 ESA's Navigation Innovation Support Programme Introduction

10.1.1 The ESA NAVISP programme

The Navigation Innovation Support Programme (NAVISP) is a relatively new (setup in CMIN16) optional programme that aims to address Europe's broad emerging position, navigation, and timing (PNT)-related needs and opportunities. It responds to our growing dependence on GNSS (estimated at 13% of the UK's GDP in 2018) by growing resilience to this vulnerability through fostering a strong and innovative industry.

NAVISP is a follow-on programme of the European GNSS Evolution Programme (EGEP) which funded R&D for Galileo 2 before that responsibility was assumed by the EU. At its inception NAVISP, led by the Swiss and the UK, was re-profiled to exclude Galileo and European GNSS R&D and focus instead on PNT and to stimulate the innovation in this market segment.

NAVISP's two key objectives are to:

- Maintain and extend the infrastructure delivering PNT technologies, concepts, and services to ensure that the latter continue to support European infrastructure, economy, and support citizen's lifestyle. This seeks to mitigate technology, market and business, and regulatory risks. It also aims to cover the entire value chain to secure technology readiness and deliver the quality of service required to compete with non-space technologies
- Maintain leadership by securing involvement in new markets and the exploitation of new business opportunities related to PNT for European industry.

NAVISP works with European businesses and researchers to develop innovative and competitive PNT technologies, services, and concepts, in a flexible, responsive, and rapid manner. It also seeks to support participating member states[81] in their national PNT objectives. NAVISP was designed to be user-focused and operate on a separate, yet complementary basis to the EU's Horizon 2020's (H2020) Galileo and EGNOS programmes. ESA does not fund any project that can be seen to be related to the evolution of EGNOS to avoid duplication of efforts and overlaps with the European Commission's RD&I programmes.

The expertise which was historically acquired through Galileo and EGNOS programmes can be applied to NAVISP on wide ranging activities, such as new satellite navigation challenges and concepts, scientific applications like navigation to the Moon and Mars, and as a comparator or baseline measurement method to PNT alternative. Overall, the NAVISP budget of €23.64M represents around 0.6% of the total ESA budget agreed at CMIN19.

The programme is divided in three elements that complement each other, as illustrated in Figure 56:

- *Element 1 (E1) – Innovation in satellite navigation and PNT*: generate innovative concepts, techniques, technologies, and systems linked to the PNT sector, covering the entire value chain. In this element, ESA funds early stage pure R&D and blue sky projects (TRL1-3), which selected through a competitive tender assessed internally by ESA staff, drawing on external experts if necessary. Projects activities are 100% funded and tenders are open to research-active companies, academics and research organisations. This element was seen to fill a

[81] Elements 1and 2 are open to 20 member states: Austria, **Belgium**, Canada, **Czech Republic**, **Denmark**, **Finland**, France, Germany, **Hungary** Ireland, **Italy**, **Netherlands**, **Norway**, Poland, Portugal, **Romania**, Spain, Sweden, Switzerland, **United Kingdom** but Element 3 is restricted to the ten highlighted in bold.

unique part of the UK R&D funding landscape in funding of research activities that sit in lower TRLs than those traditionally funded by Innovate UK. NAVISP element 1 seeks to achieve the following objectives:

- Perform feasibility and viability studies for PNT innovation
- Contribute to the formulation and implementation of PNT technology innovation
- Proof of concept of promising PNT-based services

- *Element 2 (E2) – Competitiveness in PNT*: maintain and improve the capability and competitiveness of participating Member States' industry in the global market for PNT technologies and services. In this element, ESA selects and funds projects where the technology is viable and market-ready (high TRLs) but may require scaling up from internal prototypes to the first manufacturing batch. Organisations applying for de-risking their technologies are answering a continuous open call for proposals and require a support letter from their member state delegation. Projects funded in this element were seen to provide a strong reputational statement for investors of funded companies. NAVISP element 2 seeks to achieve the following objectives:
  - Improvement or development of satellite navigation platform and payload system and equipment designs
  - Improvement or development of the satellite navigation ground segment system and equipment designs
  - Development of PNT products with a direct relevance to satellite-based navigation.
- *Element 3 (E3) – Support to member states*: support participating states in the development and promotion of products, applications, and services based on GNSS and PNT systems of national importance. The support is requested by participating member states, includes co-funding, and the extent of ESA participation is established on a case by case basis. This includes:
  - Providing system and technical assistance for the management and implementation of national programmes and activities for the development and exploitation of PNT infrastructures and techniques
  - Supporting the development of tools and facilities for test or demonstration aimed at the provision of new PNT products and services for institutional users, at (multi-)national level
  - Providing access for the exploitation and use of ESA labs, test beds, and technical facilities.

Figure 56 NAVISP programme elements

	ELEMENT 1 [Innovation in Satellite Navigation]	ELEMENT 2 [Competitiveness]	ELEMENT 3 [Support to Member States]
Content	Analyses and developments linked to new and emerging design and operational concepts, techniques and technologies related to satellite navigation systems	Ad hoc technological & product developments and pre-operational activities along the whole satellite navigation value chain in support of the competitiveness of the industrial sector in the participating Member States	Support to MS national Programmes & Activities in satellite navigation and along the whole value chain
General principles for implementation of the activities	Competitive tender, 100% ESA funding on the basis of yearly work-plan adopted by PB NAV (fully coordinated with EC/GSA)	Continuous open call, unsolicited proposals, ESA co-funding, MS support letter	On request by MS, ad-hoc mechanism to be established on a case-by-case basis that ensures ESA's full costs are met
Lead for the definition of the activities	**ESA**	**Industry**	**Member States**

UKSA

10.2 UKSA in the ESA NAVISP programme

10.2.1 Background

NAVISP is a relatively new optional programme, in which the UK has been subscribed to since its **inception at CMIN16**. As it is the **lead contributor** to NAVISP, the UK has been able to drive its **commercial focus** and shape the programme to match national priorities (e.g. steer E1 activities away from EGNSS, which countries like Spain wanted to include, and secure rapid contracting IPR with contractor, low **15% ESA overhead** (with pros and cons of lighter touch involvement of ESA staff), and **transferrable product ownership**, to ensure strong UK industry interest). Some other countries such as Switzerland were also seen to be real proponents of NAVISP since the beginning. The demand and success of NAVISP phase 1 (CMIN16) motivated a phase 2 (CMIN19), to continue and enhance the benefits acquired. The UK's continued participation in NAVISP was favoured over the development of a national programme, as the former was seen to provide more certainty and stability and, thus, better results for the country. Overall, NAVISP supports 60% SME primes in the UK and is highlighted as a programme that brings non-space companies to ESA.

10.2.2 Objectives

The UK aims to achieve the following through its participation in the programme:

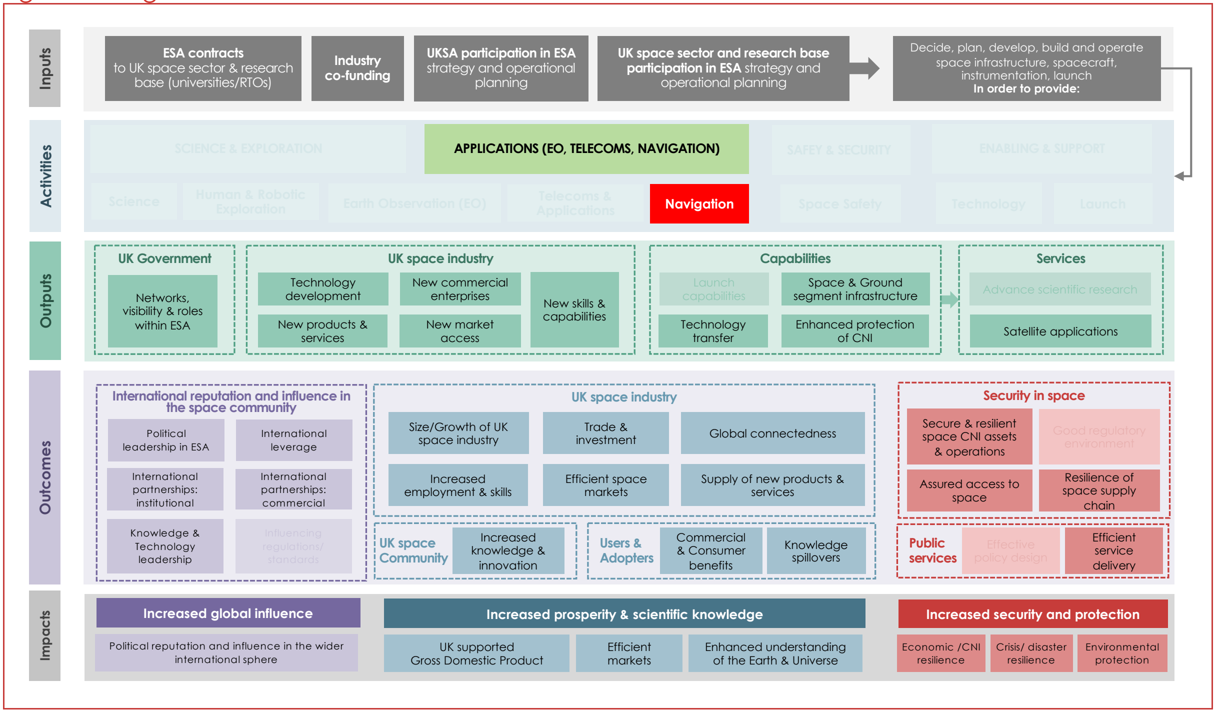
- Maintain its leadership position in PNT, within ESA and globally, by stimulating innovations, new technologies, products, and services development
- Support further investments at the member state level into adopting and exploiting GNSS-based solutions
- Ensure minimal technical barriers to the wider adoption of technologies, reduce the technical risk for industry and customer
- Grow major downstream sector by securing more business for UK companies and capturing larger market share

10.3 The logic model for NAVISP

Figure 57 presents the high-level logic model for the ESA NAVISP programme. As for other programmes, we have concentrated on highlighting the strong links and routes to impact.

Where boxes are greyed out, this should not be interpreted as there being no effect, rather than the effect may be more indirect. For example, innovative PNT capabilities may serve to enhance launch capabilities.

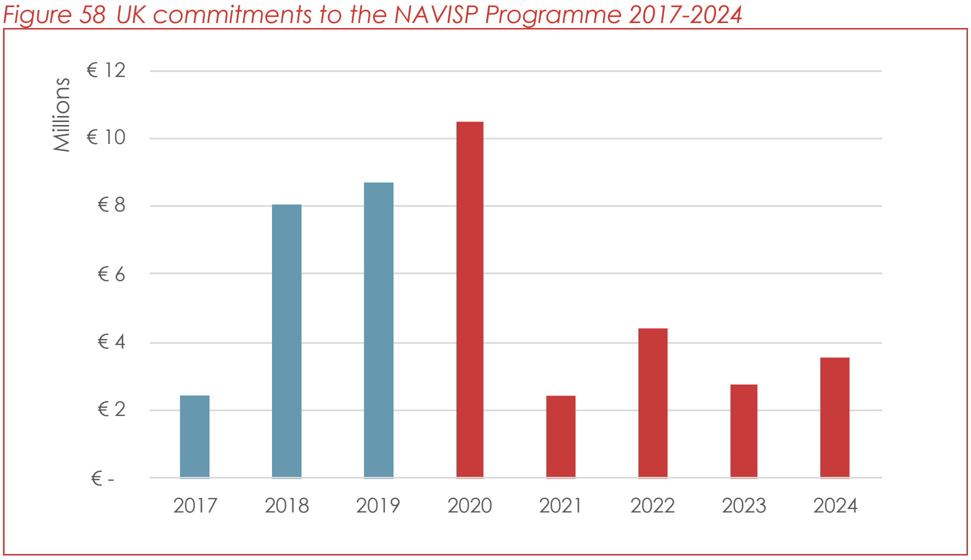
Figure 57 Logic model for ESA NAVISP



10.4 Inputs and activities

NAVISP budget for CMIN19 period is €23.64m, representing about 1% of total ESA funding. The budget profile is relatively front-loaded with 44% of the total financial obligations made in 2020. See Figure 58 below for the full profile.

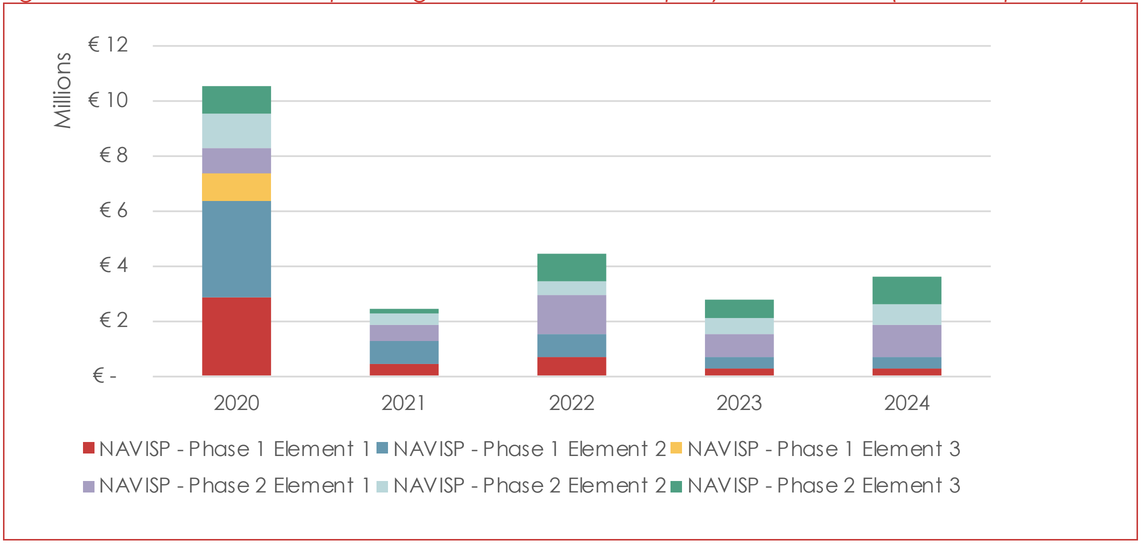
Figure 58 UK commitments to the NAVISP Programme 2017-2024



ESA datasheet on national obligations

According to the national obligations data (see Figure 59), element 2 is the largest element in both phases, though phase 2 elements are a scale of magnitude smaller than equivalent elements in phase 1. This is confirmed by the national settlements data that defines commitment in element 2 as a €9m, followed by element 1 as a €6m and element 3 as a €5m.

Figure 59 Breakdown of UK spending in NAVISP elements per year 2020-2024 (CMIN 19 period)



ESA datasheet on national obligations

10.4.1 CMIN 19 Settlement

Table 30 CMIN19 NAVISP optional programmes settlement

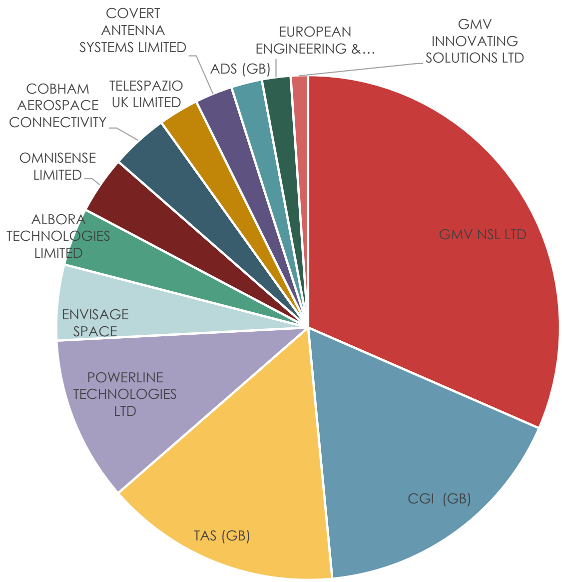
Programme	Commitment	Period
Navigation Innovation and Support Programme (NAVISP)	Element 1 - €6m Element 2 - €9m Element 3 - €5m	2020-2022

ESA Document 100

In Georeturns data, we identified 25 CMIN NAVISP contracts for the period 2020-Q2 2021 with a total of €13.57m, an average project size of €543k. All NAVISP projects were led by companies and the table below provides a list of the recipients ordered by total value of NAVISP funding, GMV NSL and CGI accounting for nearly 50% of all NAVISP funding in this period, followed by THALES ALENIA and Powerline Technologies. The programme is relatively concentrated with 12 recipients, two of which are part of the GMV group.

In preparation for participant interviews we identified all NAVISP projects in CMIN19 period but project leads found it challenging to distinguish between these and activities funded across the two periods. GMV NSL and its sister company GMV Innovating Solutions were identified as the most successful NAVISP participant with 14 projects, the vast majority of which were in element 1, three in element 2 and one participation as a subcontractor in element 3. Others such as a company new to ESA, Albora had only one NAVISP project (in element 2. All companies consulted had one or more proposals in train during our interviews and were hopeful to use NAVISP funding to progress technologies further.

Figure 60 % of total Telecoms and NAVISP programme contracts by value for 2020-Q2 2021



ESA geo-return datasheet

10.5 Outputs

Outputs of NAVISP projects differ across projects funded under each of the elements. Element 1 projects tended to lead to creation of new knowledge, patents, demonstrators of components and in some instances new follow-on funding activities. Element 2 projects, which are further along the TRL, led to more concrete marketable products, services, components or platforms that were commercialised in shorter timescales.

Element 1

While projects in element 1 tended to be in form of early TRL exploratory R&D activities, some of which admittedly on a long way to concrete products, some of the element 1 projects (though likely from CMIN period) have already produced outputs that subsequently translated into specific commercial opportunities in Rail, Road, Maritime, Space and Defence applications. The more exploratory blue sky type activities included project POSITRINO which is described briefly along with the projects from CMIN16 that led to GMV NSL's products for rail transport applications.

Figure 61 Text box project example – NAVISP element 1

Project POSITRINO 014 (led by GMV NSL) aimed to assess early feasibility of a PNT System based on Neutrino particles and answer how feasible is to imagine an operational PNT services based on neutrino particles in the coming decades? The results of the research project attracted interest from the US and DASA and led to a small follow on research study.

Projects SYSTEM SUITABILITY STUDY FOR TRAIN POSITIONING USING GNSS IN ERTMS IN 2020 (STEMS) 003 and TECHNIQUES SUPPORTING RESILIENCE FOR HIGH INTEGRITY TRAIN CONTROL APPLICATIONS 017 projects (led by GMV NSL) – the two element 1 projects that resulted in development of technologies allowing GMV to secure contracts from three out of four major train suppliers in the UK. These technologies are applied main and secondary lines on both safety critical and non critical navigation systems. Commercial arrangements are in form technology implemented per unit of system sold.

Element 2

The element 2 projects from CMIN19 covered by our interviews were still some way from commercialisation but evidence from CMIN16 projects and expected commercialisation plans were encouraging. Examples of these are in the text box below.

Figure 62 Text box project example – NAVISP element 2

CLOUD-BASED SNAPSHOT GNSS SOLUTION (CGNSS) 096 (led by Albora Technologies) – this project aimed at developing a cloud based GNSS system to allow precise geolocation in interference rich environments. It is led by a UK based SME new to ESA. The enabling technology is a cloud and edge service for assets (devices) to result in centimetre precision in environments where GPS signal is distorted – e.g. industrial or urban settings, enabling tech for autonomous vehicles or drone delivery. During the first 9 months of the project the technology accelerated from TRL4 to TRL7 and the lead company was pursuing further funding to finalise commercialisation activities relating to initial two products being piloted with customers in IOT and connected autonomous mobility sectors. The product directly related to the ESA project was going to be on the market within 12months of completion in Spring 2022.

DDK IRIDIUM BURST AUGMENTAITON SERVICE 044 (led by Albora Technologies DDK Positioning Ltd) the relatively small 370k project led to securing further 2 large long term contracts.

VANTIGE 1 014 and VANTIGE 2 058 (led by Cobham) projects along with a potential third project are being used to redeveloping Cobham's product line and contributed to securing a contract to supplying technology on Korean fighter jets.

Element 3

Projects in element 3 resulted in concrete outputs and solutions that were of national strategic significance. One of the notable examples is outlined in the text box below.

Figure 63 Text box project example – NAVISP element 2

GNSS EVENT NOTIFICATION SERVICE (GENS) 014 (led by CGI) - the project has created a demonstrator for detecting and notifying GNSS interference in a robust and secure way aligned with national interests. This development was deemed valuable by ESA and subsequently received a further 6 months of time and funding. The project received co-funding from DASA (Defence and Security Accelerator). In addition, GENS is planned to act as a catalyst to create a national centre for GNSS service threat identification and response. In support of the objective, GENS is also to provide guidance to widen the national understanding of the threats and vulnerabilities associated with using GNSS to derive resilient PNT. This is with the aim to allow informed requirements development, procurement, deployment and support for GNSS reliant PNT services by the UK. A specific output of the project was PNTIEM – PNT Incident event monitor, the system which is live today – detecting interference across whole UK and providing important info for intelligence services.

10.6 Outcomes and impacts

Funding RD&I activities, especially those covering early TRLs, tends to be associated with high rates of failure. In NAVISP, the overwhelming majority of projects discussed during interviews with project leads and programme stakeholders resulted (or were expected to result) in some form of successful outcome. Possibly this is due to the level of ambition and research questions explored. Similarly to the discussion on outputs above, the outcomes tended to differ by element. Outcomes from element 1 and 2 projects tended to be in form of follow-on funding or commercial in their nature (though timeframes varied between elements and subsectors) and element 3 in wider societal benefits such as having better overview of the GNSS interference.

Follow on funding is one of the successful outcomes of element 1 and element 2 projects. One of the examples of projects securing follow on funding and further interest from another funding agency is project POSITRINO, the main objective of which was to provide an early design of a

Neutrino PNT system and analyse its feasibility for certain applications for which alternative PNT technologies are not available or are too costly or provide poor performances. This project explored four different applications in using neutrinos for communication and PNT applications incl. submarine Neutrino communication. A follow up project is now being funded by a £45k DTSL and generated interest from the US. Other projects which are pursuing follow on funding include Albora applying for another NAVISP project giving a the next stepping stone on the road to the market. Other examples of follow-on project was a H2020 project secured by Albora in application of their technology in autonomous vehicles and QUANTUM METROLOGY FOR SECURE PNT 041 project leading to GMV-NSL being approached by several different types of organisation to discuss use of quantum key distribution in satellite payloads.

Several commercialisation outcomes were highlighted using examples of NAVISP projects originating from CMIN 2016 period. These included GMV projects that led to securing a contract for components included in driver-assist systems for BMW cars and discussions with Tier 1 OEMs, deals with majority of rail manufacturers supplying trains to UK rail network with a hope to work with tier 1 OEM's in the long term. The only competing rail manufacturer developed the same capability through another NAVISP project, which is an example of supporting two different competing technologies solving the same objective. GMV expect 7,000 trains in the UK to be fitted with their system in the next 12 months. In maritime navigation WANWEB system (output of NAVISP project MARRINAV 001), an independent navigation system for civilian maritime navigation that doesn't rely on GNSS. The system was already purchased by the German maritime authority and is being piloted by the European equivalent. NAVISP projects were also seen to be developing enabling technologies for application of products in internet of things (IOT), a product AlbaSNAP will be a direct result of a NAVISP project and is currently being piloted with an expectation to be on the market within the next 12 months.

In addition to terrestrial applications, a small number of NAVISP projects may have the potential to be integrated into future space missions. For example Moonlight consortium (public private consortium is exploring the potential for a new positioning service on the Moon.

NAVISP projects appeared to also have positive effects on the development of staff, skills and capabilities of the companies involved. Ultimately this development of skills in navigation may lead to UK's own satellite navigation. GMV pointed out their involvement contributing towards the capability of working with Inmarsat to Deliver First UK-Generated Satnav Signal, which is linked to their success in NAVISP projects.

With a clear benefit to those involved in the projects in terms of scientific and technical knowledge, the participation enabled growth of PNT teams within companies, in some instances growing the UK navigation team by around 200% (to around 60-70 people) over the space of 4-5 years. The examples of skills built were in particular in complex computer science experts who know how to build a software architecture which is robust in the specific PNT context. Other skill areas included broad GNSS and big data processing. The challenge focused nature of the project often resulted in formation of partnerships with companies in participating nations – though non-participation of some of the major ESA members in specific elements (such as Germany's absence in element 3), reduced this pool. Nevertheless participants mentioned increased proximity/understanding of research partner such as the National Physical Laboratories (NPL) as one of the positive outcomes of their participation in NAVISP. Some of these partnerships are not visible in project data as for example a sub-contract to a Car insurance 'blackblox' manufacturer.

All participant organisations interviewed mentioned reputational benefits realised as a result of working on ESA projects, noting recognition by current and prospective investors which made it easier to seek additional investment.

10.7 Attribution and additionality

Establishing the attribution of R&D projects to specific outcomes tends to pose a challenge due to the number of contextual and external factors required for impact to be realised. In case of NAVISP, the attribution of commercial outcomes from element 2 projects is straightforward and it was possible to link specific products in product ranges of participants to specific projects. NAVISP element 1 projects were also in most cases linked to products and services but these were components or data inputs into systems which were often developed by higher tier OEMs in specific sectors, so the attribution at overall user product was reduced. Element 3 projects were linked to systems sold to national and supranational bodies where the attribution is, in case of a successful project, relatively direct. For example the MARINAV project led to improving resilience for maritime transport.

Higher level outcomes such as the growth of the market and employment and skills cannot be fully relied upon from a relatively modest size programme. However the fact that the recent GMV project with INMARSAT is a linked to the UK replacing civil aviation services that were previously provided via European collaborations that the UK is no longer part of shows the power of these projects. The PNT work has a dimension of fulfilling shortcomings of GNSS system, which is highly relevant, as there is a the potential damage and vulnerability of CNI.

10.7.1 ESA-added value

NAVISP presents a uniquely positioned source of funding for UK companies who are active or want to enter the PNT relevant sectors. Each element is distinctive with no other programme funding PNT technologies and research covering all TRLs, from fundamental ideas to commercialisation. NAVISP is therefore seen to be is filling a gap in the UK R&D funding landscape.

> *"Coming from IUK and before that industry I know how funding is used and what the UK funding landscape looks like. NAVISP is unique and so popular because it fills the gap where Innovate UK doesn't. It sits in both Valleys of Death and enables companies to come with their problems rather than government-set agenda… The key advantage of NAVISP is it considers business applications from TRL 1-7…I hate to use the term but NAVISP is a One stop shop for PNT".* *Internal NAVISP Stakeholder Interview*

The expertise of ESA staff who are involved in assessment of bids and monitoring and advice of projects represents a clear added value for participants. The Technical assistance from ESA unbiased and able to ask the hard questions. ESA expertise provides lots of useful resource that isn't tainted by particular industry interest. Only one of the participants interviewed as part of this evaluation did not see this value and that was because the company employed ex-ESA staff who could provide some of this knowledge internally.

Funding for early TRL projects provided under NAVISP element 1 is not available for UK companies under any Innovate UK (or UKRI) or the UK Space Agency. This is valuable as it allows exploration of early stage science that may not be commercially viable from the outset.

In case of element 2 projects, the added value of this ESA funding comes from de-risking with finance and guidance from ESA. The assessment of viability, advice and monitoring support from the ESA technology officer. And marketing and reputational value from the ESA badge is a strong statement for investors. Element 3 projects have to meet the requirement of national importance and the industry then proposes solutions. This is a good route for new-to-ESA companies.

Reportedly NAVISP attracted 15-18 non-space orgs that never before worked with ESA but the added value from ESA comes in form of expertise that is required to test non-space alternatives to PNT solutions outside Galileo.

ESA technical expertise, established processes all make this route for funding good alternative to a national programme. Furthermore using a European instrument means that companies are not limited by state aid rules and results in favourable tax and IPR status for this funding, preferred by participating companies. NAVISP has a 15% overhead, which is lower than other ESA projects and results in higher proportion of project budget to going directly to companies.

As noted above, being funded by ESA gives reputational benefit and credibility to projects especially when they are trying to negotiate agreements and attract investments.

> *"Working on ESA projects gives us credibility for customers and investors."*

NAVISP participant interview

As an international programme funded by ESA, the additional value in comparison to a hypothetical national programme for PNT comes from the possibility of collaborating with companies from participating countries.

11 Space Safety and Security

11.1 ESA's Space Safety and Security programme

11.1.1 The ESA Programme

Since 2009 and the creation of the Space Situational Awareness (SSA) programme, space safety has become its own agenda at ESA, with the SSA programme specifically focusing on monitoring space weather for the purpose of effective forecasting and the tracking of Near-Earth Objects (NEO), satellites and debris.[82] The SSA programme represented an ambition to develop space weather forecasting capabilities, while the Space Surveillance and Tracking (SST) segment of the programme sought to manage space traffic and monitor the movement of space debris to warn spacecraft operators of potential collisions.[83]

Since the Space Safety and Security (SSS) programme replaced the SSA programme in 2019, ESA's approach to space weather has remained in effective forecasting with the additional push to provide operational services to end-users. In debris & clean space, ESA begun the evolution to become proactive rather than reactive in managing safety risks, introducing elements of debris-removal and asteroid re-direction missions.

SSS is an optional ESA programme with the aim to build on SSA and further safeguard infrastructure in space and on the ground, protecting people, infrastructure, and crucial economic activities, and ensuring the sustainability of space activity. It has three main pillars: space weather (building resilience to extreme space weather events), planetary defence (protection from asteroid impacts), and debris & clean space (prevention of debris collision for the future and remediation of past activities).

It currently covers the 3rd period of the earlier SSA programme and the 1st period of the Space Safety Programme (S2P).

The Space Safety agenda has become a topic of high priority for both national governments and space agencies. Societies globally rely on crucial infrastructure in space and on the ground, but both natural factors (like space weather) or anthropogenic factors (like space debris) can jeopardise space-based and ground-based critical infrastructure, and asteroid impacts can pose an existential threat to humanity. The SSS programme is seen as an effort to address these space threats and secure both a prosperous and sustainable future.

Overall, the covered budget for the Space Safety and Security programme is €412m, representing nearly 3% of the total ESA budget for 2020-2022. In addition to funding the core element of the programme, such as research, technology and service/operational development, the programme funds various missions, including four cornerstone (CS) missions:

- CS Space Weather Lagrange L5 (Vigil): providing space weather nowcasts and forecasts with increased accuracy and timeliness, with planned launch by 2030
- CS Asteroid Deflection Demonstration (HERA): developing asteroid deflection capabilities, with planned launch 2024 (the UK does not subscribe to this programme)
- CS Collision Risk Estimation and Automated Mitigation (CREAM): ensuring the safe operation of mega constellations, planned demonstration in 2023
- CS Active Debris Removal/In-Orbit Servicing (overall called ADRIOS, with the mission more specifically referred to as ClearSpace-1 after ClearSpace SA won the main contract):

[82] https://www.esa.int/Safety_Security/The_story_so_far

[83] In 2018 alone, 28 'Collision Avoidance Manoeuvres' were performed.

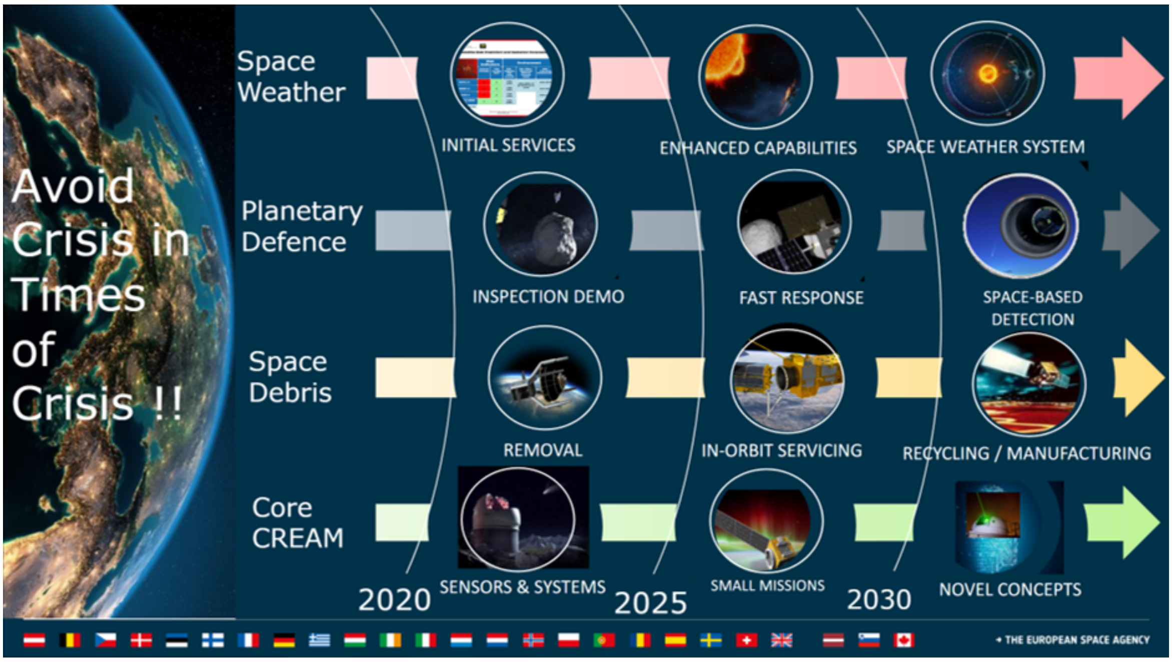
performing active debris removal on non-operational satellites (remediation approach), with planned launch 2025[TH]

Table 31 Pillars of ESA SSS

Pillar	Main mission(s)	Goal	Status
Space Weather	Vigil	• Analyse solar weather and aid in forecasting	• Contracts still pending, planned launch 2030
Planetary Defence *(No UK participation)*	HERA	• Provide detailed post-impact survey after NASA's DART impacts an asteroid	• Planned launch 2024
Debris & Clean Space	ADRIOS/CleanSpace-1 CREAM	• De-orbit the Vespa satellite • Provide automated collision avoidance	• Main contracts awarded, planned launch 2025 • Planned demonstration in 2023

ESA

Figure 64 ESA SSS programme overview



ESA

11.1.2 UKSA in SSS

The UK has participated in ESA space safety programmes since their inception and has been a key contributor in predecessor activities. Participation in space safety programmes is part of larger story around the development of key UK space safety and security capabilities, which uniquely hit on multiple key strategic Government priorities across the Government's National Space Strategy, Severe Space Weather Preparedness Strategy, Defence Space Strategy, and the National Risk Register:

- Protecting critical national infrastructure (CNI) by acquiring and developing skills, capabilities, and infrastructure to address space weather risks outlined in the National Risk Register and Severe Space Weather Preparedness Strategy.
- Ensuring a sustainable exploitation of space through debris mitigation and collision prevention, becoming international leaders in the clean space market and capitalising on commercial opportunities that support UK GDP, aligning with space-related growth ambitions outlined in the National Space Strategy.
- Ensuring UK organisations' access to space safety contracts, data, technologies, knowledge, and infrastructure to benefit both the national economy and the UK's global standing, allowing the UK to shape the space safety agenda to suit national interests and enabling new collaborations and partnerships.
- Bolstering UK defence and security by ensuring the resilience of space-based assets, as outlined by the Defence Space Strategy.

Multiple national initiatives also support the growth of space safety capabilities. The National In-Orbit Servicing Control Centre at Catapult in Harwell was built from a £4m Government grant,[84] and UK divisions of debris-removal companies Astroscale and ClearSpace have each won national funding worth £700k to perform feasibility studies for a UK debris-removal mission.[85] In 2022, UKSA has also committed £1.7m for 13 new projects to bolster the UK's national capabilities in the tracking and removal of debris.[86] Across ESA, the UK also participates in missions in other programme that have spillover impacts on space safety, particularly in the *ESA Science* programme, like the UK-built ESA Solar Orbiter (launched 2020) and the ESA-Chinese Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) (launch 2024, Thales Alenia Space UK priming the preliminary design phases).[87] Both these missions explore the Sun's impact on Earth. Astroscale UK also received £2.5m in funding from the Advanced Research in Telecommunications Systems' (ARTES) Sunrise programme.[88]

The outputs and outcomes detailed in the next sections are therefore best understood as pieces of the puzzle of realising the UK's space safety ambitions, to which SSS participation plays an important role.

[84] https://gtr.ukri.org/projects?ref=104193

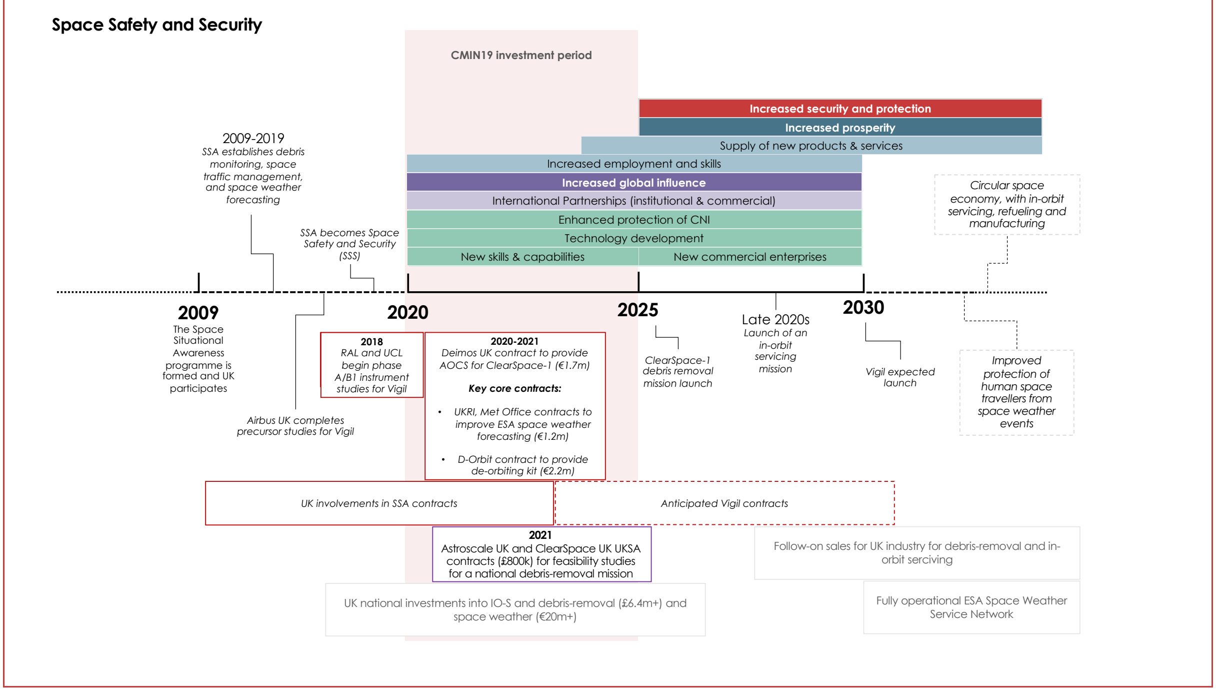
[85] https://spacenews.com/uk-funds-studies-to-remove-two-spacecraft-from-leo/

[86] https://www.gov.uk/government/news/new-funding-to-support-sustainable-future-of-space

[87] https://www.thalesgroup.com/en/worldwide/space/press-release/thales-alenia-space-signs-contract-european-space-agency-design

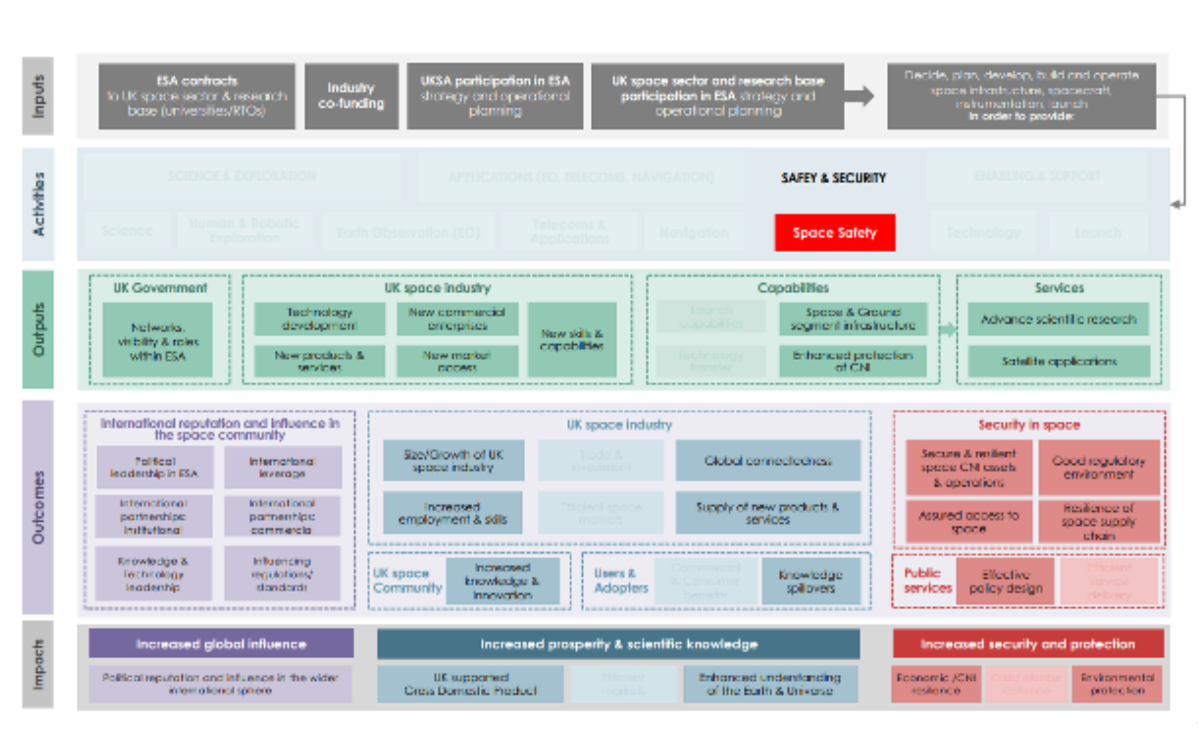
[88] https://astroscale.com/astroscale-uk-signs-2-5-million-agreement-to-develop-space-debris-removal-technology-innovations-with-oneweb/

Figure 65 Timeline of (selected) SSS CMIN19 outputs, outcomes and impacts



A logic model for SSS is presented in Figure 66 below. Reflecting the enabling impact of SSS across the space industry value chain, it covers many different routes to impact, whether through increasing UK influence, securing industry growth and socio-economic benefit, or boosting the UK's resilience.

Figure 66 Logic model for ESA SSS



11.2 Inputs and activities

The UK's contribution to the programme at CMIN19 was **€95.5m**, representing nearly 13% of total UK investment into ESA for the period and making the UK the biggest contributor, ahead of Germany (€83.7m), Italy (€46m), Belgium (€41.9m), and Switzerland (€36m).

Table 32 SSS commitments by programme area

	CMIN16 period			CMIN19 period				
Programme	2017	2018	2019	2020	2021	2022	2023	2024
S2P Period 1	€ -	€-	€ -	€ 14.44	€31.19	€25.55	€12.87	€8.50
SSA Period 3	€ 2.59	€5.17	€ 6.20	€4.71	€2.68	€0.88	€0.43	€ -

ESA datasheet on national obligations

The UK is participating in all cornerstone missions (Vigil, ADRIOS/CleanSpace-1, and CREAM) except for the planetary defence mission (HERA). Due to the unlikelihood of a severe asteroid impact compared to the relatively high likelihood of space weather and debris-related events, current prioritisation of UK funding is towards space weather and debris & clean space.[89]

Georeturn data until Q2 2021 shows 29 contracts worth €9.5m awarded since CMIN19. We are also aware of a of €2.2m contract to D-Obit UK made in Q3 2021, bringing the total covered contracts to 30, totalling €11.7m.

These are split between SSA period 3 contracts wrapping up work from the previous iteration of the programme (before being brought under the S2P umbrella), and new contracts from S2P period 1. The activity can be broadly categorised into:

Core activities, including:

- Space weather activity
- Space debris & clean space activity, including Space Surveillance and Tracking (SST) activity.[90]

Cornerstone mission activity, primarily on ADRIOS/CleanSpace-1 and CREAM.

Table 33 UK commitment and contract activity by SSS pillar and mission

Pillar and mission(s)	Commitment	Number of UK contracts	Total contract value
Space Weather	Vigil: €70m	6	€387k
Debris and clean space	ADRIOS/CleanSpace-1: €12.5m CREAM: €1m	7 1	€5.8m €256k
Core activities	€12m	16	€5.4m
Totals	**€95.5**	**20**	**€11.7m**

ESA Document 100, ESA geo-return datasheet

[89] UKSA SSS business case

[90] Space Surveillance and Tracking (SST) comprises technologies to detect, catalogue and predict the objects orbiting the Earth, and the derived applications. The recent years have shown constantly growing needs for timely and accurate SST data, especially for collision avoidance as part of operating spacecraft, and for assessing re-entry events.

11.2.1 Space weather

Despite Vigil being the UK's top priority within the SSS programme, as of 2022, most of the activity in the SSS programme since CMIN19 has occurred in the core and debris & clean space pillars of the programme. The preparation phase of the Vigil mission is underway, however, a last-minute non-participation by Germany has resulted in the need for the mission to be rescoped to fit new budget requirements. While the rescoping of a mission can cause delays, ensuring a realistic approach and a responsible use of budget is paramount, and the overall mission objectives of Vigil are still expected to be met.

Initial A/B1 studies on the sensing instruments are being conducted by STFC's Rutherford Appleton Laboratory, sub-contracting to Thales Alenia Space UK (€100k) and Teledyne UK (€20k). Progress on the mission is now awaiting rescoping to make the mission ready for B2 implementation phase before CMIN22.[91] As a result, most contracts in space weather since CMIN19 have been awarded in the core activities pillar, with almost all contracts for Vigil still pending. The funding threshold to realise the Vigil mission was €85m, and with its commitment of €70m, the UK has assumed a strong leadership position for the mission. Because of this, many large contracts are still expected to go the UK, both in manufacturing and operations, with Deimos UK already reporting being selected to lead the mission analysis (with contract pending).

For the core space weather activities, there are essentially two key components that build on work conducted during the previous SSA periods:

- Bolstering existing space weather forecasting capabilities e.g. providing funding for improved modelling.
- Providing the essential elements of the transition of the current ESA Space Weather Network towards a fully operational framework that can provide timely information to impacted users, akin to how the UK's Met Office and the US Space Weather Prediction Center operate.

To exploit the data from the eventual Vigil mission, UKRI and the Met Office, in partnership with University of Central Lancashire and University of Reading, secured contracts worth €267k to study the use of Vigil data to build better Coronal mass ejection models.

The Met Office and UKRI were also awarded €1.2m as sub-contractors to the Royal Belgian Institute for Space Aeronomy to expand on incorporation of data points from both ground-based and space-based space weather sensors. Additionally, SSTL, in partnership with University College London and Imperial College London, was awarded €375k for an 18-month feasibility study of using nanosatellites for ESA's Distributed Space Weather Sensor System (D3S), which, with other monitoring spacecraft and satellites, forms part of the wider ESA ambition for an Enhanced Space Weather Monitoring System.[92]

11.2.2 Debris & clean space

In debris & clean space, activity can be grouped into:

- Core Space debris & clean space activity, including Space Surveillance & Tracking (SST) activity
- ADRIOS/ClearSpace-1 activity
- CREAM activity

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[91] UK Space Safety Community Meeting: Part 1

[92] https://www.sstl.co.uk/media-hub/latest-news/2021/sstl-prime-on-nanosatellites-study-for-esa-s-distr

The UK has performed well in the ADRIOS/ClearSpace-1 mission, with several key contracts awarded since CMIN19:

- The Satellite Applications Catapult was awarded €1.8m to supply operations around in-orbit debris-removal services, helping build industry partnerships to bridge the TRL gap, and de-risking the mission. Further specifications on Catapult's role are pending the upcoming mission design from the prime contractor, ClearSpace SA.
- Deimos UK was awarded €1.7m to supply the Attitude and Orbit Control Subsystem, known as the AOCS, responsible for the orientation and position of the ClearSpace-1 satellite.
- 4LINKS was awarded €935k to supply a SpaceWire router and bridge to connect the satellite's systems. 93
- Nammo UK was awarded €541k for thrusting capabilities.
- Smaller contracts were awarded to insurance broker Willis (€423k) and miscellaneous (€270k)

In the smaller CREAM mission, GMV UK was awarded €265k to develop satellite navigation techniques for automated collision avoidance, marking GMV's UK division's first involvement in ESA space safety programmes.

In core debris & clean space, D-orbit was awarded €2.2m in September 2021 to develop and perform an in-orbit demonstration of a 'De-orbit Kit'. This add-on kit can enable any space vehicle to perform a propulsive self-decommissioning manoeuvre, ensuring that any operator can de-orbit satellites in case of faults, potential collisions, or after their operational lifespan. D-Orbit is leading a consortium which includes Airbus, ArianeGroup, GMV, and Optimal Structural Solutions.[94]

In addition, Deimos UK was awarded €278k to provide software that can estimate the debris impact of all future missions, which will be serviced out to operators worldwide. Rina Consulting Defence, partnering with University of Strathclyde, were awarded a total of €246k to review and harmonise ESA's Life Cycle Assessment (LCA) database, helping mission designers better assess the full lifecycle of space assets in order to increase the sustainability of space activity.[95]

In core Space Surveillance & Tracking, GMV UK and Rheatech were awarded €530k and 270k to help modernise and standardise ESA's Core SST software architecture, as part of ESA's push to take a community-approach to SST, providing interoperability, compatibility and harmonisation in system outputs and services provision.[96] Finally, Deimos UK secured additional contracts here worth €152k originally planned for SSA periods, including continued testing of SST systems to coordinate calibration of sensors and the software required to integrate Polish sensor networks into the SST system.

The big picture of UK activity in the SSS programme remains in to be seen from contracts for the Vigil mission, where contracts and activities are still in the pipeline. On current contracts, interviewees reported that work on the core elements, ADRIOS/ClearSpace-1 and CREAM is on track. Debris-removal activity in the UK through large contracts to D-Orbit, Deimos UK, and Catapult bodes well for the UK's push to be a leader in the active debris-removal and in-orbit servicing (ADR/IOS-M) market, supplementing UK national funding mentioned above.

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[93] https://digitalcommons.usu.edu/cgi/viewcontent.cgi?filename=0&article=4824&context=smallsat&type=additional

[94] https://www.satellitetoday.com/in-space-services/2021/09/10/esa-awards-d-orbit-uk-contract-for-debris-removal-demonstration/

[95] ESA_PB-SSA_2019_24, REV.15_EN

[96] https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/222/SDC8-paper222.pdf

11.3 Outputs

Again, it is critical to think of the current, past, and future SSS outputs in terms of their role in the longer-term story around developing better space safety and security capabilities. Current outputs, especially in the core pillar of the programme, build largely on activity from the SSA period – and while current activity contributes to the development of long-term capabilities, the story will rely on future outputs too.

A key company reported significant involvement in past SSA contracts, developing software and infrastructure for ground-based telescopes and SST centres, which led to further contracts after CMIN19. Jobs, capabilities, and new software & hardware relating to the SSS programme largely build on contracts awarded during the SSA-period. Other contracts in core, like the SSTL's SmallSats study, build on SSA progress on the creation of the ESA Space Weather Service Network and the SSA plans to install a Distributed Space Weather Sensor System (D3S) in Low-Earth orbit. In the same vein, contracts awarded post-CMIN22 will be a continuation of activities and outputs from CMIN19 contracts, and as such, current outputs should be soon as building blocks, not end-goals, for strengthening UK capabilities.

11.3.1 Space Weather

Most of the outputs (and indeed outcomes and impacts) of space weather funding in the CMIN 19 Ministerial are still in the future and interviewees made it clear that it is too early to tell what the outputs of these contracts will be. There was, however, a clear theme that outputs of Vigil contracts will be seen through the already-realised reputational gains for the UK within ESA and worldwide, and in further strengthening of the Met Office's pioneering space weather operations.

Once Vigil has launched, the primary expected output of the Vigil spacecraft will be the data transmitted to Earth to enhance space weather nowcasting and forecasting services. The resulting impacts of data exploitation from the mission is discussed in the 'Outcomes and impacts' section below. Interviewees also agreed that we will see significant scientific output from exploiting the data from the mission. The space weather mission STEREO was pointed to as an example, having produced over 400 publications since its launch in 2006.[97]

There is always an element of upskilling and of developing new capabilities through big mission contracts. However, our interviewees pointed out that we are unlikely to see Vigil lead to very large technological gains, as the UK already has strong capabilities and skills in this field from its involvement in building the instruments that feature on the successful STEREO and SOHO space weather missions. Equally, though, it could be thought of as TRL advancement in the sense that this is about getting the whole mission closer to mission-readiness.

While not an output of any specific contract, it was clear among both industry players and ESA that the UK's emergence as a leader in the Vigil mission has boosted UK influence in the programme, especially in Space Weather.

Additionally, organisations reported that their CMIN19 contracts have led to growth. One company reported having hired 3 new employees as a result of their contract, with another telling us of their aggressive hiring from 20 employees at start of 2021, to now 36, with 45-50 expected in 2022 (though as part of a broader growth story rather than solely related to CMIN19 funding). Contracts also led to deeper scientific knowledge and improved modelling

[97] https://www.stereo.rl.ac.uk/Documents/STEREO_publications.pdf

capability in the domains of upper atmosphere (ionosphere/thermosphere), heliosphere, solar wind/flare forecasting and Earth's radiation belt, with one company reporting that members of their science team have become internationally recognised experts in space weather fields as a result. While CMIN19 contracts do not provide the whole story, interviewees called the contracts an important contributory factor.

We were also told of newly acquired technical knowledge of space weather measurement techniques through work on CMIN19 contracts.

In terms of publications, interviewees noted the link between space weather science and forecasting and expected future space weather missions to produce significant scientific output (which in turn improve forecasting). For example, a publication around the use of small satellites for space weather forecasting will be ready for submission in 2022, and past solar physics missions have produced a great number of papers through their lifespan. This is expanded upon in the 'outcomes' section below.

11.3.2 Debris & clean space

Because of a strong national push for Active Debris Removal and In-Orbit Servicing and Manufacturing (ADR/IOS-M) capabilities, activity from ADRIOS/CleanSpace-1 contracts are unlikely to produce 'isolated' outputs. One company noted that UK's participation in ADRIOS/CleanSpace-1 influenced their decision to set up operations in the UK, but that it was the UK's national ambition in the ADR/IOS-M market that made the UK attractive to them.

There were also reports of sector growth in the debris & clean space segment. One company grew from 8 to 10 employees with expectations to grow much more. Another told us they had hired or retained a total of 7 employees as a result of their CMIN19 contract.

Additionally, the TRL of active debris-removal was expected to go from TRL3-4 to TRL9, while the TRL of collision avoidance systems was expected to go from TRL6 to TRL7. There was also clear consensus that demonstrating capabilities in debris-removal will open commercial opportunities for UK companies like ClearSpace UK and D-Orbit in the potentially huge commercial ADR/IOS-M market that could reach £3.2bn by the end of the decade.[98] One company told us 50% of their business currently comes from ESA, though this is falling, as the commercial potential for their capabilities grows as a result of R&D activity and the development of low TRLs.

There is a push from ESA to leverage private investment in debris & clean space activities: although not linked directly to UK activity, ClearSpace SA (the Swiss prime contractor for the ADRIOS/ClearSpace-1 mission) is raising €14m in private funding to help realise the ClearSpace-1 mission, and we found evidence of good progress on private investment rounds among interviewed companies.

One company saw their UK division participate in ESA space safety for the first time through their CMIN19 contract, marking the first time outputs of their ESA partnership occurred in the UK. Knowledge is being transferred from international teams to the UK team as part of the FDI and the attraction of more debris & clean space activity to the UK.

There were limited discussions around publications from debris & clean space activity, perhaps because the primary ambition of this segment is first and foremost operational. Interviewees,

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[98] https://sa.catapult.org.uk/wp-content/uploads/2021/05/Catapult-Astroscale-Fairspace-Platform-for-Growth-report-final-27-05-21.pdf

however, did not rule out possible future papers e.g. on debris-removal techniques, environmental impact of debris, or collision avoidance frameworks.

11.4 Outcomes and impacts

As the Space Safety agenda spans many ESA Ministerials, interviewees were keen to point out that CMIN19 contracts themselves are part of a larger push to increase space safety and that large-scale impacts are still in the future. These impacts, however, will be where the vast majority of benefits to the UK economy and society will be realised, i.e. through protection of CNI, reduced risk, avoided socio-economic damage, and increased commercial opportunity.

11.4.1 Space weather

In the space weather pillar of SSS, the ultimate impact is the protection of critical infrastructure, and, by extension, our modern way of life. Activity on the Sun's surface creates a steady stream of radiation and particles that protrude outwards into our solar system called *solar wind*, and under normal conditions, the Earth's magnetic field and atmosphere provide adequate protection to both assets and biological life. Occasionally, however, the Sun experiences *solar storms*, and storm events like coronal mass ejections (CMEs) or solar flares can significantly increase the solar wind and cause geomagnetic storms or increased radiation.[99] This can impact a host of technologies: power grids, astronauts and people in airplanes, radiocommunications, orbiting satellites (including those providing GPS and Global Navigation Satellite Systems (GNSS)), and more.[100] Damage to the power grid would impact virtually all modern life and could cost tens of billions to repair[101], and a major disruption to GNSS alone could cost the UK £1bn a day in terms of lost service.[102] Additionally, the UK government will invest over £1.3bn in satellites and other space technologies for national defence purposes, linking space weather risks to threats to national security as well.[103] The impact story of increased space weather forecasting capabilities is best understood as the *prevention* of negative impacts.

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[99] https://spaceplace.nasa.gov/spaceweather/en/

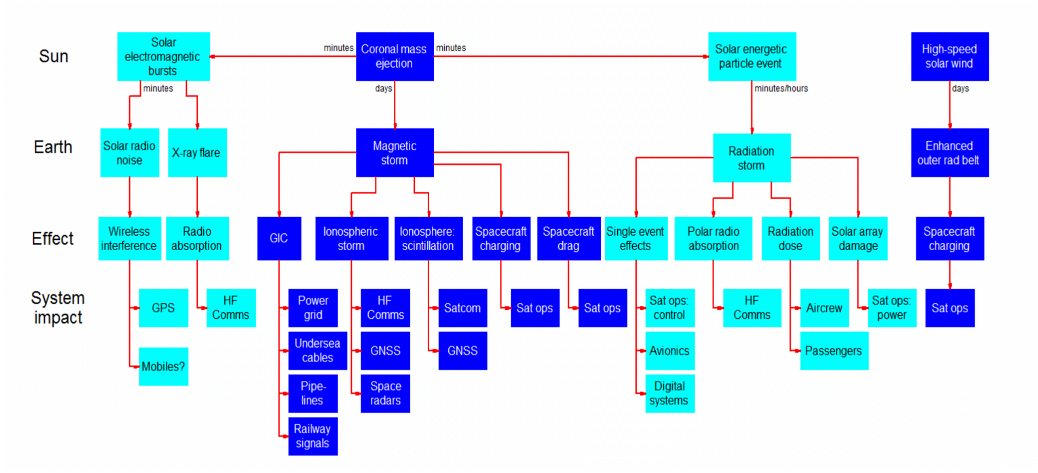
[100] https://www.metoffice.gov.uk/weather/learn-about/space-weather/impacts

[101] https://www.cam.ac.uk/research/news/solar-storms-could-cost-usa-tens-of-billions-of-dollars

[102] London Economics (2017). *Economic impact to the UK of a disruption to GNSS*

[103] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1051456/20220120-UK_Defence_Space_Strategy_Feb_22.pdf

Figure 67 Disruptive impacts of severe space weather (with timelines)



UK Space Weather Preparedness Strategy

The expected impacts do not come from the development of forecasting from scratch, but rather on the continued improvement of space weather forecasting and the benefits of further international buy-in and coordination, both via the launch of new solar weather monitoring instruments through big missions and through core activities like bolstering of data incorporation, modelling capabilities, and the setup of a cooperative ESA Space Weather Network.

The UK's Met Office and the US Space Weather Prediction Center already utilise a suite of ground observatories, satellites, and spacecrafts to provide a level of space weather forecasting services to relevant end users. However, current forecasting does not provide complete protection: a 2018 study from University of Cambridge estimated that even with current forecasting capabilities, the costs of a severe 'once in a hundred years' space weather storm could be as high as £2.9bn [104]. A 2016 report by PwC estimated that an at-the-time expected investment of €529M into ESA space weather preparedness programmes from 2016 to 2030 would return €6 for every €1 spent.[105]

Current space weather forecasting is made possible by our scientific understanding of solar physics and the solar wind, space weather modelling, and a host of instruments in ground-based observatories and space-based satellites and spacecraft. Past spacecraft, such as the ESA Solar and Heliospheric Observatory (SOHO) and the Solar Orbiter, were launched with scientific output as the primary goal (see the *ESA Science programme* chapter), while others were purpose-built with space weather forecasting in mind, such as the US National Oceanic and Atmospheric Administration's (NOAA) Deep Space Climate Observatory (DISCVR).

Depending on the type of solar activity, warning times enabled by the current space weather infrastructure can vary. CMEs travel much slower than the speed of light and reach the Earth between one to four days after ejection, which means it is possible to warn at-risk operators

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104 https://onlinelibrary.wiley.com/doi/10.1111/risa.13229

105 https://esamultimedia.esa.int/docs/business_with_esa/D7_ExecutiveSummary_(Co.4000117037-16-F-MT)_vFINAL_12102016.pdf

before the effects of the resulting geomagnetic storm.[106] However, it is difficult to establish the precise timing and severity of a hit, often leading to only 30 minutes to a few hours warning[107],[108] giving operators very little time for effective mitigation.[109] Impacts from other solar activity like solar flares can be virtually impossible to forecast with a from-Earth view of the Sun, as they often travel at (or close to) the speed of light – meaning when we see them, they have already hit.[110] On top of this, space weather spacecrafts like SOHO, DISCVR and NASA's STEREO, are all nearing the end of their expected lifespan.[111] Forecasting models are only as effective as the data they exploit, and while core activities that strengthening modelling capabilities, data integration, and cooperation are crucial, effective forecasting requires the continuous monitoring of the Sun and the space weather environment.

The Vigil mission represents a unique upgrade to available space weather forecasting capability. Its planned position at the Lagrange point L5 will, for the first time, identify sources of developing dangerous solar activity before they rotate into view from the Earth. This is expected to increase the warning time and accuracy of solar storm forecasting significantly. With a view of solar activity before it is rotated into view of the Earth, Vigil could give early indications of developing solar storms, potentially enabling forecasting of solar flares currently impossible, and providing crucial data on the speed and nature of CMEs.[112] With added warning time and accuracy, infrastructure (both on Earth and in space) could more reliably be put into safe-mode at the right time, protecting infrastructure that would otherwise be damaged, resulting in major cost savings and increased resilience.[113],[114]

[106] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/449593/BIS-15-457-space-weather-preparedness-strategy.pdf

[107] https://web.archive.org/web/20150210181113/http://www.nesdis.noaa.gov/DSCOVR/pdf/DSCOVR%20-%20PlasMag%20Instrument%20Info%20Sheet.pdf

[108] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/449593/BIS-15-457-space-weather-preparedness-strategy.pdf

[109] In February 2022, Starlink lost 40 satellites due to increased drag caused by particles from a solar storm. https://www.spacex.com/updates/

[110] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/449593/BIS-15-457-space-weather-preparedness-strategy.pdf

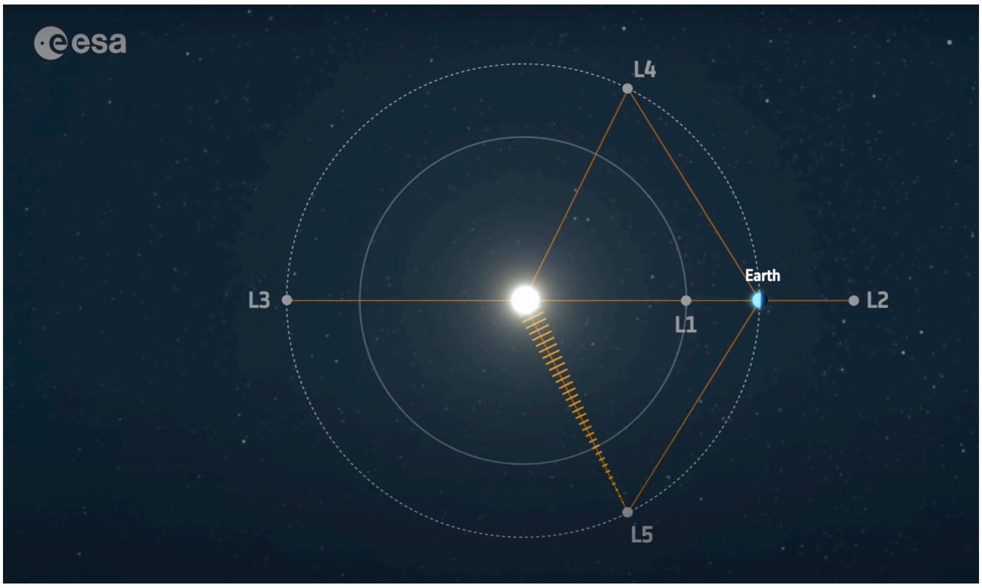
[111] https://www.icams-portal.gov/meetings/swef/2019/presentations/4-4_ullman.pdf

[112] https://www.youtube.com/watch?v=xc50DEr_GfU

[113] https://www.youtube.com/watch?v=xc50DEr_GfU&t=52s

[114] UK Space Safety Community Meeting, 16th February 2022

Figure 68 Diagram showing Vigil's intended position at the Lagrange point 1



ESA video on Vigil

Future human exploration missions planned to the moon (and beyond) are also at risk of bursts of radiation from the Sun, which pose a significant health hazard.[115] More sophisticated and timely space weather forecasting, through Vigil and other core activities, could remove a major barrier to safe human activity in cis-Lunar environments and protect human lives in space.[116]

Space weather forecasting is not only a strict calculation of cost-savings associated with protection of CNI. Our modern way of life depends to a large extent on the utilisation of critical infrastructure, and while there have been efforts to economically quantify the costs of severe space weather, it is important to understand the context of the numbers: outages of CNI disrupt health care and emergency services, transportation networks, food supply, energy, and more. Seeing space weather forecasting solely as a cost-saving tool underplays the potentially significant social costs endured by civilians should CNI be severely impacted.

Interviewees called attention to the multi-purpose nature of Vigil and expected significant scientific impact. Since its launch more than 25 years ago, SOHO has led to over 6000 papers published and 300 PhD theses[117], and the Solar Orbiter, despite its recent launch in 2020, has already led to more than 50 papers.[118]

Space weather is not isolated to Vigil but is part of a larger push by ESA to build a full-scale, meteorology-like space weather forecasting service by 2030.[119] The bulk of contracts in the

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[115] https://www.nasa.gov/mission_pages/rbsp/science/rbsp-spaceweather-human.html

[116] https://www.nasa.gov/feature/goddard/2019/how-nasa-protects-astronauts-from-space-radiation-at-moon-mars-solar-cosmic-rays

[117] https://sci.esa.int/web/soho/-/soho-s-pioneering-25-years-in-orbit

[118] https://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter/Solar_Orbiter_publishes_a_wealth_of_science_results_from_its_cruise_phase

[119] https://www.esa.int/Safety_Security/Plans_for_the_future

core space weather segment of the programme aim to lay the groundwork for transitioning the current forecasting capabilities into a complete Space Weather Service Network that can provide timely and reliable space weather information to industries worldwide.[120] To realise the full benefits of forecasting, the forecasts need to reach end-users timely and effectively, and the ESA Space Weather Service Network is expected to enhance cooperation between existing forecasting providers and increase space weather resilience for its end-users.[121]

There was a clear theme in our consultations of already-realised reputational gains from the UK's commitment to space weather and willingness to making Vigil a reality. This was reported as having led to the UK having increased influence over the space weather agenda within ESA and making it more likely for ESA to adjust the programme to UK interests in the future. Furthermore, in 2019, ESA, NASA, and NOAA agreed to split space weather forecasting responsibility across Lagrange points[122], and there was significant risk of ESA falling short on this split if Vigil had not been realised. Stakeholders told us the UK's leadership in Vigil was therefore an opportunity to greatly strengthen the UK's relationship with ESA, NASA, and NOAA. This continues the UK's decade-long commitment to space weather collaborations with ESA and US, and Vigil is a key piece to fulfilling these international agreements and ensuring future fruitful partnerships.

The strengthening of the UK's space weather capabilities was reported as having long-term benefits for UK space weather operations. Participation in SSS increases the number of trusted working relationships across Europe which can help UK organisations leverage the benefits of European space weather funding, enabling the UK to continue to grow its space weather leadership, particularly in hosting one of only two organisations in the world currently providing space weather forecasting services, the Met Office.[123]

11.4.2 Debris & clean space

All space activity depends in some way or another on the ability to operate satellites safely with low risk. The amount of debris in key orbits is already posing a risk to Earth observation, telecommunications, navigation, exploration, and science missions explored elsewhere in this evaluation. Debris and clean space activities (and indeed space weather and other areas of the SSS programme) therefore play a critical cross-cutting benefit-protection role, and these benefits beyond the more immediate outputs and outcomes associated with CMIN19 contracts should not be overlooked.

Even though the debris agenda has shifted towards active debris-removal and mitigation, interviewees were clear that successful debris-removal missions that can target more than one piece of debris are still years away, and with more than 26,000 monitored pieces of debris (of which 2,850 are satellites and 1,950 are discarded rocket stages)[124], the removal of large debris with rendezvous missions is only a small (but important) piece of the overall puzzle. There are other non-ESA debris-removal projects with participation from the UK, including the UK's

[120] https://swe.ssa.esa.int/ssa-space-weather-activities

[121] https://swe.ssa.esa.int/ssa-space-weather-activities

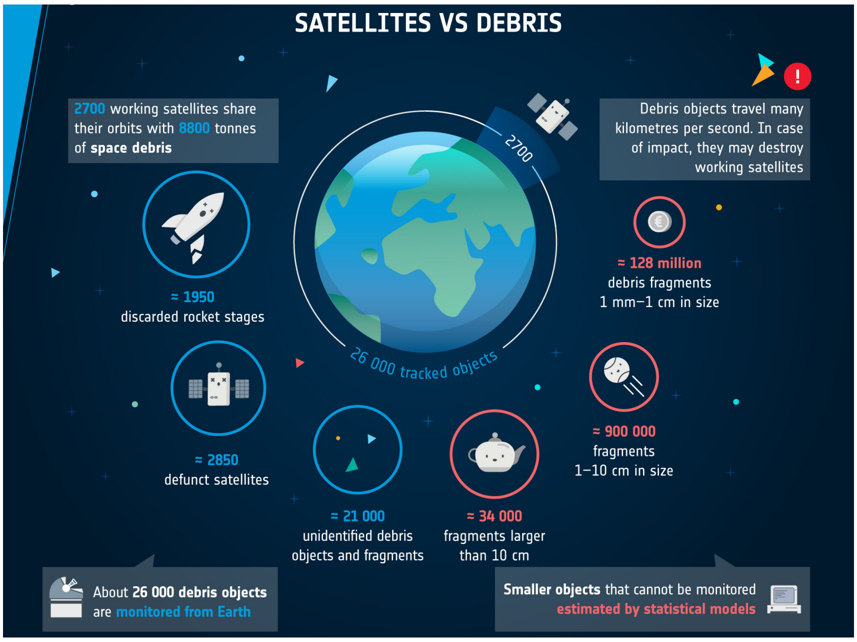
[122] https://ams.confex.com/ams/2020Annual/meetingapp.cgi/Paper/370660

[123] UKSA Business Case

[124] https://www.esa.int/ESA_Multimedia/Images/2021/02/Satellites_vs_Debris#:~:text=Satellites%20in%20orbit%20share%20near,travels%20many%20kilometres%20per%20second.&text=debris%22.

national debris-removal mission partnering with ClearSpace UK and Astroscale UK[125], and SSTL's removeDEBRIS mission, which successfully demonstrated the use of a harpoon to capture space debris.[126] The CMIN19 funding represents just a small fraction of the estimated £550m+ current global debris-tracking and removal market[127], and the impacts associated with these contracts should be considered steps in the progress to more complete debris-removal capabilities in the coming years and even decades.

Figure 69 ESA 2020 infographic on the space debris problem



ESA

Because of the risks from space debris to satellite services, there are strong benefits from strong ADR/IOS-M capabilities. The current overhead of debris mitigation for operators may amount to 5-10% of total costs, often hundreds of millions of pounds.[128] The total loss in revenue for the European space and upstream service sector due to debris in Low-Earth orbit (LEO) could amount to €1.5bn in 20 years. [129] Other satellite services that the UK rely on, such as satellite-based meteorological observations (possibly worth between £670m and £1bn annually)[130] could lose efficiency. There is a non-zero risk that we could see a 'Kessler syndrome', where satellite collisions could domino and cause debris in the most popular orbits to grow exponentially. Worst-case domino outcomes have the potential to render parts of popular

[125] https://www.gov.uk/government/news/uk-working-with-global-partners-to-clear-up-dangerous-space-debris#:~:text=The%20UK%20government%20is%20taking,with%20our%20ELSA%2Dd%20mission.

[126] https://www.surrey.ac.uk/news/harpoon-successfully-captures-space-debris#:~:text=The%20Airbus%20Stevenage%20designed%20harpoon,a%20harpoon%20to%20capture%20debris.

[127] https://www.fortunebusinessinsights.com/space-debris-monitoring-and-removal-market-104070#:~:text=The%20global%20space%20debris%20monitoring,USD%20803.44%20million%20in%202020.&text=The%20market%20is%20projected%20to,in%20the%202021%2D2028%20period.

[128] https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/12/SDC8-paper12.pdf

[129] https://space-economy.esa.int/download/space-economy-brochure.pdf

[130] https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/12/SDC8-paper12.pdf

orbits unusable – this would impact the whole satellite sector and lead to the negative impacts associated with the loss of satellite services outlined in the space weather section above.

As SpaceX, Amazon, and others are planning large-scale constellations, Euroconsult estimate that 17,000 satellites could be launched by 2030.[131] As the UK seeks to play a significant role in the launch of these satellites through its national launch initiative and as OneWeb, part-owned by the UK government, will launch its own constellation, the UK will be increasingly liable for collision events and debris. While this depends largely on how the international licensing landscape develops in this decade, this could lead to potentially huge liabilities and costs for the UK in the event of collisions, and represents a key rationale for UK Government investments in space safety.[132] While current CMIN19 debris-removal contracts awarded to UK companies were reported by our interviewees as crucial to developing the ADR/IOS-M capabilities that will establish the legitimacy of UK launches and constellation management and ensure a strong licensing position.

This applies not only to debris-removal but also collision automated avoidance techniques developed through the CREAM element of the programme. As the number of satellites in key orbits increase greatly in the coming decade, continued monitoring, warning, and manual avoidance manoeuvres come with significant operational costs – and risks – to satellite operators. Strong UK automated collision avoidance capabilities developed through ESA CREAM contracts could help both boost future UK commercial opportunities and further position the UK as a responsible and cost-efficient satellite operator.

Interviewees firmly believed in the long-term wider impacts of reduced space debris, they also agreed that the 'long-term game' of UK's involvement in the space safety programme is around solidifying UK leadership in the emerging ADR/IOS-M market. There was a theme among stakeholders around the lack of global organisation and lack of funding for the debris problem with the currently limited number of countries in EU actively supporting the space safety programme. This was called an opportunity "that the UK should take" to influence the SSS programme and shape it to support national interests.

If the UK can successfully demonstrate advanced capabilities in ADR, our interviewees asserted that they expect techniques will spill over into in-orbit servicing, manufacturing, and (in the more distant future) asteroid mining and space-based solar power. In terms of in-orbit servicing and manufacture, capabilities developed during current and past space safety contracts could lead to more advanced rendezvous, grappling, and de-orbiting techniques in the UK, representing the potential for significant commercial activity for the UK space industry. ESA expects the ADR/IOS-M market to grow to more than £2.5bn by 2036[133], and Northern Sky Research project total ADR/IOS-M revenue, mainly driven by demand for satellite life extension, to reach a cumulative £3.4bn by 2032.[134] ADR is expected to be the fastest-growing area, at 38% annually[135], driven by the demand on orbits posed by planned satellite constellations.[136]

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[131] https://satelliteprome.com/news/17000-satellites-to-be-built-and-launched-by-2030-euroconsult/#:~:text=Satellite%20market%20forecast%20anticipates%2017%2C000,to%20be%20Built%20%26%20Launched%20by

[132] UKSA SSS Business case

[133] https://space-economy.esa.int/download/space-economy-brochure.pdf

[134] https://www.nsr.com/street-insider-nsrs-in-orbit-services-report-projects-14-3-billion-in-revenues-as-non-geo-constellations-grow-demand/

[135] CAGR

[136] https://www.nsr.com/street-insider-nsrs-in-orbit-services-report-projects-14-3-billion-in-revenues-as-non-geo-constellations-grow-demand/

Companies interviewed already reported that their ESA contracts have led to demonstrated commercial interest from buyers worldwide and the UK-developed 'de-orbit kits', on-board add-on kits that allow satellites to self-decommission (de-orbit) themselves, represent another opportunity for the UK to capitalise on the fast-growing market. Another company reported expecting £3m in income from selling collision avoidance technology developed during their CMIN 19 contracts to future satellite launchers.

Finally, interviewees were keen to stress the wider sustainability benefits of their debris & clean space activity as a key step in the transition to a fully sustainable, circular space economy with minimal junk in orbits around Earth. There was agreement that licensing and regulation will play an increasingly important role in this endeavour and that UK licensing leadership could be impactful. Strong ADR, 'self-decommissioning', and automated avoidance capabilities would provide a rationale for the UK to actively help shape the upcoming licensing landscape, which would help realise wider space safety and sustainability benefits.

Although not directly attributable to CMIN19 contracts, multiple interviewees reported representation on boards across ESA (for both space weather and clean space) and that the UK is represented on "too many international committees and boards to list".

11.5 Attribution and additionality

When discussing long-term impacts of space safety, it is difficult to attribute benefits to ESA contracts as opposed to (for example) non-ESA activities and other UK national funding. Space weather forecasting and debris-tracking already have other significant contributors (such as the US), and the ESA activity should be seen as part of this wider global push. In practice, space safety is about complementary capabilities and as such, future (uncertain but sizeable) benefits cannot easily be attributed to any single input within a wider, internationally-collaborative endeavour.

For debris & clean space, ESA's purposeful approach to stimulate a commercial ADR/IOS-M market both as a *customer* and *service provider* means contracts will be inputs into a wider, commercial industry – particularly as private investment into ADR/IOS-M companies increases.[137]

For space weather, consultees were of the view that despite the UK funding the vast majority of Vigil, the UK could not pull off such a mission unilaterally with the UK's current capabilities. To realise the benefits of Vigil, funding through ESA was described as absolutely necessary. While SmallSats and satellites could be funded nationally, larger spacecraft missions would (without significant budget reallocation) be both be too costly for the UK to launch on its own. On top of that, the value-add of ESA expertise – unanimously mentioned in our interviews – to missions would be lost.[138]

There was also a clear theme across consultees that for the global problems that SSS aims to solve, it is important to have a 'seat at the table' to fully reap the global gains. Numbers can tell one story, but the relationships that ESA participation creates can be easy to undervalue. To be part of missions that 'unite the globe', interviewees stressed the importance of not sitting on the side-lines and missing out on the relationships that will be built.

However, specifically within debris & clean space, there was a less clear picture of the attribution of ESA funding in realising benefits. Some consultees saw a clear benefit to

[137] For example, Astroscale (global) announced raising $51m in private funding in 2020.

[138] UK Space Safety Community Meeting: Part 1

participating in the ADRIOS/ClearSpace-1 mission, while others were optimistic that the UK commercial momentum in ADR/IOS-M could continue through national funding. Debris-removal companies such as Astroscale UK[139] and D-Orbit could possibly continue to grow if national funding replaced ESA funding. However, stakeholders were optimistic that participation through ESA helps attract companies to the UK, both through georeturn and due to the clear signal the UK is sending through its international commitment to the space safety agenda. As discussed above, some companies reported that UK involvement in the ESA space safety programme was a key factor in their choice to set up operations in the UK.

Across the programme, interviewees pointed out that national or bilateral programmes come with more control, but that ceasing ESA participation would mean losing crucial technology and knowledge transfers between member states and the UK, and that without involvement across the space safety pillars, the UK could slowly lose some of the strong capabilities it has today.

As in other programme areas, the ESA 'stamp of approval' effect was reported to be an important piece of leverage both in terms of future private investment and attracting future customers.

Finally, for both space weather and debris & clean space, there was consensus that involvement in ESA gives international visibility, ability to work on bigger, more wide-ranging projects (which increases upskilling), access to new partnerships, and the ability to tap into ESA expertise. To add, debris-removal companies reported that, on top of the stamp-of-approval effect, ESA plays a commercially important role by de-risking both R&D and production – partly through being an anchor customer, but also due to the high risk-mitigating standards at ESA that result in robust products and services that are market-ready ("if you can sell to ESA, you can sell to anyone").[140]

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[139] Astroscale UK also received a £2.5m contract through the ARTES Sunrise programme.

[140] UK Space Safety Community Meeting, 16th February 2022

12 Commercial Space Transportation Services

12.1 ESA's Commercial Space Transportation Services programme

ESA's key objective for the CSTS programme is to build the economic resilience of Europe's space transportation sector. It seeks to do so by supporting economic growth, diversification, and the competitiveness of commercially viable, privately led initiatives for space transportation services, thereby ensuring Europe's affordable and reliable access to space. ESA seeks to foster entrepreneurship and innovation to respond to the growing global trend towards smaller scale, commercial space activities.

The programme, familiarly known as 'Boost!'[141], provides tailored support to UK launch companies and related infrastructure, focused on developing commercial small-scale launchers. It provides access to funded firms to ESA's heritage and expertise in launch.

As a new, optional programme in CMIN19, it supports and co-funds commercial initiatives that offer space transportation services to, in, and returning from space, and supports participating ESA Member States in developing commercial micro-launchers and launch-related infrastructure. It is flexible and adapts itself to match the needs of European economic operators through responsive tailored support (financial, technical, programmatic, business), giving them the tools to succeed without a guaranteed institutional customer/market.

The overarching principle is that activities are initiated by incoming proposals from entities residing in Participating States. The programme aims to streamline the traditionally burdensome programme management of previous launcher programmes and builds upon the successful approaches of ARTES and NAVISP by keeping ESA overheads to 10%. Overall, CSTS is a relatively small programme: its total covered budget is €53.3m (2020-2022), or 0.4% of the total ESA budget for the period.

12.1.1 UKSA in CSTS

The UK has not traditionally invested in ESA launch programmes and thus, has only limited related capacity and capabilities. This is notably due to the considerable cost of larger launch programmes like Ariane and Vega, and the misalignment of these to UK priorities. Nevertheless, the UK wants to develop expertise in space transportation and access the considerable new market opportunities, hence its participation in CSTS since its inception at CMIN19.

CSTS complements and enhances existing national grant-funding run through LaunchUK, the UK's commercial spaceflight programme.[142] Indeed, many of the outputs, outcomes and impacts discussed in this chapter should be seen within the context of the UK's wider ambitions to be at the global forefront of small satellite launch and emerging space transportation markets, and to establish commercial vertical and horizontal small satellite launch from UK spaceports from 2022. The UK's objectives through participation in the programme are:

- Developing national space flight capability and market access and gain trust and legitimacy to achieve the first launch in Europe and access foreign markets.

[141] Boost! has two elements: the Commercial Space Transportation Services (Element 1), which provides support that is flexible and tailored to the needs of European economic operators pursuing privately-led developments for commercially viable new space transportation services, and Support to Participating States (Element 2) in meeting the demand of ESA Member States to provide them with assistance in the implementation of national space transportation objectives in the field of spaceports infrastructure and related services. The vast majority of the UK's investment (€14.35m out of €15m total at CMIN19) was in the CSTS / element 1 strand, with €0.65m in element 2.

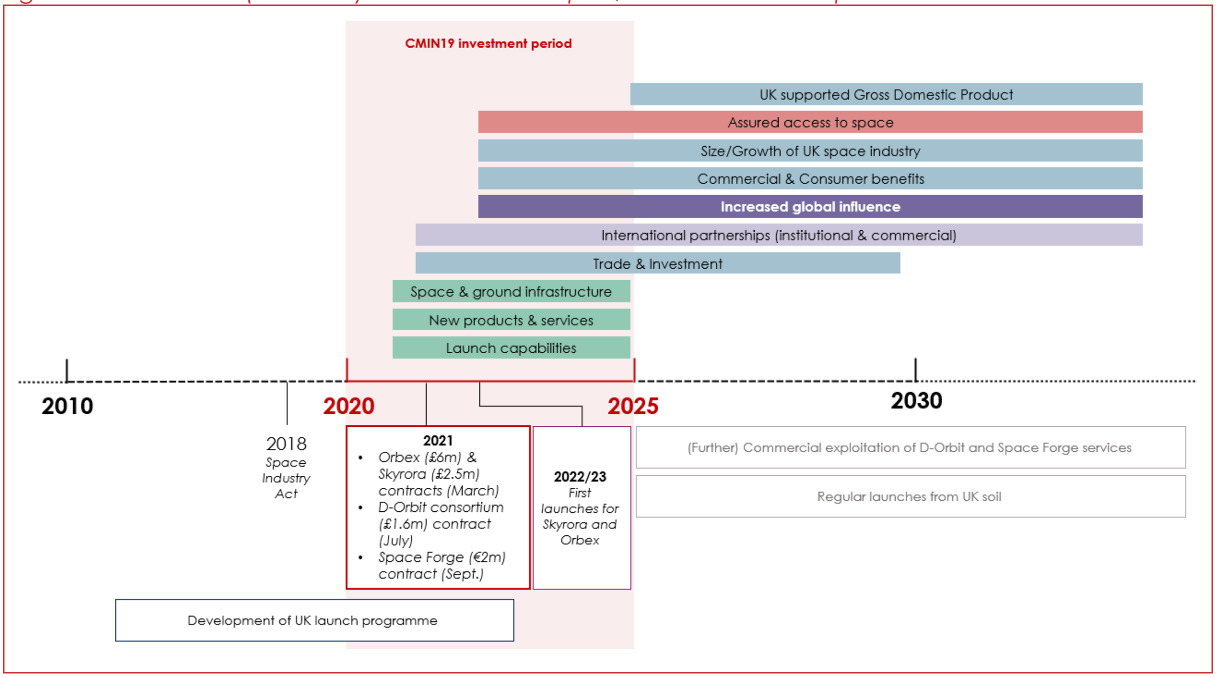
[142] See: https://www.gov.uk/guidance/how-we-are-promoting-and-regulating-spaceflight-from-the-uk

- Gaining technical assistance and expertise from ESA and participating member states to support the development of its national launch capabilities.
- Supporting economic growth by enabling UK-based organisations to access ESA support, which may facilitate their subsequent access to funding through increased legitimacy and reputation.

Our discussions with UKSA also highlighted that in addition to the Technology Safeguards Agreement (TSA) for spaceflight activities that is in place with the US[143], a subscription to CSTS is required in order for the US to consider granting export licences for satellites to launch on UK launchers and US launch technology on a case-by-case basis. As such, a core aim of the UK's subscription to the programme at CMIN19 is also to ensure that US payloads are permitted to launch on UK launchers. The North American market represents 40% of the UK-addressable market for smallsats requiring launch over a 2022-2034 forecast period, and ensuring access to this market is critical to the UK spaceflight programme (i) securing forecast cumulative revenue for UK launchers of over £1bn and (ii) creating and sustaining nearly 1,000 high-skill jobs over the 2022-2034 period.[144]

UK involvement in CSTS is focused on four specific contracts: two for launchers (Skyrora, Orbex) and two for prospective launch customers (D-Orbit, SpaceForge).

Figure 70 Timeline of (selected) CSTS CMIN19 outputs, outcomes and impacts



12.1.2 Logic model

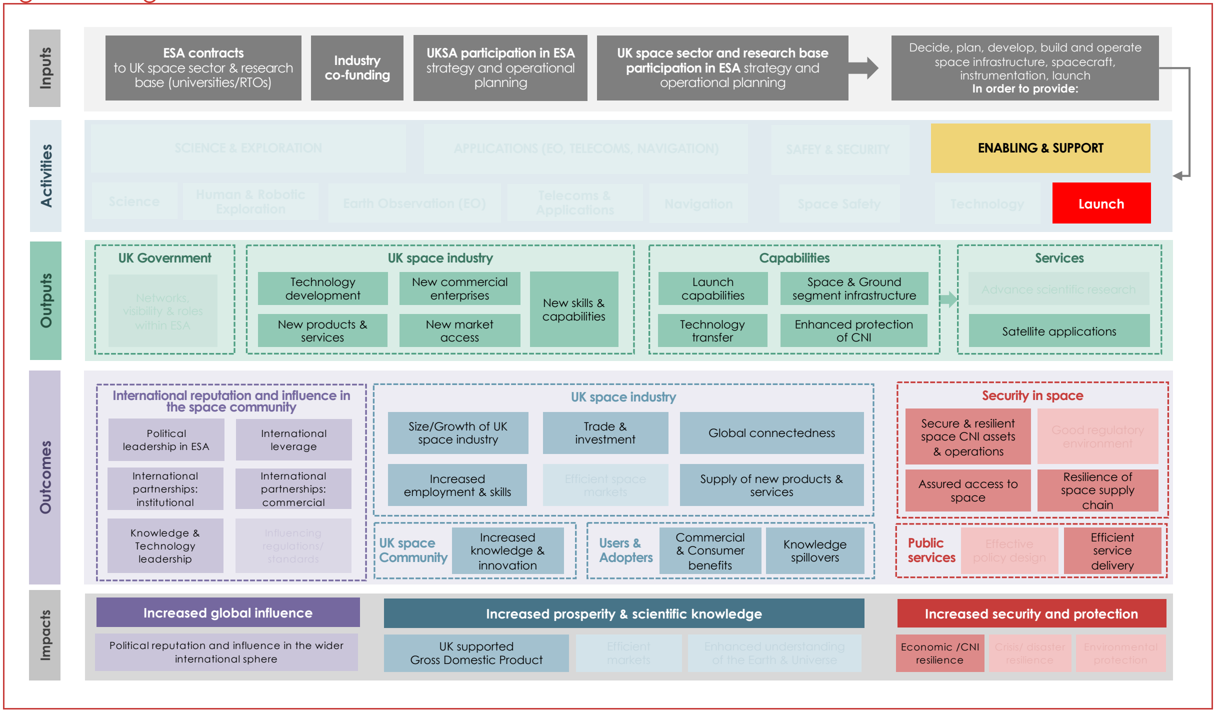
Reflecting launch's role as an enabler of the wider space industry value chain, the routes to impact are varied and cover most of the outputs and outcomes aside from those relating to scientific knowledge, influence on the regulatory environment, and policy design. These routes can be both direct, for example with new products and services being enabled through CSTS

[143] https://www.gov.uk/government/publications/ukusa-agreement-in-the-form-of-an-exchange-of-notes-between-the-united-kingdom-and-the-united-states-of-america-on-technology-safeguards-associated/uk-us-technology-safeguards-agreement-tsa-for-spaceflight-activities-understanding-the-tsa

[144] Internal UKSA Spaceflight analysis based on know.space & NSR (2021), *UK Satellite Launch Market Study*

such as Forge Star (discussed below), or indirect, through its role as part of the wider UK launch endeavour which is expected to help grow the UK space industry and enable new activities.

Figure 71 Logic model for ESA CSTS



12.2 Inputs and activities

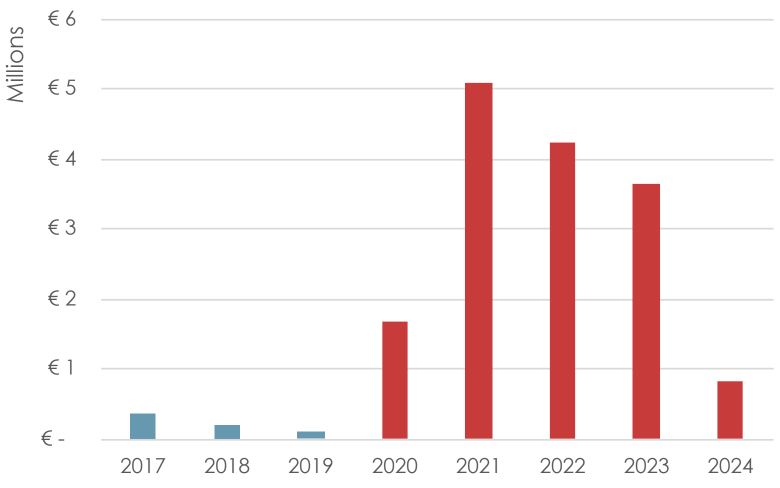
At CMIN19 the UK subscribed €15m into CSTS, representing around 2% of all UKSA investments at CMIN19 for 2020-2022 and a quarter of the total covered budget for CSTS. The UK is the second largest contributor to the programme after Germany (€27.5M) and far ahead of Italy (3rd largest contributor, €5M).

Table 34 UK CSTS financial obligations to ESA (M€)

	CMIN19 period				
	2020	**2021**	**2022**	**2023**	**2024**
CSTS funding	€1.68	€5.07	€4.22	€3.64	€0.84

ESA datasheet on national obligations

Figure 72 UK commitments to the CSTS Programme 2017-2024



ESA datasheet on national obligations

Table 35 CSTS commitments by programme area

	CMIN19 period				
Programme	**2020**	**2021**	**2022**	**2023**	**2024**
CSTS - Element 1	€1.45	€4.86	€4.02	€3.56	€0.82
CSTS - Element 2	€0.17	€ 0.21	€0.19	€0.09	€0.01

ESA datasheet on national obligations

Across the programme as a whole, UKSA expect leveraged private investment to be at least as much as the CSTS public investment. All the key contracts have now been let, with the four UK contracts detailed below. In addition to these, there may potentially be some further small, quick proposals to use up any leftover funding.

1. £6m for Orbex (€7.45m), for development of their 'Prime' microlauncher rocket

Announced in March 2021[145], The funds from the award will go towards the completion of spaceflight systems in preparation for the first launches of Orbex's 19-metre microlauncher rocket, Prime. Orbex are supplementing the funding with an additional €4.7m in private investment. The Prime launch vehicle is expected to launch small satellites into orbit from Space Hub Sutherland in 2023.

€11.25 million of this total funding will be assigned to work undertaken in the UK, in particular the lightweight avionics designed in-house by Orbex in Forres (Scotland), and the guidance, navigation and control (GNC) software subsystem being designed by Elecnor Deimos, as a UK subcontractor. The remaining €900,000 of the total funding package will support the development of the GNC for the orbital phase being developed by Elecnor Deimos for Orbex in Portugal.

[145] https://www.gov.uk/government/news/scottish-based-space-companies-secure-85-million-to-bring-pioneering-launch-technologies-to-market

2. £2.5m for Skyrora (€3m), to complete development of their Skyrora XL launch vehicle

Also announced in March 2021[146], this ESA co-funding will be used by Skyrora to complete the crucial technology required to deliver consistent orbital launches from the UK with Skyrora's XL launch vehicle. Skyrora XL is a 23-meter 56-tonne three-stage rocket capable of carrying up to 315 kg into orbit. The vehicle is expected to be test-launched in 2022 from a UK spaceport.

The funding will enable Skyrora to complete the setup of their larger Engine Test Complex, complete the 70kN engine programme, and static fire test fire the first and second stages of Skyrora XL. As well as technology development, the funding covers facilities, teams and network-building.

3. £1.6m for D-Orbit and consortium partners, for in-orbit transportation services

D-Orbit's responsive microlauncher service, which provides end-to-end delivery of payloads in orbit, is designed to use the upcoming small launchers that are due to launch from the UK. This contract with D-Orbit UK was announced in July 2021[147], and focuses on logistics coordination and process standardisation between different European spaceports and launcher providers.

It will bring the responsive microlauncher service to the UK, aiming to establish D-Orbit as a key enabling provider in an end-to-end UK supply chain that transports and operates space assets into orbit. The new service is based at the Spaceport Cornwall Centre for Space Technologies, and the project is a wide-reaching collaboration across key actors in the supply chain. The £1.6m represents the overall value of the CSTS/Boost! contract for D-Orbit and consortium, including co-funding, and where £1m is ESA contributions via UKSA and PT Space. Consortium partners include the ScotSpace (for Prestwick Spaceport), the Atlantic Spaceport Consortium (ASC – who lead the Portuguese component in the service project), KISPE (representing Virgin Orbit), Skyrora, and the Sky and Space Company (SAS, on behalf of customers). The Satellite Applications Catapult are also supporting market surveys, service definition and liaising with Spaceport Cornwall on the specification, funding and operation of physical service facilities.

4. €2m for Space Forge for Forgestar, a reusable and returnable suitcase-sized vehicle

ForgeStar will be part of a complete commercial service offering 'microgravity on demand' as a routine access to and return from space service, that can be launched from a variety of launch vehicles. ESA is supporting the project (announced in September 2021[148]) through a two-year contract worth €2m within the CSTS programme, covering the preliminary and detailed design phases, as well as the launch, in-orbit operation and return of the first operational ForgeStar demonstration vehicle.

12.3 Outputs

As a new programme, the outputs from CSTS are typically more 'standalone' than in other programme areas. However, as in other areas, there is also often a wider ESA story at play, with (for example) Space Forge's ForgeStar previously supported through (c. £100k) GSTP funding. Interviewees were also keen to contextualise the programme within the bigger picture of launch costs and/or the LaunchUK programme. Even the biggest contract, at £6m, is relatively

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146 Ibid

147 https://www.esa.int/Enabling_Support/Space_Transportation/Boost/ESA_s_Boost!_fosters_new_launch_and_in-orbit_services

148 https://www.esa.int/Enabling_Support/Space_Transportation/Boost/Microgravity_on_demand_with_Earth_return_through_ESA_s_Boost

small when compared to the tens or even hundreds of millions that can go into small launcher development over many years (for example noted as a "supporting piece" to the overall vehicle development).

Interviewees were however keen to point out that even if the funding amounts are relatively small, it is still expected to deliver good outputs and outcomes. There is also the critical point that (as discussed above an in more detail later in this chapter) regardless of the funding amounts, the UK's CMIN19 investments are also critical for ensuring UK launchers' access to the US market. Being unable to access US demand for small satellite launch would substantially jeopardise the UK launch market, which is forecast to generate over £1bn in launch revenue and create and sustain nearly 1000 high-skill jobs.[149]

Contracts are at a relatively early stage, only having been announced in 2021. We were informed of some delays to the broader CSTS programme due to wider issues with other ESA launchers programmes, though the general picture was one of contracts being broadly on track with important milestones being met and passed. The general view from UKSA, ESA and industry was one of good progress towards test launches and speeding up the route to market ("it gives us a leg up").

While interviewees were unanimously keen to stress that the CSTS funding is only part of a bigger story, there are positive outputs already being seen where CSTS has played a role. These include:

- In terms of commercial progress, both Orbex and SpaceForge have since secured Series A funding: $24m for Orbex (announced in December 2020150), and $10m for Space Forge (announced in December 2021151). In one of our interviews we were told that the ESA CMIN19 contract is "fundamental" to the investment.
- Similarly, all companies have hired relatively aggressively since receiving the ESA contracts, with dozens of new employees, and expectations for hundreds more in some cases. We heard examples of growth from 2 to 25 people, of two people (with the caveat that "we're just getting started"), while Skyrora expect to create >170 jobs at their new test complex – which has been directly enabled by the CSTS funding - by 2030.152
- An emerging story around local growth and levelling up, where new facilities and jobs are being created in Wales (Space Forge's new facility – with the company now Wales' largest true space company and the country's first satellite manufacturing capability) parts of Scotland (Skyrora's new facility and Orbex's expansion of their Forres site) and in Cornwall (D-Orbit).
- Expectations for technology development, where for example one interviewee noted that ESA funding will help them raise the TRL of their product from TRL 4/5 to TRL 9. While in some cases the technology itself has already been developed, here the ESA funding can be for continuing R&D and 'proving' of the technology, so relates to the high TRLs of the broader process in that sense. Interviewees also noted that the funding is often to do with "service readiness" rather than pure technological readiness, but stressed that this is an important part of commercialisation and longer term sustainability of their product offer.

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[149] Internal UKSA Spaceflight analysis based on know.space & NSR (2021), *UK Satellite Launch Market Study*

[150] https://orbex.space/news/orbex-secures-24-million-funding-round-for-uk-space-launch

[151] https://www.businessleader.co.uk/space-forge-secures-10-2-million-in-record-breaking-seed-round/

[152] https://www.skyrora.com/post/skyrora-opens-rocket-engine-test-complex-expected-to-create-over-170-jobs

- New assets, with Skyrora for example having opened their new test site[153]. Again, the broader picture related to the UK launch ambitions beyond CSTS is one of developing new indigenous launch capacity and infrastructure, which CSTS plays into.

12.4 Outcomes and impacts

With contracts at a relatively early stage and test launches yet to come (as expected), most outcomes and impacts can mostly only be discussed in terms of expectations rather than already-realised benefits for firms and the wider sector. Some interviewees noted that – while it depends on the outcome in question – a typical timescale to outcomes might be 2-3 years from the time a contract is awarded, with first launches often in 2023.

12.4.1 Increased global influence

Our evidence collection painted a picture of UK participation in CSTS already helping to raise the profile and influence of the UK, and creating new opportunities.

From an institutional perspective, the role of CSTS in providing access to the US market is also a critical underpinning rationale for the UK's investments in CMIN19 (discussed in more detail below).

Access to the ESA market is also seen as a core target – the UK wants to use UK launchers for ESA missions, and are using their voice in CSTS to push that agenda. Being part of CSTS was noted both by UKSA and ESA as giving the UK "more voice in the room" and enabling new partnerships. Access to the institutional ESA market for launch is not part of the present set of programmes, but is a topic of discussion for future design. Being part of CSTS from day one increases UK influence here.

CSTS is seen by both UKSA and industry stakeholders (and indeed ESA themselves) as having a potentially notable effect in improving the UK's reputation as a launching nation, and in giving the UK more weight in ESA programme boards.

While more relevant for some stakeholders than others, the role of the programme in giving access to ESA heritage and expertise – and indeed to institutes and information – was often highlighted as a particular benefit from participation. For example, ESA noted that one of the launch companies asked for two ESA reviewers to assess whether their chosen approach and documentation were correct. With the choice being up to the company, and not mandated, this can be a useful resource for participants to tap into.

The programme was described to us as "win-win" for both the UK and ESA. For the UK, it develops competences, attracts investment, grows resilience and improves sustainability, while for ESA there will be benefits for the wider space ecosystem if it brings launch costs.

12.4.2 Increased prosperity & scientific knowledge

There is a positive story already emerging on trade and investment, with (as noted above) Orbex and Space Forge recently having secured substantial series A funding. Some interviewees noted that ESA participation has played a role in enabling them to prove themselves to investors, helping them to show how what they are doing links to the investment 'story'. Companies discussed plans for importing new product and service offerings to the UK, which could have strong commercial potential, noting the role that CSTS funding is playing in

[153] https://www.skyrora.com/post/skyrora-opens-rocket-engine-test-complex-expected-to-create-over-170-jobs

enabling this. UKSA noted their hopes for to lead to new UK manufacturing and services that will be offered UK-wide.

The programme could have particularly significant benefits if it plays out in terms of global connectedness through improved access to US or European markets, which was often a stated aim for the companies we spoke to. One industry interviewee noted markets valued in the "low $ billions" that might be made accessible, representing a potentially huge source of export-driven revenue, while others were more cautious, noting that the ESA funding was "probably" good for their bottom line in the long run.

This market access point was stressed by UKSA – and indeed is an underpinning rationale for UK involvement in the programme at CMIN19. We understand that the €15m CMIN19 investment in CSTS is responsible for ensuring that US payloads are permitted to launch on UK launchers, as it makes the UK a 'certified launcher' from the US perspective. It is an essential prerequisite (along with the Technology Safeguards Agreement[154]) for the US to consider granting export licences for satellites to launch on UK launchers and US launch technology on a case-by-case basis. The reasons for this are elaborated on in the 'attribution' section below.

Without the CMIN19 subscription to CSTS, it may critically impact the ability of US launch companies such as ABL to launch from UK spaceports and of companies launching from the UK to access US demand, which is critical to ambitions of UK launch to access major markets.[155] The UK was the first European state to conclude a TSA with the US, and if the UK removes its subscription with CSTS then the benefits of the TSA will be lost. If the UK loses its TSA-dependent launch benefits while rivals like Norway enter into a TSA and take the steps necessary to realise its benefits, the UK risks missing the National Space Strategy commitment to be the leading provider of commercial small satellite launch in Europe by 2030.

Indeed, the North American market represents 40% of the UK-addressable market for smallsats requiring launch over the 2022-2034 forecast period, and so being unable to access US demand for small satellite launch may substantially jeopardise the UK launch market, which is forecast to generate over £1bn in launch revenue and create and sustain nearly 1000 high skilled jobs from 2022-34.[156]

All of those we spoke to discussed a stamp of approval effect. For example, as a relatively young company, Companies noted the role of this effect both in terms of improving their reputation, but also in boosting company morale through having endorsement from highly qualified engineers from ESA. One company noted how the effect helps perceptions of them being "the logical choice" within the UK for their activities. This, in turn, helps attract new business.

The programme is expected to help grow the UK space industry in many ways. Firstly, there is the direct effect associated with funding recipient company growth and the dozens of new jobs discussed above. One company discussed how CSTS (together with various other activities) would help them bring across a service over to the UK from overseas, with a resultant increase in manufacturing and jobs expected in the future. While the CSTS funding is often a relatively small amount of funding in terms of launch technology development, as noted above, the programme was noted as playing a particularly important role in creating new

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154 https://www.gov.uk/government/publications/ukusa-agreement-in-the-form-of-an-exchange-of-notes-between-the-united-kingdom-and-the-united-states-of-america-on-technology-safeguards-associated/uk-us-technology-safeguards-agreement-tsa-for-spaceflight-activities-understanding-the-tsa

155 Internal UKSA Spaceflight analysis based on know.space & NSR (2021), *UK Satellite Launch Market Study*

156 Ibid

partnerships, which should help to unlock future growth. Beyond the hundreds of jobs discussed above, there would (if the UK launch offer is ultimately commercially successful) be many more high skill jobs created in the wider supply chain.

There is also a route to space sector industry growth though its role as part of the national launch endeavour in terms of helping to deliver sustained launch and commercial markets, which will lead to new, high-skill jobs and economic activity. Indeed, if launch solutions are able to offer UK-based companies a superior / lower cost service or new ability to achieve something that was previously too difficult or expensive (e.g. insertion into specific orbits), then new economic activity will be 'priced in' and various efficiency benefits will be realised.

The UK launch market has significant long-term commercial potential, though to realise this potential it must survive a high risk period in its first years of operation. The know.space / NSR 2021 UK Satellite Launch Market Study advised that UK launch would be especially vulnerable in its first years of operation when building heritage (the confidence associated with a proven history of successful safe launches). The UK's CSTS subscription acts to help UK launch service providers and other actors in the UK launch ecosystem develop their unique selling points and business operations and investment in and expand their businesses and operations in the UK. Collectively, CSTS acts to reduce risk and enhance the competitiveness of the UK launch offer and more deeply integrate and connect the UK launch market, supporting the UK launch offer and the benefits generated by launch for the UK economy.

One company noted that the CSTS funding has given them "confidence to think about scaling", improving their ability to grow. Again, the link to the wider UK launch story was emphasised, with CSTS noted as a relatively small part of this, but one that is enabling them to speed up deployment and reduce supply chain risks. The added impetus from ESA was noted as having enabled them to meet milestones on time despite external pressures, while giving them confidence and the opportunity to "spread the word". ESA noted that by the end of the CMIN19 period, they expect to be in the position where some of the companies will be close to starting commercial exploration of their services. Again, they were keen to stress that this is all part of a wider story, where the funding can help speed up time to market but is one of many ingredients that factor into commercial readiness.

We heard a clear story around the potential supply of new products and services due to new capabilities that CMIN19 funding has helped enable. For example, one interviewee discussed the potential applications of their technology to manufacturing automation, renewable energy, pharmaceuticals, semiconductor manufacture, and other areas stemming from "potentially billions" of new alloy capabilities through in-space manufacturing. One interviewee noted how their CSTS funding is helping them to deliver an end-to-end service, reducing difficulties for potential customers. bringing flexibility and potentially reducing cost.

All industry interviewees were keen to highlight the important role that CSTS is playing in leading to new collaborations and partnerships. One interviewee noted that the programme helps "align them with the data people", while other non-launcher interviewees were keen to stress the importance of the programme in connecting them to launchers, spaceports and potential customers ("for us, the value is in the new partnerships").

On scientific knowledge the impact is perhaps lower than in other, more directly science-focused programme areas, though new products and services enabled by CSTS funding will in turn help enable new science to be conducted through experiments in space, with fast return to Earth.[157] This could enable new, previously infeasible, scientific experiments to be carried out. More broadly, the scientific community is a potential customer of UK launch, so some new activities may be enabled or sped up through CSTS-funded activities.

12.4.3 Users, adopters, and the wider space community

While the commercial benefits to CSTS funding recipients are important, CSTS and the wider UK launch endeavour can also be seen as a means to an end, and all the services that are launched have their benefits. The ESA funding was noted as helping to "grease the wheels" to enable UK launch to happen and become a functional system – in turn enabling the wider benefits through better/cheaper services from space once launch capabilities are established.

Some stakeholders were therefore keen to make the point that ultimately, UK launch (and so CSTS as part of this wider story) is about unlocking benefits in the wider value chain. Recent analysis of the UK launch market by know.space and NSR shows a varied customer base – with four market segments (commercial non-GEO EO, commercial non-GEO comms, science and technology development, other) all having at least a 15% share of total satellites expected to be launched from the UK.[1] Customers will choose UK launch due to the offer being more appealing than alternatives, suggesting that there will be efficiency benefits unlocked, e.g. through the ability to reach better orbits more cost-effectively and so provide better/cheaper services. Furthermore, the existence of launchers can also spur on growth in the wider sector and supply chain through attracting investment, and cluster / agglomeration effect.

While there is not yet much evidence around technology transfer, spinouts, and knowledge transfers as a direct result of CSTS funding, some interviewees were keen to highlight the criticality of technology transfer between different projects. For example, a technology could receive funding through two different ESA programmes at different times, or ESA and UKSA national funding, with substantial knowledge transfer between projects – and often in both directions. Beyond pure knowledge transfer, this can also play out in terms of transfers of people, techniques, technologies, and so on.

12.4.4 Increased security and protection

There are defence and security benefits through the role of CSTS as part of the wider UK launch story. Indigenous launch capability has strategic value for military and other institutional purposes (e.g. CNI resilience), as it reduces reliance on other countries. Furthermore, if CSTS is able to speed up deployment for launch (and develop new products through non-launcher support, with associated new capabilities unlocked) then it could help enhance these benefits.

One interviewee also highlighted the benefit from the sovereign perspective of the UK being able to retrieve payloads from UK / friendly-controlled land, as well as closed-loop defence capabilities with launch-and-return. They also highlighted expected environmental and sustainability benefits from reducing the burden of bringing experiments and other materials back from space, and potentially through opening up new sustainability angles through the ability to return assets from space and re-launch, rather than having to manufacture from afresh.

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157 https://www.esa.int/Enabling_Support/Space_Transportation/Boost/Microgravity_on_demand_with_Earth_return_through_ESA_s_Boost

[1] Know.space & NSR (2021), *UK Satellite Launch Market Study*

12.5 Attribution and additionality

Ultimately, the UK's participation in CSTS is to support the UK spaceflight programme, and this bigger picture must be kept in mind.

However, a major reason for the UK engaging in CSTS was that Missile Technology Control Regime (MCTR) regulation would not allow export of US launch technology, and likely US payloads, to a country that does not already have launch heritage. CSTS is viewed by the US as a launcher programme managed by an established European launching agency (i.e. ESA). UK-developed launchers funded through CSTS are therefore seen as European launchers, with the heritage this brings.

The UK's subscription to CSTS was a critical factor to the US executing a Technology Safeguards Agreement (TSA) with the UK. However, whilst the TSA is necessary to enabling US launch and satellite companies to export technology for use at UK spaceports, it is not sufficient. Both the TSA and a UK subscription to the CSTS are required for the US to consider granting export licences for satellites to launch on UK launchers and US launch technology on a case-by-case basis. If a subscription to CSTS is lost it may critically impact the ability of US launch companies such as ABL to launch from UK spaceports.

Further to this, the UK losing its CSTS subscription might mean the US payloads might not be granted export licences to be launched from UK spaceports or on UK launch service providers. As discussed above, this would close off the substantial US potential customer market, leading to losses in launch revenue and jobs, i.e. without CSTS, these benefits would be lost.

For launch service providers, it was seen that launch activity would likely have taken place anyway, but slower. Some were keen to point out the importance of CSTS funding in helping them get first launches ahead of competitors, which may not have happened in the absence of participation, which would have had various knock-on effects. Non-launch interviewees were also keen to note that they would not be in the same position as they are now without the CSTS funding.

12.5.1 ESA-added value

Stakeholders were typically – though not unanimously - of the view that national funding could have been used, targeting the same aims, but that this would have taken years longer. Those we spoke to were generally positive about the way the programme is run through ESA, in a relatively light-touch way, and were keen to emphasise the value of getting access to ESA expertise (both programmatic and technical) through the programme, which would be lost if a purely national approach were pursued.

For example, one interviewee noted that ESA has capabilities that UKSA does not – and that it will not have, so long as it remains a civil service agency (i.e. technical capability is not a focus). They noted that ESA involvement increases market visibility ("it allows you to see what everyone else is up to"), and that ESA themselves are very good at helping companies find suppliers, facilities, incubators, and investors.

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