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TECHNICAL ANNEX: Impact evaluation of UK investment in ESA

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1 Introduction

1.1 Study objectives

The European Space Agency (ESA) is an important route for UK government objectives for space and a significant proportion (around 75%) of the UK's public investment in space is made via ESA. The UKSA is committed to ensuring that UK investments made via ESA are properly evaluated. The development and implementation of an appropriate monitoring and evaluation (M&E) framework was a condition underpinning the approval of the business case for UK's ESA funding commitments made at the 2019 ESA Council of Ministers and is a commitment of the UKSA 2020/21 Corporate Plan.

The UK Space Agency (UKSA) commissioned a consortium of Technopolis Ltd, know.space, Cambridge Econometrics and Science-Metrix to:

- Develop a monitoring and evaluation (M&E) for framework for UK investments in the European Space Agency (ESA) agreed at the 2019 ESA Council of Ministers (CMIN19)
- Capture a baseline for evaluations of CMIN19 investments
- Implement a first impact evaluation and a process evaluation

The M&E framework will set the basis for understanding the effects of the CMIN19 investments in the near and longer-term and provide evidence to inform future strategy, policy and investment decisions. The framework has been developed in line with the HMT Magenta Book, the BEIS and UKSA Evaluation Strategies[1]

The study covers eight space domains programmes where UKSA invests via ESA,[2] the mandatory Space Science programme plus seven optional programmes.

Table 1 ESA programmes

	Programme	Short name
Mandatory	Space Science (mandatory)[3]	Science
Optional	Telecoms & Integrated Applications	TIA
	Earth Observation	EO
	Human & Robotic Exploration	HRE
	General Support Technology Programme	GSTP
	Space Safety and Security	SSS
	Navigation Innovation and Support Programme	NAVISP
	Commercial Space Transportation Services	CSTS

[1] Magenta Book, Central Government guidance on evaluation, HMT, March 2020
https://www.gov.uk/government/publications/the-magenta-book
BEIS (2020) and UKSA (2015) Evaluation Strategies
https://www.gov.uk/government/publications/beis-monitoring-and-evaluation-framework
https://www.gov.uk/government/publications/evaluation-strategy-uk-space-agency

[2] The eight programmes go by different names in various UKSA and ESA documentation. Throughout this report we use the terminology in the table presented here

[3] The evaluation specification required these eight programmes to be the focus of the evaluation. The ESA Mandatory Activities referred to as 'Basic' were not considered separately in terms of the programme level assessments but were included in the economic analysis and the survey of ESA contractors

1.2 This report

This report presents the baseline position and the first impact evaluation for CMIN19 investments based on data collected during the period from June to December 2021.

- Chapter 2 presents an overview of the methodology
- Chapter 3 presents an overview of the theory of change for UK investments in ESA
- Chapter 4 presents the *inputs* – the planned and current investments made in the CMIN19 investment period
- Chapters 5-9 present the impact evaluation structured into four high-level impact domains
  - Knowledge
  - Prosperity
  - Security and protection
  - Global influence
- Chapter 9 presents ESA added-value
- Chapter 10 presents the economic assessment
- Chapter 11 presents a consideration of the contribution of UK ESA investments to net-zero
- Chapter 12 presents consideration of the contribution of UK' ESA investments to levelling up
- Chapter 13 presents the summary and conclusions

2 Approach to monitoring and evaluation

2.1 Theory-based evaluation

The overarching approach to the evaluation of CMIN19 investments is a theory-based evaluation (TBE). TBE is particularly suitable for the evaluation of complex interventions with long timescales to impact and where it is not possible to identify a suitable counterfactual control for an experimental or quasi-experimental methodology.[4]

A TBE captures evidence to test an identified theory of change (ToC) for a public intervention and explores external factors and alternative influences, using both to identify effects and assess attribution causality. This approach enables the evaluation to not only assess *what* the impacts are but *how* impacts are generated.

UK investments in ESA operate in a complex environment and following features influenced the section of a TBE approach:

- The qualitative data gathering methods within TBE allows the **complexity of the ESA investments to be fully explored**. ESA investments and their impacts are complex in two ways:
  - The UK investments do not operate in isolation: ESA is a pan-European endeavour coordinating the investments and activities of its 22 member states to build and operate space infrastructure and support R&D and innovation activities (RDI) to develop relevant cutting-edge capabilities in the space sectors of its member states.[5]
  - Multifaceted impacts: the space infrastructure targets a range of different scientific, economic and social purposes from understanding the universe and the Earth's climate to providing communications capabilities in remote places, weather forecasts and monitoring disasters
- **Long-lead times of space R&D and innovation (RDI) investments**: the UK and ESA are investing in the development of space infrastructure that is innovative and complex and has very long lead times from concept to operations (sometimes decades) – with ESA and its member states making investments over several ESA investment cycles. TBE allows the long-lead times to be considered, and where impacts have not yet been generated, by exploring the validity of the expected pathways to impact detailed in the theory of change.
- **High use of ESA investments across the UK space industry**: the UK space industry is relatively small and highly concentrated (13 organisations account for 82% of total space income) and the large space businesses are regular holders of ESA contracts. In addition, 75% of the UK's public investments in space RDI and infrastructure development are made via ESA and therefore there are limited alternatives for the types of activities supported by public funding. This means that it is not possible to construct control group for a quantitative counterfactual analysis.

[4] HMT Magenta Book, March 2020

[5] ESA has 22 Full Member States (who sit on the ESA Council): Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. There three Associate members: Slovenia, Latvia and Lithuania. Canada and five EU states have Cooperation Agreements with ESA: Bulgaria, Croatia, Cyprus, Malta and Slovakia. Canada sits on the ESA Council.

While complexity and long-lead times make identifying causality challenging, the high use of public investment via ESA means that attribution cannot be determined via experimental methods as no control group can be identified. The mixed methods approach inherent to TBE enables the evaluation to encompass the complexity and breadth of investment, impacts and stakeholders involved in ESA investments and activities by both quantitative and qualitative methods and explore causality and attribution.

2.2 Unit of analysis for the evaluation

ESA investments are structured into eight programmes (Table 1) that span a wide range of technologies, space infrastructures and underpinning activities. The unit of analysis for the evaluation is firstly the **portfolio level of ESA investments** (i.e. investments in all programme domains) and secondly the **individual eight programmes**. The scale of investment in the eight programmes varies considerably and therefore they were split into two groups in order that the M&E efforts were proportional to the size of programmes:

- **The four larger programmes**: four of the eight programmes - Science, TIA, EO and HRE - account (together) for 90% of the UK CMIN19 budget commitments[6]
- **The four smaller programmes:** together the other four smaller programmes – GSTP, NAVISP, SSS and CSTS - account for 10% of budget commitments.

2.3 Methods

The methodology is described in full in the evaluation framework in the inception report[7] and here we present the key features:

- Figure 1 presents an overview of the evaluation methodology including the different approaches to the large and small ESA programmes and the portfolio level analysis.
- Table 2 presents a summary of the methods used for each of the four impact domains in the ToC
- The primary and secondary data (quantitative and qualitative) and analytical methods are used to (i) populate a set of indicators designed to capture effects for each of the elements of the ToC and (ii) analyse the extent to which the effects can be attributed to UK investments via ESA. The full list of indicators is provided in Appendix A.
- The methodology is designed to provide a quantitative economic assessment that captures the direct, indirect and wider spillover effects of ESA investments. Figure 2 illustrates the main data collection and analysis methods used in the economic assessment

[6] More details are provided in Chapter 4

[7] PART A: Design, development and implementation of a monitoring and evaluation programme for the UK Space Agency's investments in the European Space Agency, Version 2.0, May 2021

Figure 1 Evaluation methods at programme and portfolio level

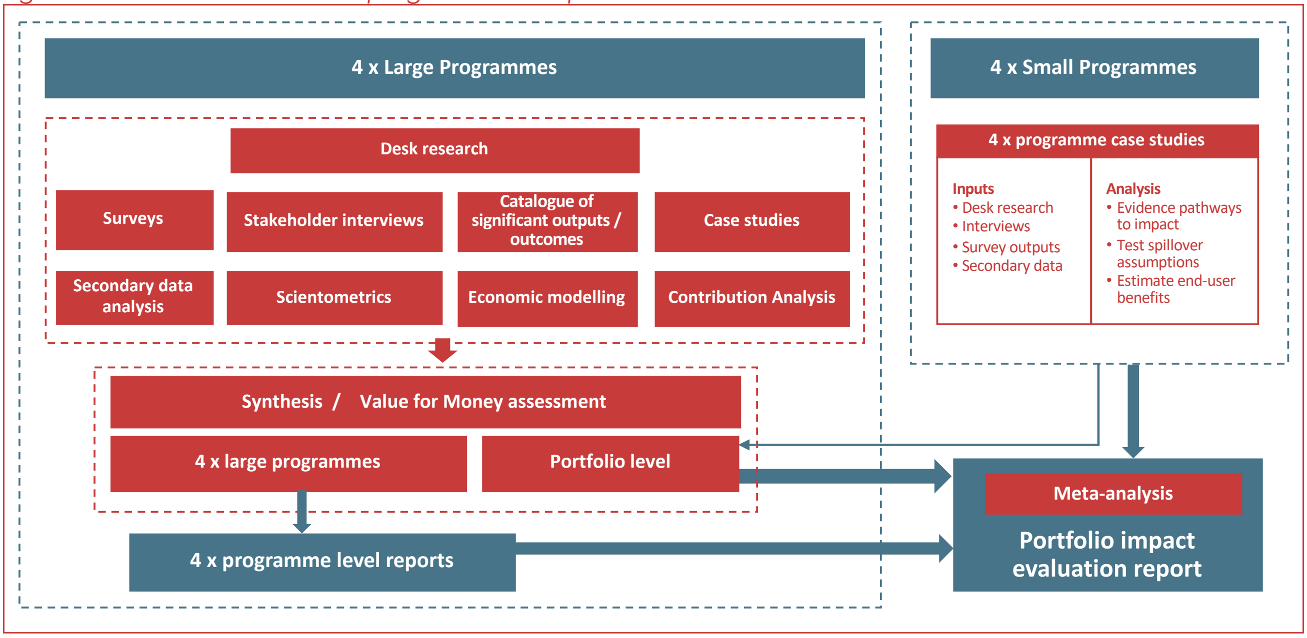

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Figure 2 Structure of the economic assessment

Type of benefit	Evaluation methods
Direct effects of ESA funded activities (ESA CMIN19 contracts)* Benefits for ESA contractors New technologies and capabilities available for ESA missions and activities	• Primary data collection: survey of ESA CMIN19 contract holders • Economic modelling
Indirect effects of ESA funded activities (ESA CMIN19 contracts) On CMIN19 suppliers	• Economic modelling
ESA-derived activities ESA-funded activity (above) plus any additional 'ripple effect' follow-on sales leveraging the capabilities developed in a ESA CMINi9 contract **These are benefits for the UK space industry**	• Primary data collection: survey of ESA CMIN19 contractors • Interviews and case studies – exploring this type of benefits in more depth
ESA-derived spillovers **Wider socio-economic effects from ESA-derived activities** • **Innovation benefits** • **Usage benefits** from government/ commercial/ consumer use of resulting products • **Coordination benefits** of a coherent network with common standards and exerting influence	• Parameters from the literature – spillovers are unlikely to have been generated yet from investments in the CMIN19 period • Primary data collection: case studies - exploring the mechanisms of exemplar spillovers in more depth

* ESA contracts since 1 Jan 2020

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Table 2 Methods to assess the impact categories

Impact groups	Desk research	Primary research	Analytical approaches	Counterfactual
Scientific knowledge	Literature review Secondary data	Interviews Case studies	Descriptive statistics Bibliometric analysis Altmetrics	Qualitative (CA)
Prosperity (& innovation)	Literature review Secondary data	Beneficiary survey Interviews Case studies	Descriptive statistics Economic modelling Patent analysis	Quantitative international comparative analysis Qualitative (CA)
Security & protection	Literature review	Interviews Case studies	Meta analysis	Qualitative (CA)
Global influence	Literature review	Interviews Case studies	Meta analysis	Qualitative (CA)

The UK National Space Strategy was published during the evaluation (in September 2021) and therefore after the Theory of Change was developed. The table below provides a mapping of the outcome/ impact domains used in the evaluation to the five goals of the new National Space Strategy published during the evaluation. The goals are also included in the synthesis overleaf.

Table 3 Mapping of ToC impact domains to the 2021 National Space Strategy

CMIN19 Business Case (Sept 2019)	National Space Strategy 2021 (5 goals)
	Over-arching: Goal 5: Use space to deliver for UK citizens and the world
Increased global influence: driven by Global Britain – stimulate partnerships with other ESA member states and countries engaged in space activities that align to UK strengths and ambitions	**Goal 2:** Promote the values of Global Britain **Goal 4:** Protect and defend our national interests in and through space
Increased prosperity and (scientific) knowledge: support industry and research communities to stimulate science, research and development and innovation. Drive exports and foreign investment through engagement with the wider UK economy and space sector (ensure markets are working effectively & driving economic growth)	**Goal 1:** Grow and level up our space economy **Goal 3:** Lead pioneering scientific discovery and inspire the nation
Increased security and protection: Support national efforts around protection of critical national infrastructure, emergency services, crises and civil contingencies and to build national resilience (protection from negative externalities)	**Goal 4**: Protect and defend our national interests in and through space **Goal 5**: Use space to deliver for UK citizens and the world

2.4 Time periods and investment covered by the first evaluation

The focus of the evaluation is the UK investments agreed at CMIN19. According to the UKSA CMIN19 business case these investments are agreed for the five-year period from January 2020 to December 2024.[8] However, investments in space infrastructure are inherently long-term and are expected to span several CMIN investment periods. Therefore, there is no 'blank-slate' starting point prior to CMIN19. In addition, while CMIN investment periods are typically five years, the CMIN agreement process occurs more frequently. Prior investment agreements were made at ESA Ministerial Councils ('CMINs') in 2012 and 2016. This means that CMIN investment periods overlap and, in ESA's annual budget planning documents, it is not possible to identify and separate budgets agreed at different CMINs. Therefore, it is not possible to evaluate the CMIN19 investments in isolation and therefore we took 1 January 2020 as the starting point for the evaluation period and including all investments and activities starting from that date i.e. all ESA contracts let after 1 Jan 2020. This means that it will include investments and activities agreed at CMIN19 plus an element of funding agreed at CMIN16. We estimate that around 25% of the budget assigned to the 2020-2024 period to be the 'carry-over' from CMIN16.

We define the baseline as the period **'before 2020',** taking a pragmatic approach to the time period of the baseline depending on the data source:

- Where secondary data allow it, we provide a time series over several years for indicators. This allows past trends to be identified and tracked into the future as the CMIN19 investments continue and as outputs and outcomes are generated. The exact time period depends on the historic data available – we aimed to go back at least 10 years wherever possible and/or to align with the starting of year of a prior CMIN period
- For the primary data collect via the surveys of ESA contractors, we selected the two-year 2018-2019 time-period immediately prior to 2020. Two years was selected to match the time period for which CMIN19 data was collected (i.e. 2020-2021).

2.4.1 Timing of the initial evaluation

CMIN19 investments will be made from the start of 2020 to the end of 2024 and therefore this first impact evaluation of CMIN19 investments was undertaken at an early point in the investment lifecycle. Data was collected over six months from July to December 2021 (with primary data collected in Oct-Dec 2021). At this point in time, not all investments (contracts) have yet been made and most of the contracts that are in place have not yet finished. This means that in terms of elapsed time, the evaluation is taking place 35% of the way through the five-year investment period. However in terms of value of contracts let to date, we are only 20-25% into the CMIN19 investment period (Table 4) and many of the contracts will not have finished. In addition, many contracts, will not yet have generated outputs and outcomes and impacts will not generated until further into the future. This affects the availability of data for an impact evaluation. The issue of a lack of output and outcome data was mitigated by asking ESA contractors (in the survey) to provide only data for outputs generated to date but also projections for future outputs and outcomes. The projected data was requested for a sub-set of indicators that were essential for the economic assessment.

[8] The business case also shows 5% of the agreed total CMIN funding allocated to 2025 for TIA, GSTP and SSS, to 2026 for HRE and 2028 for EO

Table 4 Estimate of progress through the CMIN19 investment period

	Time (months)	Planned UK obligations to ESA[9] #	Total value of contracts let since 1 Jan 2020*
Position to date	**18-24**	**€910m** *(planned budget commitments for 2020 & 2021)*	**€392m** *(Jan 2020 to Jun 2021)*
CMIN19 total (Jan 2020 – Dec 2024)	60	€2,114m	Estimated €1,598-€2,114m[10]
Percent progress	**35%**	**43%**	**19-25%**

Technopolis (2021): based on UKSA and ESA data

#this data will include annual expenditure for contracts signed prior to 2020

*data for the value contracts let captures the total value of contracts let and not the years the contract budget will be spent. This means the data in columns 3 and 4 cannot be directly compared – this is explained further in the chapter on 'CMIN19 Inputs' (Chapter 4)

2.5 Evaluation challenges and implications

The evaluation faced two particular and related challenges:

- ESA does not systematically capture and collate data on the outputs of its contracts. Contractors are required to provide a very detailed final report but the contents are not standardised or extracted in a way that can support M&E activities. This meant increased reliance of primary data collection via the survey of ESA contractors (than is typically the case for in the evaluation of RDI programmes)
- Initial response rates to the industry and academic survey were very low. This appeared to be due to a combination of factors: a general reluctance to share data in a sector with a culture of confidentiality and trade secrets; the requirement to complete a survey per programme (for many key ESA contractors); and 'survey fatigue' as, as our survey time period extended, the survey overlapped with the UKSA annual Size and Health of the UK Space Industry survey. Significant efforts were made to increase the response rate including extending the survey period from three weeks to nearly three months, sending additional reminders to respond (from the evaluation team and from senior UKSA staff), telephone calls to secure responses and a shortened survey to increase coverage of data points required for the economic assessment

We also faced an additional challenge securing interviews and additional data inputs from ESA and UKSA staff. It proved difficult to secure timely meetings and data gathering interviews with ESA and USKA staff. This caused delays in identifying and accessing relevant data held by ESA and UKSA and delays to identifying ESA contractors and gaining permission to contact them.

As a result, some data collection and analytical methods had to be modified during implementation. In practical terms, in terms of the evaluation outputs, the methodology and data availability means that:

[9] Data from the ESA Financial Obligations datasheet - this provides the expenditure for each ESA member states for each programme from 2017 to 2026 (a combination to actual and planned expenditure)

[10] It is not possible to determine the total value of contracts to be let due to overlapping CMIN16 and CMIN19 (and later CMIN22) investment periods. The lower bound estimate of €1,600m is the total value of the CMIN19 for 2020-2024 proposed in the UKSA CMIN19 business case. The upper bound is the total of the ESA annual plan for 2020-2024 (this will include contracts starting before 1 Jan 2020 but with spend continuing past 1 Jan 2020)

- The quantitative data in this report are presented at portfolio level and disaggregated for the four large programmes wherever it has been possible and meaningful to do so. The **primary data for the direct outputs was collected via survey of ESA contractors** for each programme, however survey response rates were not sufficient for an assessment at programme level for all programmes and all indicators. Each indicator is treated on a case-by-case base and disaggregated when possible.
- Similarly, for **the economic analysis** – the principal analysis was conducted at portfolio level. In addition, the economic modelling of direct and indirect GVA and employment effects were conducted for the four large programmes (Science, TIA, EO and HRE). The ESA-derived effects (based on survey data) were analysed only for TIA, EO and GSTP as these were the only programmes with sufficient surveys responses to support a programme level analysis.
- The collation and analysis of **outcome data from secondary data sets** is, in most cases, at portfolio level. It is disaggregated at programme level wherever possible. This is due to the fact that in many secondary data sets the data 'unit' is organisations (and groups of organisations) and, as many organisations are involved in more than one ESA programme, they (and their data) cannot be assigned to a single programme.
- The exploration of ToC for each of the eight programmes in provide in Report B.

2.6 Survey respondents

The *ESA contractor survey* was targeted at each UK organisation ('entity') holding at least one ESA contract in an ESA programme in the evaluation period. This meant that organisations involved in more than one ESA programme were asked to complete one survey per programme (Table 6). The target population for the survey was 358 across 255 organisations i.e. 358 requests for survey responses was made to a total of 255 organisations.

Table 5 presents the number and type of organisation who were sent requests to complete the survey questionnaire. The number of organisations is the total number of organisations holding ESA contracts in the evaluation period. The number of targets for the survey is higher as this counts all requests for survey responses (i.e. organisations involved in more than one programme are counted for each programme they are involved in).

An overall response rate of 34% was achieved, which is sufficient to draw conclusions about the ESA investments in terms of descriptive statistics. Significant efforts were made to gain responses from the contractors that account for a high proportion of the total value of contracts let to date. In total, the survey respondents represented 61% of contracts by value. Table 6 presents the number of survey targets and responses and response rates by programme.

Table 5 Survey targets and response rates

	No. of organisations	Total no. of targets for the survey	No. of responses	Response Rate
Industry	206	270	101	37%
Academia /Other*	49	88	22	25%
TOTAL	**255**	**358**	**123**	**34%**

Technopolis (2022)

*Other includes Research and Technology Organisation (RTO and Public-sector Research Establishments (PSRE) (RAL, NPL, Met Office, Satellite Applications Catapult, Plymouth Marine Laboratory, National Oceanographic Centre, UK Centre for Ecology and Hydrology, Trinity House). The response rate for Academic/Other was dominated by RTOS and PSREs as very few academics responded

Table 6 Survey targets by programme

Programme	Total target population (for the survey)	No. of responses	Response Rate
Science / Mandatory	69	16	23%
Telecoms & Integrated Applications (TIA)	130	40	31%
Earth Observation (EO)	61	31	51%
Human & Robotic Exploration (HRE)	30	10	33%
General Support Technology Programme (GSTP)	31	15	48%
Space Safety and Security (SSS)	18	4	22%
Navigation Innovation and Support Programme (NAVISP)	15	7	47%
Commercial Space Transportation Services (CSTS)	4	0	-
TOTAL	**358**	**123**	**34%**

Technopolis (2021)

Table 7 presents the characteristics of the survey respondents by type of organisations. This aligns with the distribution of contracts amongst organisation types (Table 14 in Chapter 4).

Table 7 Type of organisation (all respondents, N=123)

	No. of respondents	% of total	% of total
Industry: Micro business <10 employees	24	20%	82%
Industry: SME (11-250 employees)	46	37%	
Industry: Large firm (>250 employees)	18	15%	
Industry: size unknown	13	11%	
Academic organisations	11	9%	9%
Other (RTOS/ PSREs)	11	9%	9%
Total	**123**	**100%**	**100%**

ESA contractor survey *Other includes RTOs and PSREs (RAL, NPL, Met Office, Satellite Applications Catapult, Plymouth Marine Laboratory, National Oceanographic Centre, UK Centre for Ecology and Hydrology, Trinity House)

Table 8 Ownership (industry respondents, n=88)

	No. of respondents	% of total
UK-owned	61	50%
Foreign-owned	18	15%
Mixed ownership (UK and foreign)	19	15%
Not known	25	20%
Total	**123**	**100%**

ESA contractor survey

3 Theory of change for UK investments in ESA

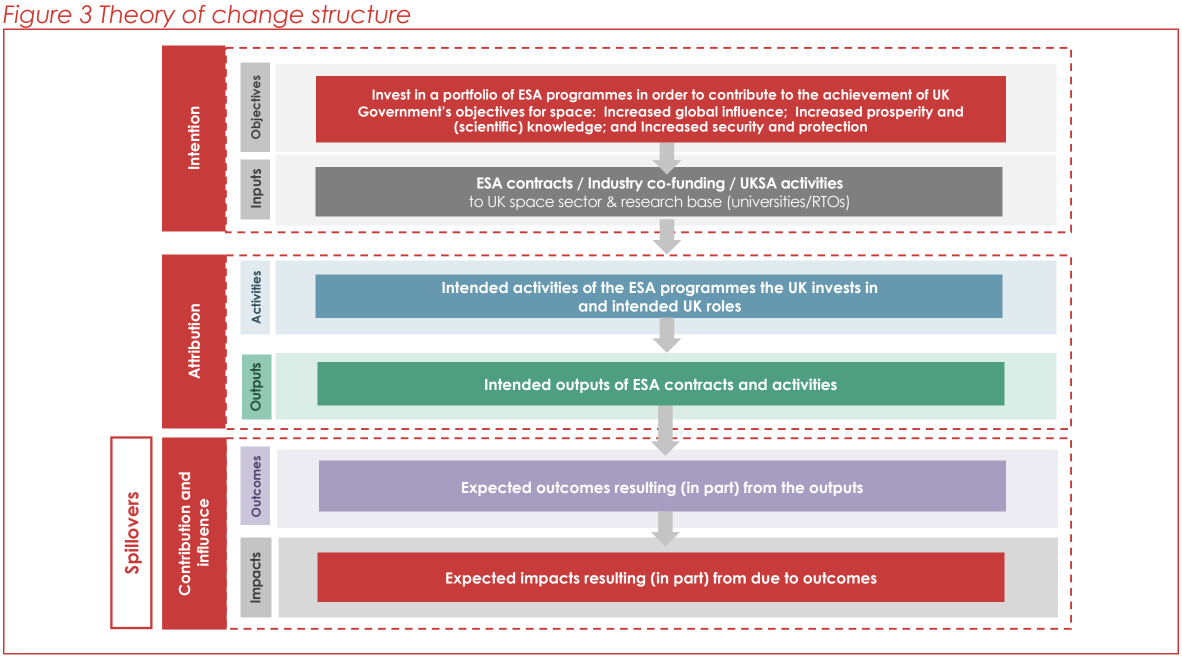
3.1 Theory of change for UK investments in ESA

A ToC comprises a logic model that illustrates the expected causal steps between an intervention's inputs and impacts plus a narrative that explains how the impacts are expected to arise as well as implicit assumptions, risks and external factors. The desk research, consultations and workshop in the inception phase of the evaluation demonstrated that a single over-arching logic model can be applied at portfolio level and for each of the individual programmes. The over-arching logic model is presented in ESA (Figure 4). The ToC for each programme level is provided in the Inception Report (Part B), with each presented as a tailored version of the over-arching logic model and a detailed explanatory narrative. The tailored logic models essentially 'turn off' the outcome and impact categories that are less relevant to each programme. While most programmes contribute to many outcome and impact categories to some extent, each programme is primarily directed at a particular sub-set. The Science Programme for example is primary directed at increasing scientific knowledge, while TIA and GSTP are primarily directed at generating economic benefits and SSS at increased security and safety.

The ToC structure moves progressively from

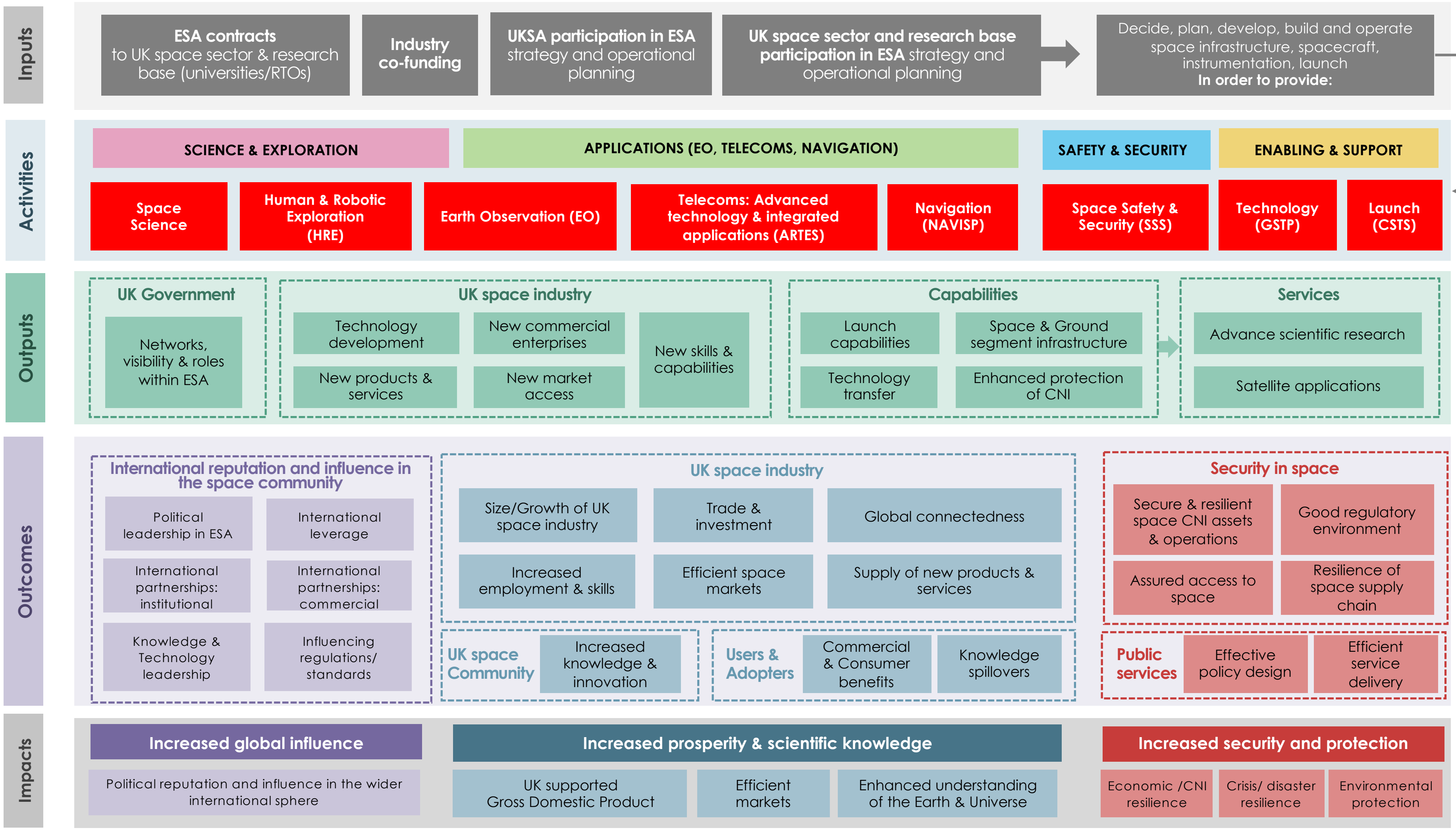
- **Inputs and activities** the ESA investments and the activities they are intended to support
- **Outputs** of ESA contracts - these direct outputs of contracts are, in the main, wholly attributable to the ESA funding
- **Outcomes and impacts –** the expected wider effects arising, in. part, due to the outputs and whose achievement of is dependent on many of external factors and other initiatives, investments and drivers and therefore are not solely due to the UKSA / ESA investments. These effects can also be referred to as spillovers of the investments. The ESA programmes will make a contribution to the outcome and impacts but they will not be fully attributable to ESA investments.

Figure 3 Theory of change structure



Technopolis (2021).

Figure 4 Logic model for UK investments in ESA



* The activity titles in the pink, green, blue and yellow boxes are the ESA programmes. Those in red boxes are the UK programmes. *

4 CMIN19 Inputs

4.1 Introduction

This section presents the UK's financial investments for the CMIN19 period at both portfolio and programme level i.e. the total level of financial contribution the UK has committed to ESA at the portfolio and programme level.

Due to the complexities of the overlaps of CMIN investment periods, the financial data is presented in two different ways based on two sources of data provided by UKSA (Table 9).

Table 9 ESA financial data formats

Data type	Data source	Comments
UK's annual commitments to ESA	ESA Report on Contributors' Financial Obligations (shorthand "*ESA Financial Obligations Report*")	• UK's actual and expected expenditure via ESA. The data is combination of actual expenditure (for years past) and projected for future years • The principle of geo-return within ESA means that there is a target to return all of UK's commitment to ESA to UK organisations - minus the UK's contribution to the overhead costs of operating ESA. The data presented in this chapter present the full UK investment in ESA (including ESA overheads) • The early years will contain expenditure resulting from contracts signed prior to Jan 2020, i.e. those agreed in the previous CMIN period • All years to 2024 may include investments agreed under CMIN16 and/or CMIN19, which we estimate to be 25% of the total.
Value of UK ESA contracts	ESA geo-return datasheet, Q2 2021 (shorthand "*ESA geo-return*")	• This was the current datasheet at the time of the evaluation and included contract let up to the end of Q2 (30 June) 2021 • Value of contracts let to UK organisations in any year. The data set includes contracts let to UK primes and subcontracts to UK organisations • The total value of each contract is assigned to the year in which it was signed (contract start dates were identified by the first year it appears in the geo-return datasheet) • Contract values are a sum of all years in the datasheet (including negative values) • The end date of contracts is unknown and therefore the profile of contract expenditure is not known • The holders of these contracts were the target population for the ESA contractor survey

Technopolis (2021)

As a result of the two different formats of financial data available to the evaluation and the fact that the five-year budgetary periods for each CMIN overlap by at least two years[11], we took a pragmatic approach to the time period of the evaluation - taking a five-year 'window' (2020-2024 inclusive) of ESA investments in what is, in effect, an on-going year-on-year programme of ESA investments. In practice this means that:

[11] It can vary as the periodicity of CMINs is not always every three years

- The evaluation period for the M&E framework for CMIN19 is taken to be 2020 to 2024 and all budgets expended and expected to be expended in that time period are included
- The first evaluation reported here, undertaken in Q4 2021, included all UK ESA contracts that were signed since 1st Jan 2020 plus any other contracts that were identifiable as active in 2020 and 2021 in the ESA geo-return datasheet (i.e. contracts expending ESA budget in 2020 and 2021).[12]
- All of the organisations holding these contracts were invited to respond to the survey. In the survey the outputs and outcomes arising from the contracts were collected for the period 2020-2021 plus a baseline for the prior three years 2017-2019 (which aligns with the prior CMIN16). Data for the entire five-year period cannot be collected until all relevant contracts have been let and had time to generate outputs and outcomes
- The economic modelling is based on a combination of actual and projected expenditure, outputs and outcomes based on the inputs in the period from 2020 to 2024 (as defined in the from ESA obligations datasheet)
- Data from secondary sources was captured as timeseries to show past trends against which future performance can be tracked. The time period collected and presented varies with data sources with the latest data being in the range 2018-2021 depending on source and start date selected in most cases to align with a prior CMIN agreement.

[12] However, the majority of survey respondents (all but one) were contractors holding contracts that have started since 1 Jan 2020 i.e. only one respondent was from the group that only s ere all

4.2 UK's annual commitments to ESA

Table 10 presents the UK investments made and expected to be made via ESA from 2017 to 2026. **The data relevant to the evaluation is the actual and planned expenditure for the CMIN19 period from January 2020 to December 2024**. As noted in chapter 2, it includes the funding agreed at CMIN19 plus the funding agreed at CMIN16 that 'carries-over' into the 2020-2024 period. We present this data alongside the data for the three-year period from 2017 to 2019[13] as this represents the baseline period for the M&E activities, with this prior period referred to as the 'CMIN16 period.' We also present the expected investment for 2025 and 2026[14] to illustrate that funding does not simply end at the end of 2024 but is expected to continue.[15] Figure 5 presents the data disaggregated at programme level.

All figures are in Euros (€) as this is the currency ESA uses and it allows for stability for making comparisons as it is unaffected by changes in exchange rates. In practice the cost to the UK of ESA participation is subject to changes in exchange rates.

The total investment for committed the CMIN19 period 2020 to 2024 is €2,114m, with 25% of this estimated to be carry-over from the investments agreed for the CMIN16 period.[16]

Table 10 UK commitment to ESA 2017-2026 (M€)

				Evaluation period						
Year	2017	2018	2019	**2020**	**2021**	**2022**	**2023**	**2024**	2025	2026
UK commitment to ESA	€375.0	€300.0	€361.7	**€490.7**	**€418.8**	**€438.5**	**€433.0**	**€332.7**	€273.2	€251.7

ESA datasheet on national obligations

The budget profile is agreed between ESA and its members states and is predominantly driven by the stage of development of the missions, the large missions in particular,[17] with a high level of funding assigned to contracts to build spacecraft.

The four large ESA programmes – Science (and the mandatory 'Basic' activities), TIA, EO and HRE - account for 90% of the planned expenditure from 2020-2024 (Figure 6) as these are programmes that develop and launch the majority of ESA's medium and large scale (and costly) missions. SSS will launch one large mission, Vigil (formerly known as Lagrange) and is therefore the largest of the for small programmes.

[13] i.e. for the three full calendar years 2017, 2018, 2019

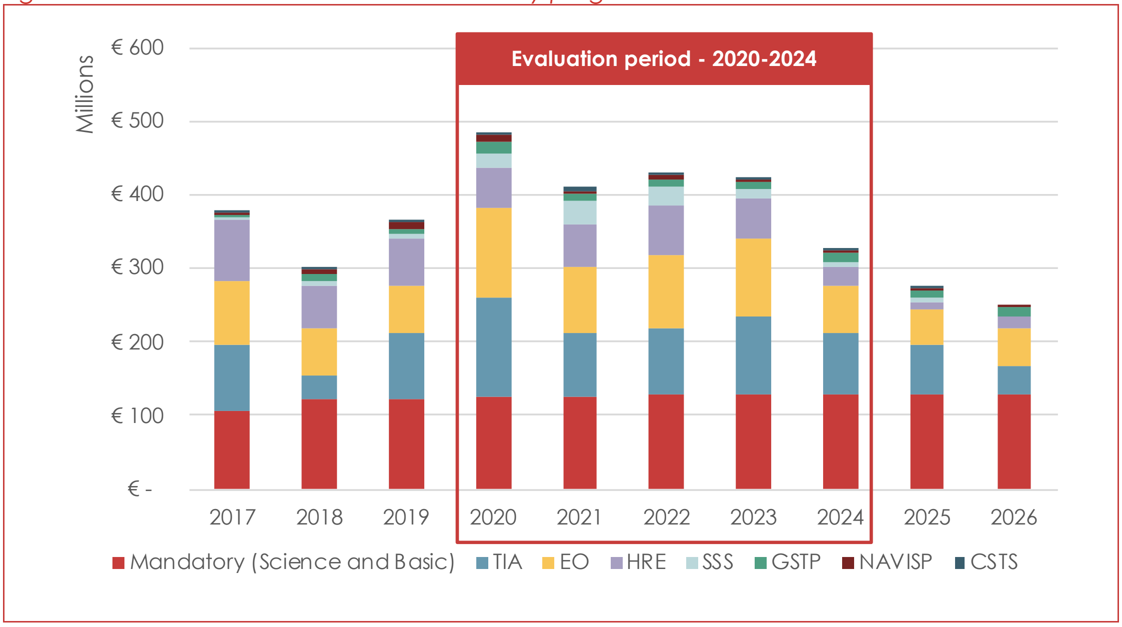
[14] This was also agreed at the 2019 Council of Ministers (CMIN19) for the programmes that require very long-term investments (EO and HRE) but that falls beyond the standard five-year agreement period

[15] The data for 2026 and 2027 is taken from the ESA obligations data set. The figures are higher than the additional funding agreed in the CMIN19 for EO and HRE (and shown in the CMIN19 business case). It reflects ESA's current expectation regarding funding in these years to continue work on missions in development. The actual figures post-2024 can be expected to change as result of the next ESA Ministerial Council in 2022 (CMIN22)

[16] This figure was estimated as annualised data for the final figure agreed at CMIN19 was not available. We have used the figure for 2020-2024 from the CMIN19 business case

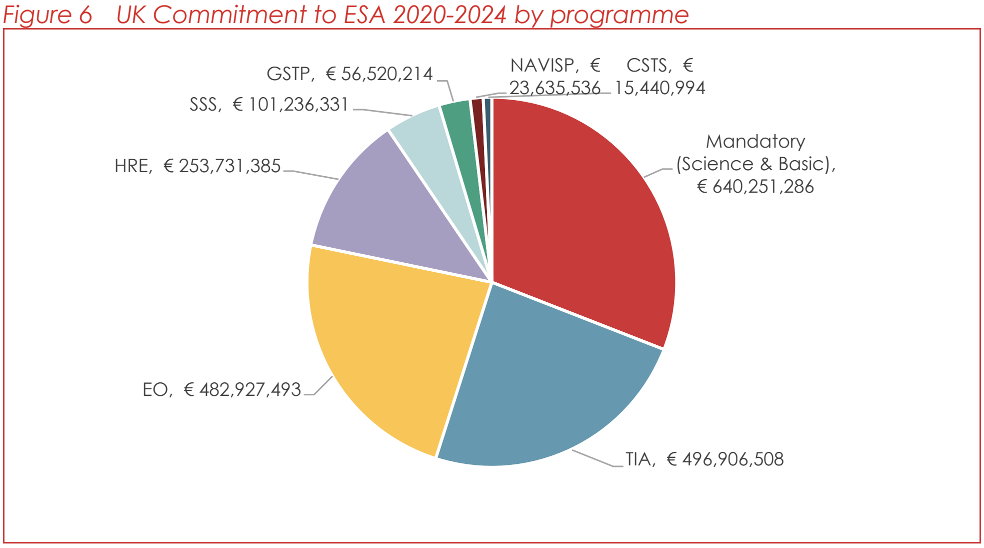
[17] https://www.esa.int/Science_Exploration/Space_Science/How_a_mission_is_chosen

Figure 5 UK Commitment to ESA 2017-2026 by programme



ESA datasheet on national obligations

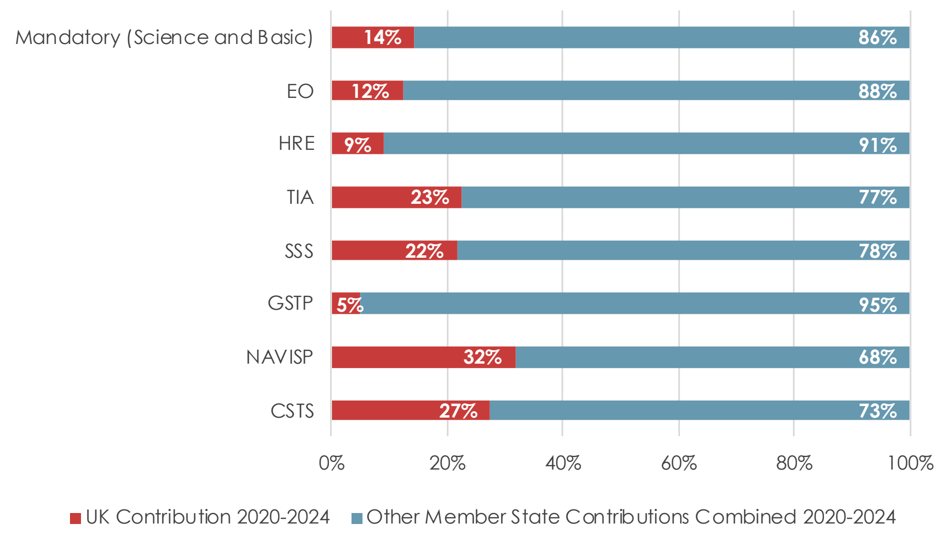
Figure 6 UK Commitment to ESA 2020-2024 by programme



ESA datasheet on national obligations

Figure 7 presents the UK contribution to each ESA programme, illustrating UK choices about which space domains and activities it wishes to invest it. This shows that that although the UK contributes 10% of ESA's total budget it invests at a higher level in three of the four large programmes (Science, EO and TIA) and at 9% in HRE. It is able to do this as it does not invest in ESA's launch capabilities (other than the very small CSTS) programme and the support to the Giana Space Centre via the mandatory activities), where it only invests 0.3% of the €4.5b budget. The UK invests at a particularly high rate in TIA which plays a key role supporting UK's commercial satellite communications businesses. The UK also invests at a high level in the three of the four small programmes, again areas where the UK has or is seeking to develop a strong commercial activity (SSS, CSTS, NAVISP) and/or take a technical lead (SSS).

Figure 7 Relative proportion UK investment in each ESA programme *



ESA Financial Obligations Report. * the data above excludes the ESA Space Transportation Services (STS) (other than the CSTS programme) which covers the development and operations of ESA's launch capabilities. For STS as a whole the UK contributes 0.3% of the €4.5b programme

4.3 Value of UK ESA contracts let to date (to Q2 2021)

Table 11 and Table 12 presents the number and value of ESA contracts let to UK organisations for the evaluation period to date (Jan 2020 to Jun 2021) and the prior three-year period 2017-2019. Figure 8 presents the annual data disaggregated by programme.

ESA contracts with a total value of €392m were let to 255 organisations in the UK between Jan 2020 and Jun 2022. This represents 19% of the €2,114m committed to ESA (or 25% of the total value when the carry-over expenditure from the CMIN16 commitment is excluded). At 21 months into a five-year investment period (i.e. 35% of the way though), this suggests that contracts for the UK may be running behind schedule. However, the contracts vary greatly in size and a number of large contracts are expected for UK organisations in the Science, EO and HRE programmes that will change the total value considerably. For example, since the data was provided for the evaluation, Airbus (in France and the UK) have been contracted (to a value ~€200m) to build the exo-plant research mission ARIEL spacecraft, SSTL has been contracted (€24m) to build the HyrdoGNSS EO mission spacecraft and develop the communications services for Lunar Pathfinder under the HRE programme (€12m).

Table 11 Value of contracts let under CMIN16 and CMIN19 (to Q2 2021)

	No. of unique contracted entities	No. of ESA contracts	Value of ESA contracts (M€)
2017-2019	373	1,100	€750.7
2020-Q2 2021	**281**	**675**	**€391.6**

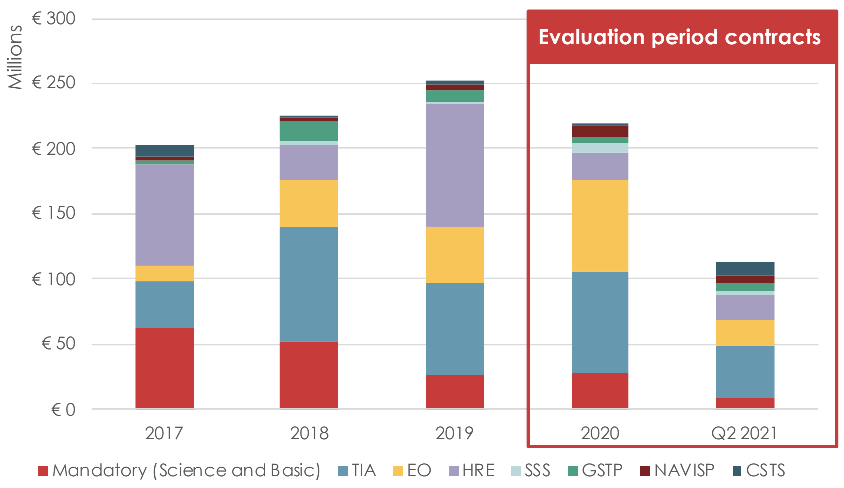
ESA geo-return datasheet

Table 12 Value of UK ESA contracts let per annum 2017-Q2 2021 (M€)

	CMIN16 period			CMIN19 period	
	2017	**2018**	**2019**	**2020**	**Q2 2021***
Total value of contracts	€230.5	€260.9	€259.8	**€296.1**	**€95.4**

ESA geo-return datasheet *2021 data is for 6 months only

*Figure 8 Value of ESA contracts per annum 2017-Q2 2021**



ESA geo-return datasheet *2021 data is for 6 months only

4.4 Industrial co-funding

Industrial co-funding is a requirement for some funding mechanisms in some ESA programmes. Co-funding is usually required in mechanisms where ESA supports R&D and technology development in businesses (i.e. the contractors are businesses) where there is a reasonable expectation of commercial benefit at some point. The co-funding rates vary depending on the mechanism but typically are 50% for large companies and up to 20% for SMEs and no co-funding is required from universities or public research institutes. For example, an ESA contract will cover 80% of the value of project undertaken by an SME, with the SME expected to fund the remaining 20% from their own resources. However, the co-funding rates are decided on a contract-by-contract basis and the values agreed are not systematically recorded by ESA. In Table 13 we provide an estimate of industry co-funding for relevant contracts let during the CMN19 period to date (Jan 2020 to Jun 2021) based on publicly available information on co-funding rates or estimates of average co-funding rates provided by UKSA programme leads. The majority of the co-funding is due to the requirement for co-funding in TIA and, in particular the large partnership projects. Therefore, any change from the estimated 50% co-funding rate would make a noticeable difference to the final estimate of total co-funding.

Table 13 Industrial co-funding 2020 to 2021 Q2 (estimate)

Programme	Programme elements that require co-funding	Average industry co-funding	UK contract value 2020-2021 Q2	Estimated (additional) co-funding
TIA	Core competitiveness, Space for 5G, 4S, Partnerships BASS: Feasibility and Demo, ASPIRE	50% average (can be less for some programme elements)	€112m	**€112m**
GSTP	All	50% average (can be 20% for SMEs)	€11.5m	**€11.5m**
NAVISP	Element 1, Element 2	60% average	€11.3m	**€16.7m**
CSTS	All	30% average	€10.6m	**€4.5m**
TOTAL			€145.4m	**€144.7**

Technopolis (2022): ESA documents / UKSA programme leads

4.5 Composition of ESA contractors

The majority of ESA contracts (88%) have been let commercial businesses, with most of the remaining 12% let to research organisations and universities. Six organisations account for 50% of the value of contracts let since Jan 2020 to Q2 2021and the top 10 account for 59% (Table 15), reflecting the structure of the UK space industry where 13 organisations accounting for 82% of total space-related income.[18] For ESA contracts, 21% by value has been let to Airbus UK which is the UK's leading space 'prime' i.e. a business that can lead an ESA contract to build a spacecraft. Very few companies across ESA member states have the capacity and capabilities to do this and these contracts can be large in value and are preceded by several smaller contracts to develop spacecraft designs. Airbus UK (and its subsidiaries such as SSTL) is particularly active in Science, EO, HRE and SSS with multiple contracts related to the development and build of spacecraft for missions including LISA, TRUTHs, Earthcare, Mars Sample return, Lunar Gateway, Lagrange / Vigil.[19] Teledyne UK is contracted directly by ESA to provide its world-leading CCD detector systems for instrumentation in Science and EO missions. Satixfy has won several large contracts under TIA as part of wider consortium to develop innovative next-generation satellite communications technologies.

Table 14 Portfolio contracts breakdown by entity type 2020-Q2 2021

Entity type	Value of Contracts (M€)	% of total value	No. of Contracts	% of total number
Company	€344.89	88%	426	63%
Research organisations (universities and public research labs)	€46.08	16%	235	35%
Other	€0.49	0%	14	2%

ESA geo-return datasheet

[18] UK Space Industry: size and health report, 2020, know-space for UKSA https://www.gov.uk/government/publications/uk-space-industry-size-and-health-report-2020

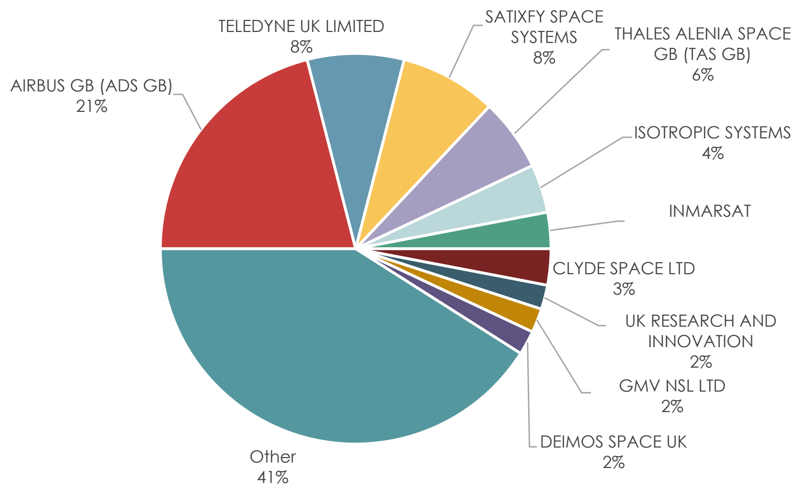
[19] Airbus (France and UK) also signed a contract for around €200m to build the spacecraft for the ARIEL mission in Dec 2021, though this does not appear in the data presented here

Table 15 Top 10 contract recipients 2020-Q2 2021[20]

Entity Name	Total value of contracts (M€)	% value of all contracts le	Cumulative % of contracts let	No. of individual contracts
AIRBUS UK (ADS UK)	€62.77	21%	21%	33
TELEDYNE UK LIMITED	€24.42	8%	29%	11
SATIXFY SPACE SYSTEMS	€23.40	8%	37%	1
THALES ALENIA SPACE GB (TAS UK)	€17.92	6%	43%	13
ISOTROPIC SYSTEMS	€12.91	4%	47%	1
INMARSAT NAVIGATION VENTURES	€10.34	3%	50%	2
CLYDE SPACE LTD	€9.87	3%	53%	1
UK RESEARCH AND INNOVATION[21]	€7.40	2%	55%	26
GMV NSL LTD	€7.29	2%	57%	22
DEIMOS SPACE UK	€5.16	2%	59%	12

ESA geo-return datasheet 245 organisations account for the remaining contracts

Figure 9 Distribution of ESA contracts to top 10 contract recipients



ESA geo-return datasheet

4.6 Activities

ESA programmes undertake a range of different activities to deliver their purpose – developing, building and operating space infrastructure and developing satellite-based technologies and services for society and also ensuring relevant space technologies and industry capabilities are available to ESA and other public and private space activities. We have classified ESA activities into three types:

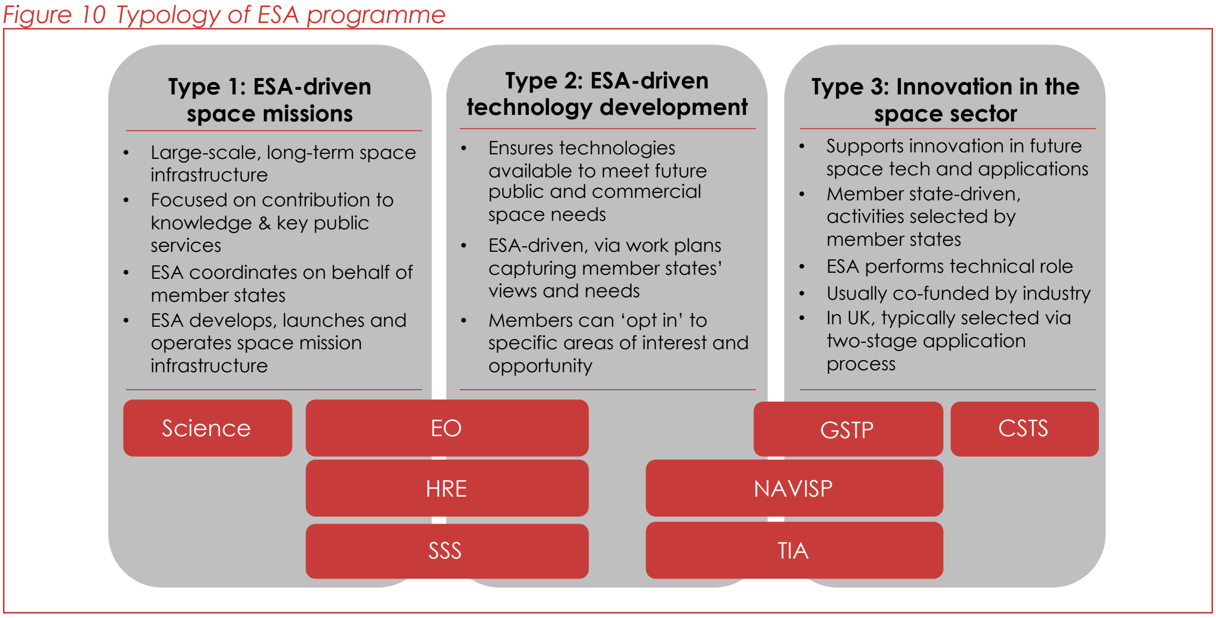
[20] Values are exclusive of subcontracts

[21] It is unclear in the dataset provided by ESA what contracts with UKRI constitute as UKRI owned or funded research labs, such as RAL Space, Plymouth Marine Laboratory, are identified separately in the ESA dataset

- **Type 1: ESA-driven space missions** – building and operating large-scale space infrastructure. Each mission is a highly complex and long-term endeavour that requires equally complex management and oversight and includes ESA activities to: coordinate members states to develop long-term strategies and implementation plans; select missions to be funded by ESA and member states; procure and fund mission spacecraft; coordinate member states' to design missions' scientific objectives and appropriate instrumentation; and integrate, launch and operate missions in space.
- **Type 2: ESA-driven technology development** – identifying needs and ensuring the technologies needed for Europe's future public and commercial space infrastructure are developed. This involves ESA activities to: coordinate members states and the space community (industry and academia) to identify needs, propose ideas and agree workplans to develop the technologies needed for the future; procure and fund technology development; and monitor contracts, provide technical support to contractors and validate outputs.
- **Type 3: Innovation in the space sector** – enabling the space community to develop innovative space technologies, concepts and applications. This is largely driven by member states who each take their own approach to governance and administration of ESA funding. The UK administers most of these programmes as 'bottom-up' open calls, allowing organisations to propose projects in broad thematic areas. UKSA selects and approves the funding. ESA's role is: technical review and final approval of proposals for funding; monitoring contracts, providing technical support to contractors and validating outputs

The eight ESA programmes differ in the extent to which they utilise each of the activity types (Figure 10).

Figure 10 Typology of ESA programme



Technopolis (2022): based on programme documentation and interviews

Table 16 provides a summary of the key activities in each programme. A more detailed description of each programme is provided in the accompanying PART B report.

Table 16 ESA programmes

Programme	Description
Space Science	Coordinating, developing and implementing a long-term strategy for a wide variety of scientific space missions to enhance our understanding of the universe. During these CMIN19 period these includes missions to study the sun, planets and comets, to search for exo-planets and for astronomy and astrophysics.
Telecoms & Integrated Applications (TIA)	TIA has two components • Supporting the competitiveness of the satellite communications industry – the economic powerhouse of the commercial space industry - by supporting advanced research in underpinning technologies, new products, space systems and services • Supporting the development of innovative solutions and applications using space infrastructure (satcom, EO, navigation)
Earth Observation (EO)	Supporting research and gathering of information about planet Earth's physical, chemical and biological systems from space to support Earth and climate science and enable us to respond to global challenges such as climate change and the water–energy–food nexus. It builds on ESA's existing operational satellites and develops the next generation of EO capabilities. This programme includes ESA's partnerships with the EU (Copernicus system) and EUMETSAT (meteorology)
Human & Robotic Exploration (HRE)	Leading Europe's human journey to the Moon and Mars using robotic missions as precursors and scouts. It builds on ESA's work in the International Space Station and prior robotic missions and places Europe at the centre of human space exploration
General Support Technology Programme (GSTP)	GSTP is intended to make sure the right technology, at the right maturity level is available at the right time for future space missions. It supports technology development – taking leading-edge technologies that are not ready to be sent into space and then develops them to be used in future missions
Space Safety and Security (SSS)	Supports the development of capabilities (technology, missions, processes) to give Europe the capacity to safeguard satellites in space and infrastructure on ground, protecting people and vital economic activities.
Navigation Innovation and Support Programme (NAVISP)	An advanced navigation research and technology programme that develops and applies ESA's expertise from Galileo and EGNOS to new satellite navigation challenges and concepts to scientific applications including on navigation to the Moon and Mars, and more generally to positioning, navigation and timing (PNT) applications.
Commercial Space Transportation Services (CSTS)	A programme that enables ESA to support the development of commercial space transportation services and supports national space transportation objectives in the field of spaceports, testing facilities and associated services. It co-funds and assists the pre-commercial development of new space transportation services.

Outputs and outcomes

Note on structure of the presentation of outputs and outcomes

The presentation of the **outputs** and **outcomes** are structured in terms of the three key impact domains identified in the ToC:

- Increased prosperity and (scientific) knowledge
- Increased security and protection
- Increased global influence

We do this to keep data for outputs and outcomes for each theme together, while noting that the themes are not mutually exclusive and that there are overlaps and links between them.

We have focused on outputs primarily as it is too soon, 21 months into a five-year investment period, for outcomes and impacts to have been generated. However, where early outcomes have been identified they are reported.

Data is presented to provide evidence of outputs and outcomes achieved to date (to Q4 2021).[22] We note that many contracts have not finished and not all contracts expected within CMIN19 have been let and therefore the outputs and outcomes can be expected to increase. We have not extrapolated the data for all contracts as the role of a mid-term evaluation is to assess progress to date.

However, survey respondents were invited to provide projections for the future for a sub-set of indicators. These are presented wherever they were collected. Projections for future income and employment arising from the outputs of ESA contracts were used in the economic assessment presented in chapter 10.

We start with ***knowledge***, presenting data on quantity and quality of scientific publications generated from ESA contracts and ESA missions and on skills uplift. This is followed by ***prosperity*** where we present data for a range of innovation-focused indicators. The indicator definitions are provided in Appendix A. ***security and protection*** and ***global influence*** are primarily treated qualitatively.

Note on the baseline data presented

We present the baseline data for the indicators used wherever it has been possible to do so. As described in section 2.4 we took two approaches to the baseline and we present both:

For survey data we present the baseline data for the two-year period 2018-2019 alongside the output data collected for the two-year period 2020-2021. However, we note that the baseline data is always lower than the output data due to the fact that the majority of survey respondents reported that they did not hold ESA contracts in the period 2018-2019 and therefore any baseline data taken from the survey are inherently lower. This means the baseline for outputs is problematic as, while it represents the baseline for current UK ESA contractors (a portion of whom did not have ESA contracts during the baseline period), it does not include all CMIN19 contractors (as not all contracts have been let yet) and some of the forthcoming contractors may have held previous ESA contracts in the baseline 2018-2019 period (as the pool of potential ESA contractors is relatively small). Nevertheless, we present the baseline data

[22] The survey was conducted in the Q4 2021, respondents were asked to estimate values for the full 2021 year

from the survey in the chapters below as it does represent the position at a specific point in time. However, in future evaluations it would be advisable to also track changes in performance from the output data for the 2020-2021 period (in addition to the 2018-2019baseline).

For data from secondary sources, we present long-run time series data, seeking to go back at least 10 years wherever possible.

5 Increased Knowledge

5.1 Introduction

The indicators for the **Knowledge** domain address the increase in scientific knowledge as a result of ESA contracts.[23] The data for the indicators are based on primary data collected via the survey of ESA contractors and secondary data from bibliographic databases.

5.2 Direct outputs from ESA contracts

The first indicator under 'increased knowledge' captures the direct scientific outputs of ESA contracts in terms of published papers in peer-reviewed journals.

This data is not captured systematically by the ESA reporting systems and was captured via the survey of ESA contractors. Data was captured for a baseline period 2018-2019 (two complete calendar years) and for the CMIN19 period to date i.e. for 2020-2021.[24]

Table 17 No. of papers arising directly from ESA contracts

	No. of papers authored / co-authored by ESA contractors					
	2018-2019 (baseline)			2020-2021		
Programme	**Industry**	**Academics/ Other***	**Total**	**Industry**	**Academics/ Other***	**Total**
Science	-	-	-	1	8	9
EO	8	36	44	13	39	52
HRE	8	-	8	14	-	14
TIA	3	1	4	7	3	10
GSTP	4	3	7	6	3	9
NAVISP	4	-	4	15	-	15
SSS	-	-	-	-	-	-
CSTS	-	-	-	-	-	-
Total	**27**	**40**	**67**	**56**	**53**	**109**

ESA contractor survey

ESA contractors[25] reported a total of 67 papers in the baseline period and 109 papers in the current CMIM19 period (Table 17).

- The majority of papers published in both time periods were in EO (66% in baseline period, and 48% in CMIN19 period)
- Three organisations account for a large share of the papers in both periods (54% in the baseline period, 38% in the CMIN19 period) with these being public sector research establishments (PSREs) and research and technology organisations (RTOs) Plymouth Marine Laboratory (PML); National Oceanographic Centre (NOC) and National Physical

[23] The indicator s and their definitions are provided in Appendix A

[24] We selected a two year period (2018-2019) for the baseline period in order that it was comparable to the current position, timewise, for the CMIN19 investment period i.e. 2 years in.

[25] The term 'ESA contractors reported' refers to those that responded to the survey

Laboratory (NPL). These three organisations are predominantly active in the EO domain (PML and NOC have only reported papers in EO, NPL has reported papers in EO and GSTP)

- Industry is publishing papers in peer-reviewed journals. Papers have been reported by both technology-driven companies developing hardware and software for space activities (upstream) and by companies developing applications using space data (downstream)
- A number of respondents noted that they also frequently reported contract outputs at conferences. While a company noted that their ESA contract work is commercially sensitive and so they do not tend to publish, but they do occasionally report some outputs at conferences
- Some respondents also noted that projects are only just coming to an end and that publications may arise in the future
- Respondents reported that, on average, it takes 1.6 years from the start of an ESA contract to publishing a paper (with a range of 0 – 5 years). Therefore, many contracts will not yet have resulted in papers. Once published the benefits of these papers then last for an average of 8.6 years (with a range of 0 – 40 years) (Table 18).
- It is interesting to note that some survey respondents reported a time from the start of a contract to the start of the benefit (papers published in this case) of zero years – which is rather surprising given that R&D activities will have had to have taken place to generate content for research publications (and that it can take 6-18 months from submission of a paper to publication). Taken with the fact that the majority of papers published are reported by three research labs which have had contracts over prior CMIN periods, it may be that some of the papers reported to date are based on R&D activities in these prior periods.

Table 18 Timing of benefits: papers published (n=35-56)

Paper published	Mean (years)	Range (years)
Time from start of ESA contract to start of benefit	1.6	0 – 5
Duration of benefit	8.6	1 - 40

ESA contractor survey

5.3 Outcomes: ESA-related research (baseline)

The indicators here assess the quantity (no. of papers) and quality/ impact (citations) of research outputs that are generated as a result of:

- Scientific research undertaken once ESA missions are operational (the primary purpose of Science and HRE programmes and for some EO activities)
- Complementary nationally funded activities to develop instrumentation for ESA missions

These are considered to be **outcomes of the ESA investments** because they are not direct outputs of ESA contracts themselves, but occur as the subsequent, and intended, result of ESA missions once in flight.

At the time of the evaluation, in the early phases of the CMIN19, no papers have been published as a result of data from missions funded under CMIN19. This is as expected. Firstly, because only two missions have been launched since Jan 2020 and they have not yet resulted in published papers. The other missions under development in CMIN19 will launch in the future (from 2022 through to early 2030s). Secondly, time lags to research publications. Even where research related to mission development is currently being undertaken (such as for instrumentation development), the research and drafting of research papers itself takes time and is then followed by a time lag of the order of 6-18 months (and sometimes longer) between submission of a paper and publication in a peer-review journal. While Solar Orbiter, for example, has launched and has just started to produce data, the data is still to be analysed and papers still to be written. Thirdly, there are time lags for papers to be indexed in bibliographic databases. The most up-to-date data available at the time of the evaluation was for papers published in 2020. Furthermore, citations will not arise until after publication (and continue for many years) and citation data is not deemed robust until at least two years have passed since publication. Therefore, it is too soon for citations to have arisen for any papers arising from CMIN19 investments.

For the reasons above, it is too soon to see any outcomes of CMIN19 investments in the bibliometric data. Therefore, the bibliometric data presented in the remainder of this chapter are provided as the baseline for future evaluations. They can be updated and tracked annually as CMIN19 progresses. Though it should be noted that many of the research outcomes of CMIN19 investments will extend for many years after the CMIN19 period.

Papers can be published at various points in time with respect to the development and launch of a mission– starting from the design of potential missions through the design and build of the spacecraft and instrumentation, to the intended use of mission data for research once the launched and operational. ESA space missions will be used for many years, sometimes decades. As Figure 12 shows for previous missions, research continues to be published based on missions launched in 2009 (e.g. Herschel and Planck) as well as missions dating back to the late1990s (such as SOHO and XMM-Newton). For missions supported during CMIN19, Solar Orbiter, launched in February 2020 and ESA instruments are aboard NASA's James Webb Space telescope (JWST) and these are expected to start generating papers in the coming year. EUCLID and JUICE are planned to launch during the CMIN19 period (in 2022) and missions such as PLATO and ARIEL are expected to launch in the following CMIN periods (2026 and 2028 respectively) and TRUTHS, LISA and ATHENA not until 2029 to the early 2030s.

Papers were identified in the bibliographic databases via a reference to ESA and/or specific named ESA programmes or missions in paper titles, abstracts or acknowledgements. Papers were assigned to individual programmes based on reference to the programme name, a specific mission or a research domain that clearly aligned to a specific programme. We refer to these as '**ESA-related papers'**. Funding for the scientific research behind these papers will have come from a range of sources and not solely ESA. We address this further in section 5.5 on attribution.

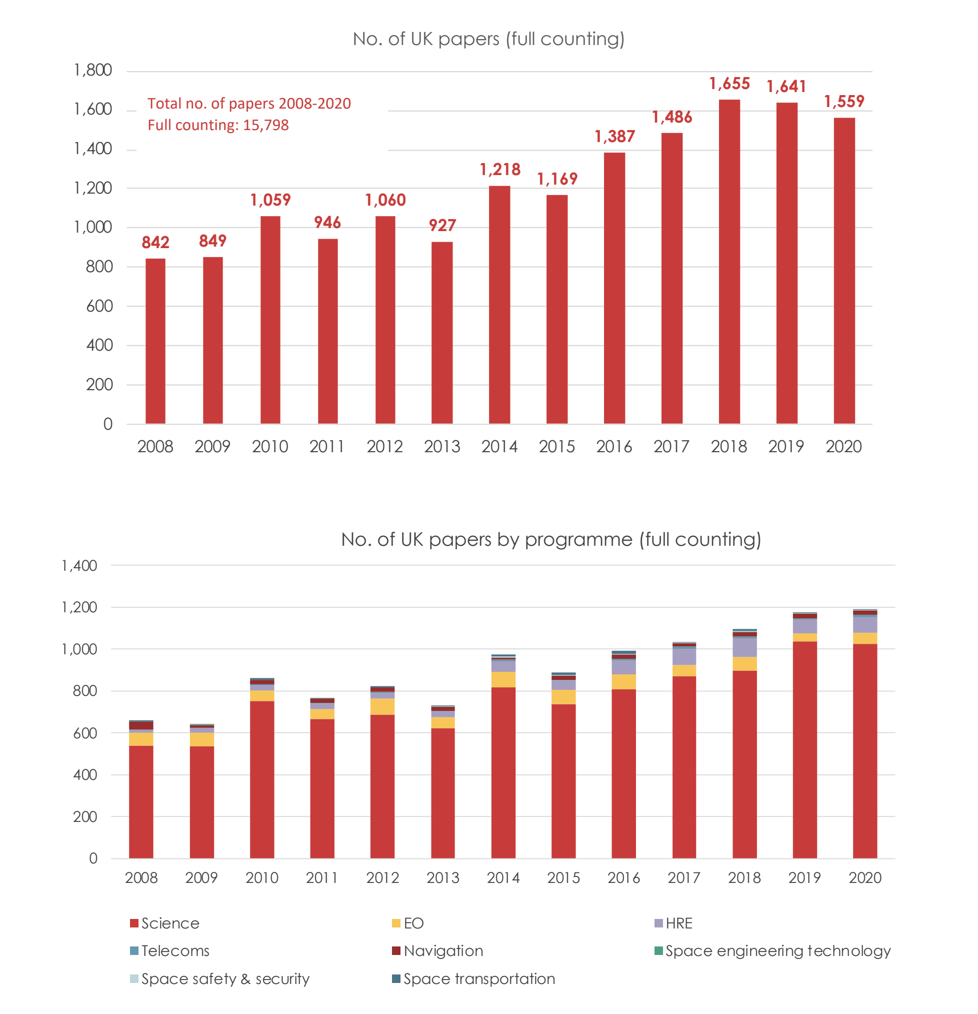
5.3.1 Quantity of ESA-related research (baseline)

The number of ESA-related published by UK authors (i.e. with at least one UK author per paper) has been on an upward trajectory since 2016 increasing from a fairly stable 800-1,000 papers published per year from 2008 to 2013 to c.1,600 in the years from 2018-2020 (Figure 11).

Using full counting[26] a total of 15,798 papers were published across the whole time period from 2008 and 2020. Three-quarters of all the papers could be assigned to specific programmes and of these 84% were related to the Science programme (Figure 11).

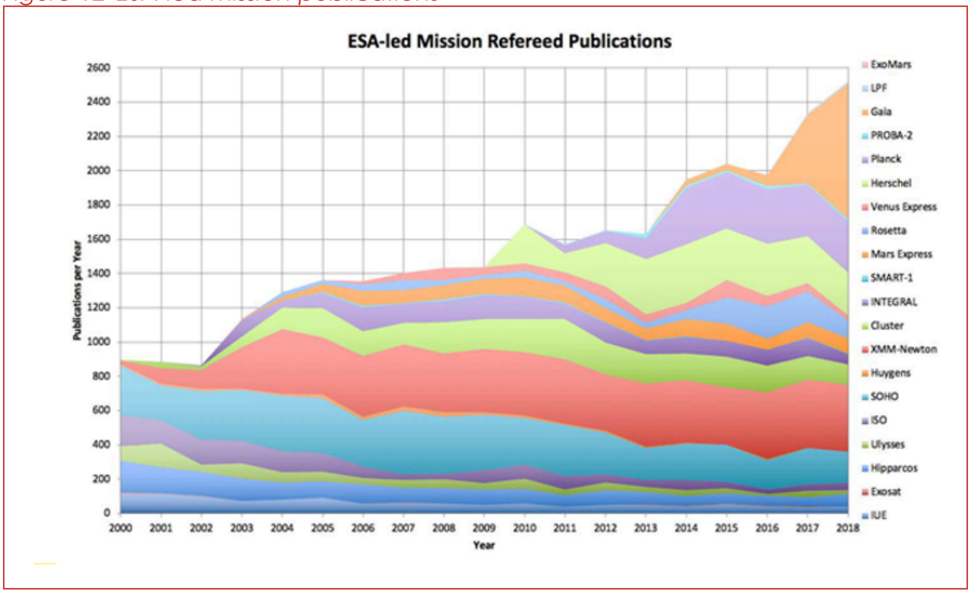
[26] Full-counting assigns a count of '1' to all papers with at least one UK author

Figure 11 No. of ESA-related papers (UK)



Science-Metrix (2021) / Scopus

Figure 12 ESA-led mission publications



UKSA CMIN19 business case

International comparison

Figure 13 presents an international comparison of numbers of papers published for the top eight performing countries during the period 2008-2020. This includes the five countries that invest the most in ESA (France, Germany, Italy, UK, Spain)[27] plus the USA and China - the two largest investors worldwide.

We note that papers are assigned to countries based on the location of the institutions to which the authors are affiliated. Therefore, papers with authors from ESA's European Space Research and Technology Centre (ESTEC) for example are assigned to the Netherlands, and similarly for authors based at other ESA locations. This explains the relatively high position of the Netherlands in terms of research outputs, while it is ranked 8th in term of its investment in ESA.

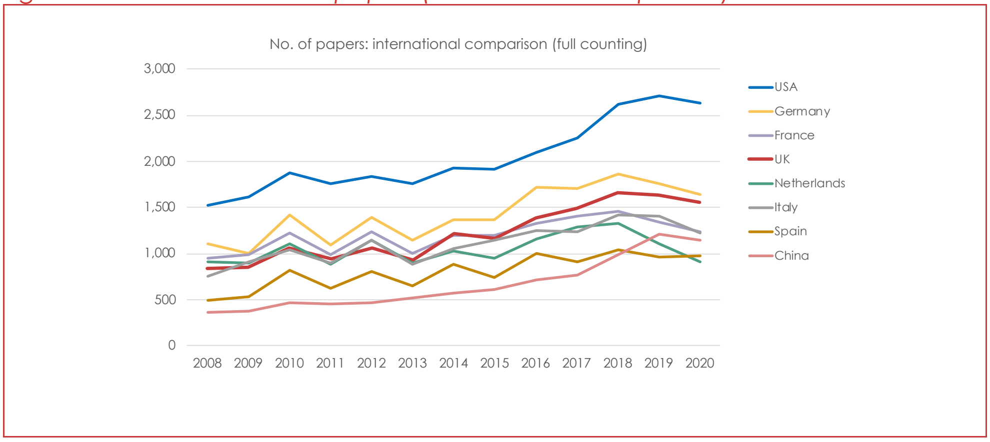
While most countries increased their research output over the 2008-2020 period, the UK, USA and China have experienced a higher growth rate (Figure 13). Over the 13-year period the UK has moved up from ranking 4th or 5th place to a consistent 3rd place since 2016, moving ahead of France and the Netherlands, and reaching a point just below that of Germany and some way below the USA. The UK in invests in ESA and in its national space programmes at a much lower level than France, Germany and Italy (Figure 14) and therefore, to achieve such a high relative position in the scale of research outputs, suggests we get considerable benefits from investment. We do note, however, that ESA contributions do not represent all sources of funding that may lead to ESA-related papers. National space programmes provide funding to develop and build the instrumentation within ESA spacecraft and national research programmes typically fund space research using mission data.[28] To account for differences in both the scale of space investment and economic outputs of these six countries, Table 19 presents an analysis of the numbers of papers published normalised in terms of civil space investment (including both ESA contributions and national programmes for ESA member states) and GDP, taking 2019 as a typical year. The UK performs well on both measures, ranking first in terms of the rate of papers published for its space investments and second in terms of GDP.

- As is the case for the UK, the majority of comparator countries' papers are in space science, with annual publication numbers in the 500-1,000 range (Figure 15). The UK has performed at the same level as Germany in space science with only the USA publishing more papers
- EO is the second most frequent domain for research outputs, but at an order of magnitude lower in scale than Science, reflecting the fact that EO encompasses research activities as well as the provision of operational services. Here the output has been relatively stable across the 10-yeat time period
- The UK's increased investment in HRE in the period before and after Tim Peake's visit to the International Space Station are evident in the research outputs for HRE. Equally, the UK's choice to invest at a low level in ESA's transportation activities is also evident in the scale of research outputs

[27] in order of investment levels

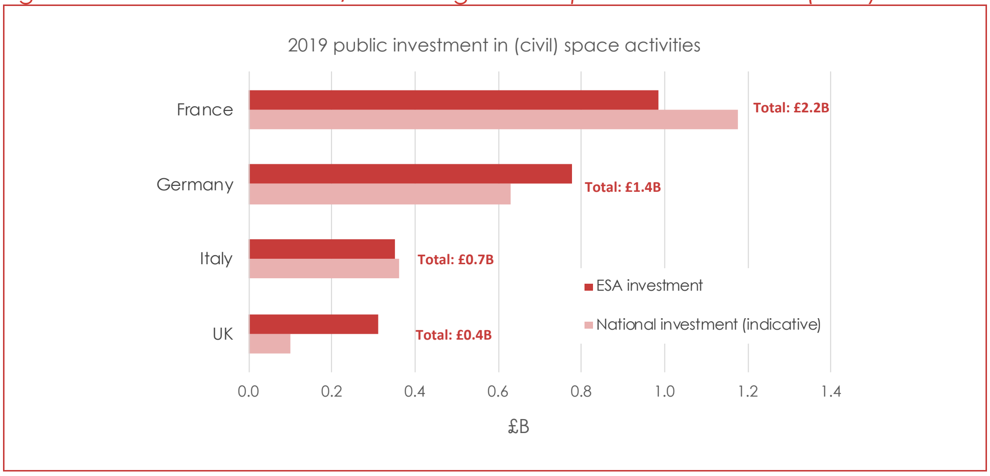
[28] Prior to the UK leaving the European Union, additional funding was also available via the Framework Programmes

Figure 13 No. of ESA-related papers (international comparison)



Science-Metrix (2021) / Scopus

Figure 14 Indicative national / ESA budgets for top 4 ESA contributors (2019)



Technopolis (2021)[29]

Table 19 Assessment of no. of papers in terms of countries' investment in civil space activities and GDP

	No. of ESA-related papers (mean 2017-19)	**Estimated public (civil) space investment (2019) £M***	**Papers per £M space budget**	**Rank (papers per £M space budget)**	**GDP (2019) £B**	**Papers per £B GDP**	**Rank (Papers per £B GDP)**
UK	1,594	400	4.0	1	2,117	0.8	2
Germany	1,778	1,400	1.3	3	2,859	0.6	4
France	1,399	2,200	0.6	4	2,007	0.7	3
Italy	1,352	700	1.9	2	1,477	0.9	1
USA	2,530	15,000	0.2	6	15,760	0.2	5
China	989	3,700	0.3	5	10,500	0.1	6

Technopolis *The estimated total (civil) space budgets are indicative[30]

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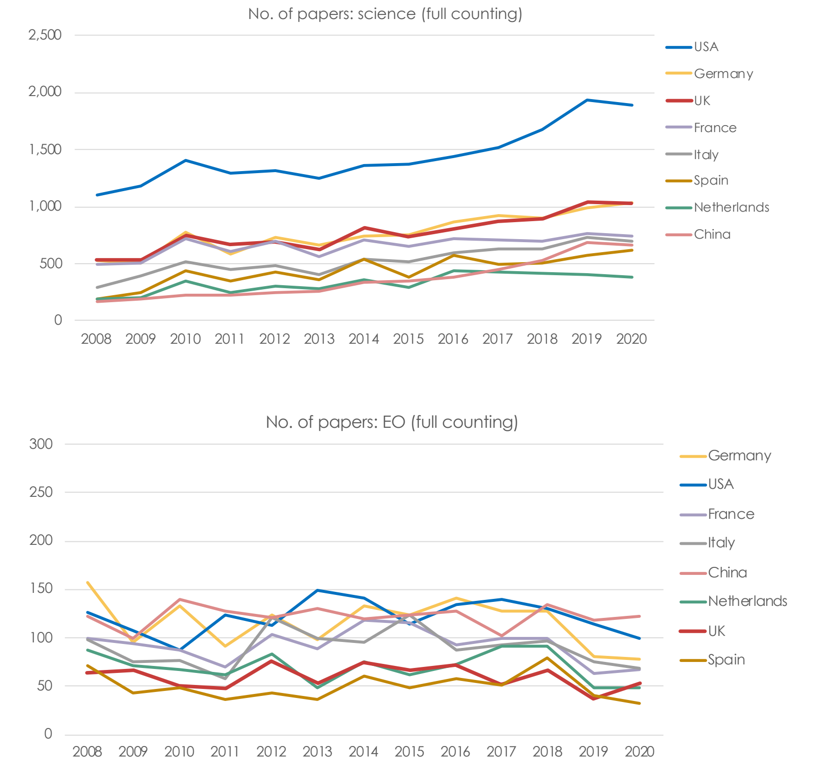
[29] ESA: https://www.esa.int/ESA_Multimedia/Images/2019/01/ESA_Budget_2019
National space budgets are provided as indicative figures only. They are from space agency annual reports and articles and may not be exactly comparable

[30] The data for total public civil space expenditure is intended to be indicative only. For ESA member states the total estimated figure is comprised of the members state's contribution to ESA plus an estimated value for national budgets. National space budgets come from a space agency annual reports and articles and may not be exactly

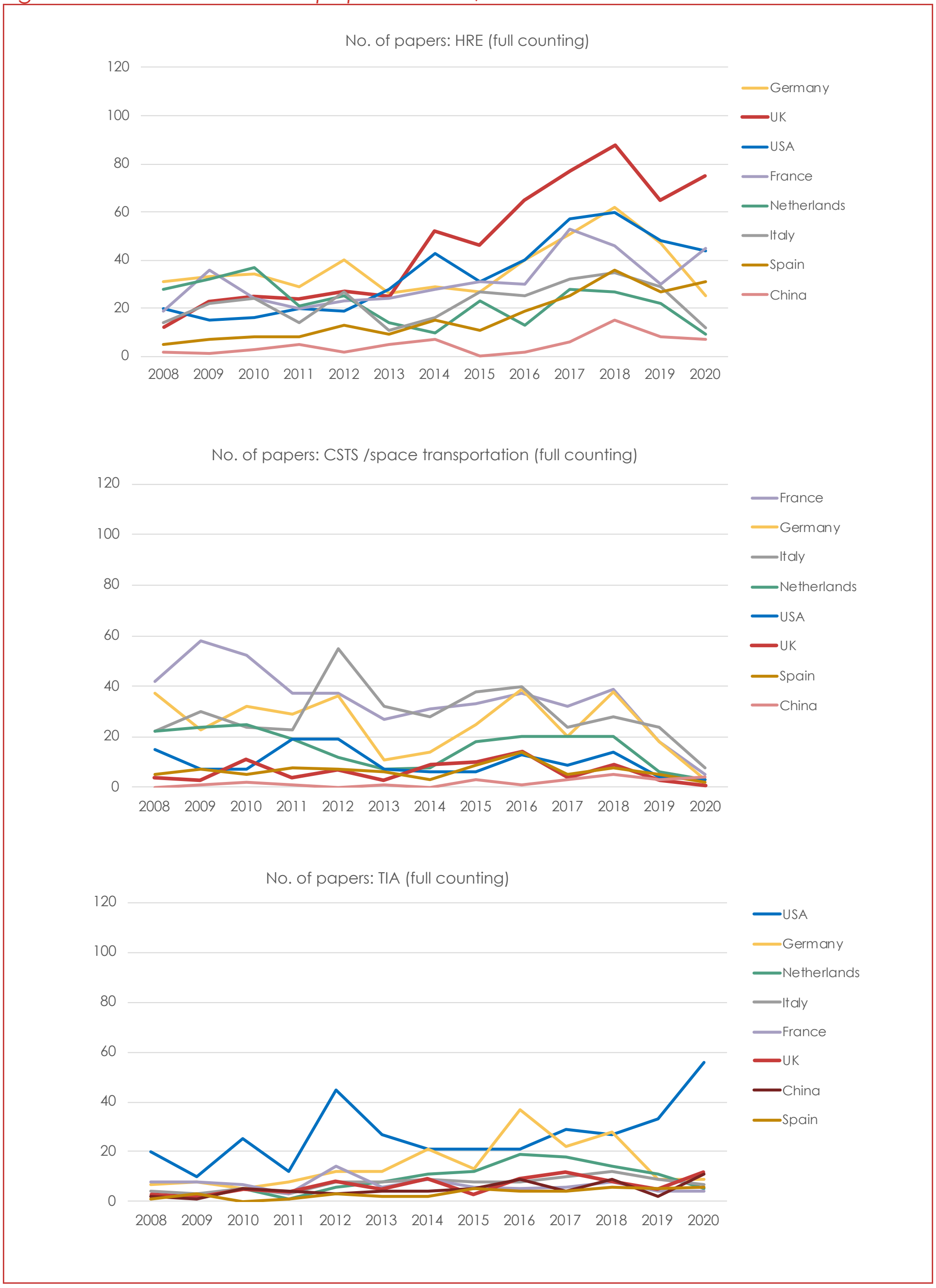
Figure 15 No. of ESA-related papers for Science and EO



Science-Metrix (2021) / Scopus

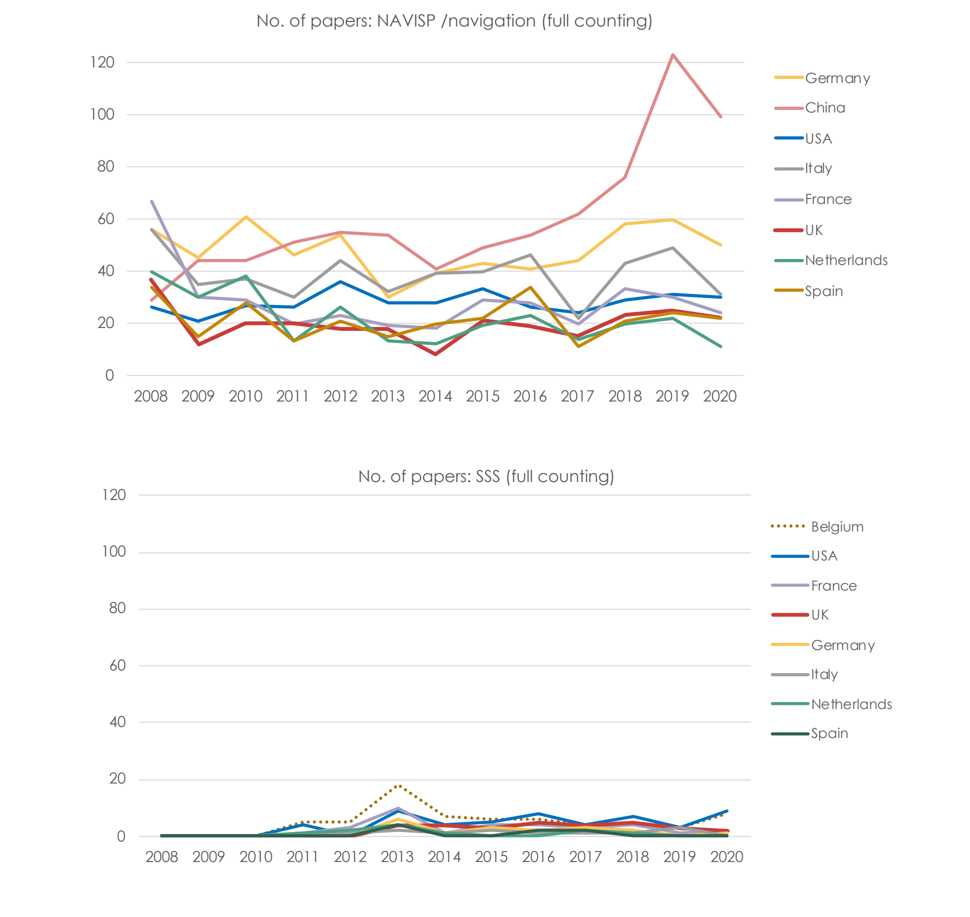
comparable. A definitive budget for China's civil space investment is not available and it is estimated from articles in the public domain ESA national contributions for 2019: https://www.esa.int/ESA_Multimedia/Images/2019/01/ESA_Budget_2019

Figure 16 No. of ESA-related papers for HRE, CSTS and TIA



Science-Metrix (2021) / Scopus

Figure 17 No. of ESA-related papers for NAVISP and SSS



Science-Metrix (2021) / Scopus

5.3.2 *Scientific impact of ESA-related papers*

The impact (also referred to as 'research quality') of the ESA-related papers is assessed in terms of the extent to which they are cited by others – as a measure of their value to other researchers and subsequent research. Citations do not arise until after publication and citation data is not deemed robust until at least two years have passed since publication and therefore, there are no citations to report for CMIN19 publication outputs.

Citations are assessed in two ways (full description and definition is provided in Appendix E)

- Field-weighted citation impact (FWCI). This assesses the extent of citations of all papers published by a given entity (be that a research group /department /institution or geographical area) normalised in terms of research discipline, type of publication and year of publication (to allow for comparisons across time and discipline). The FWCI is normalised to 1 for all papers world-wide, meaning that an FWCI above 1 indicates that an entity's papers have higher-than-average impact, an FWCI below 1 means that the entity's articles have lower-than-average impact.
- Highly cited papers (HCP). This assesses the extent to which the level of citations of the papers of a given entity are among the highest in their respective field. For this study we considered highly cited papers at three levels: the top 10%, top 5% and top 1%. The indicator is frequently used to examine research excellence, measuring how many high-impact papers are produced by a given research entity, relative to their expected

contribution to world-leading research. For HCP10, an entity with an HCP above 10% contributes more than its expected number of highly cited publications and an entity with an HCP below 10% contributes fewer than its expected number of highly cited publications (and similarly above and below 5% for HCP5 and above and below 1% for HCP1).

Over the 10-year period from 2008 to 2018 the UK has improved its research impact citation (Figure 18, Figure 19), increasing its FWCI from a value the same as the world average for all ESA-related papers in 2008 to a value almost 20% higher than the world average in 2018. The UK's HCP performance has also increased at a rate greater than the world average for all ESA-related papers (Table 20). It should be noted that the FWCI values for all ESA-related papers worldwide ('world' in Figure 18) are above the normalised world-average of 1 and has improved over the period 2008-2018. This indicates that that ESA-related papers as a whole are performing better than all other papers within the space thematic domain.

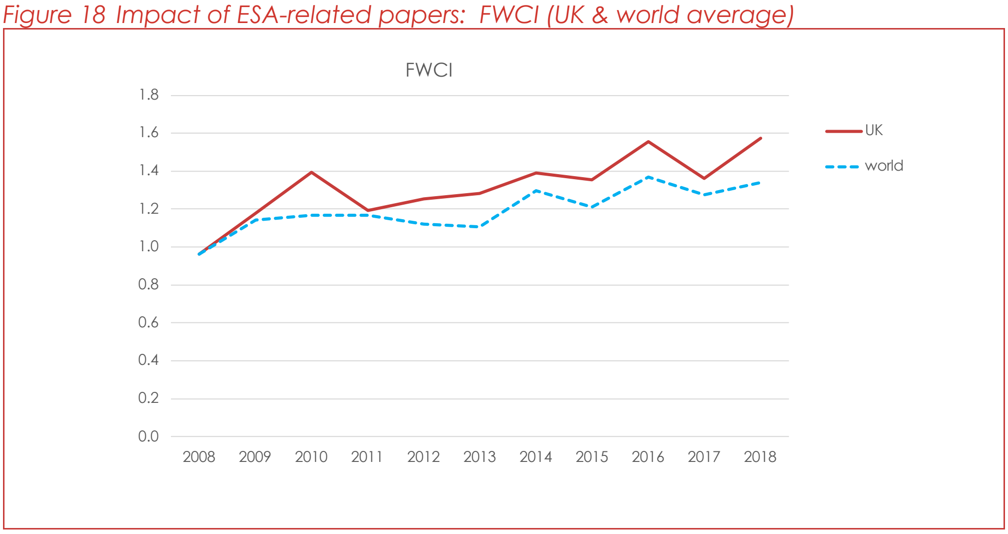
Table 20 HCP increase for ESA-related papers

	HCP increase 2008-2011 to 2017-2019	
	UK	**World**
HCP10	45%	33%
HCP5	45%	41%
HCP1	95%	66%

Science-Metrix (2021) / Scopus

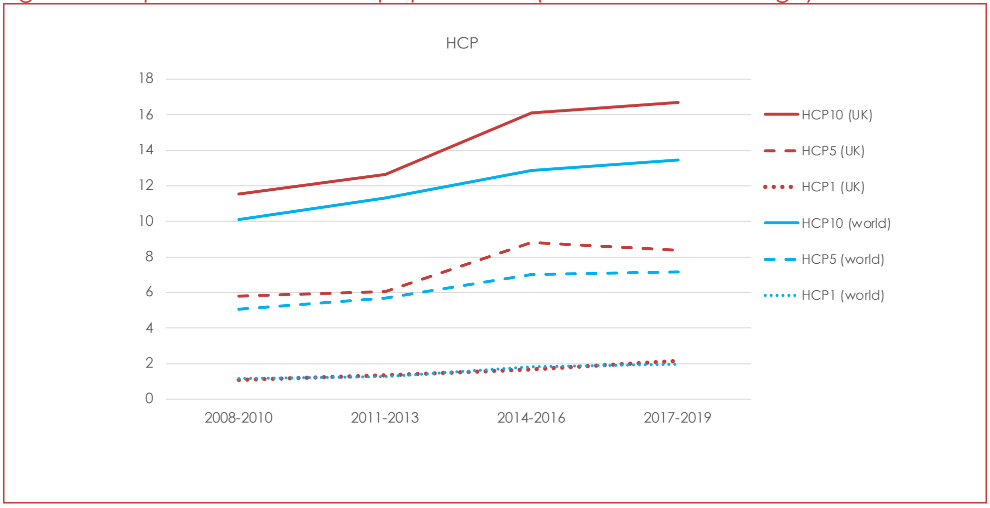
The performance of the eight comparator countries has also improved in terms of the FWCI and HCP indicators (Figure 20, Figure 21). Nevertheless, the UK's performance has improved at a greater pace, with the UK increasing its ranking for FWCI, HCP10 and HCP5 from 5th to 2nd place among the group of eight countries over the 10-year time period. The UK's HCP1 position hasn't changed and it remains on a par with the world average but below that of France, Italy and the Netherlands. While HCP1 can be more volatile that HCP5 and HCP10 due to the influence by a small number of highly cited papers, the HCP1 performance of the UK, Italy and the Netherlands have been rather stable over the period.

Figure 18 Impact of ESA-related papers: FWCI (UK & world average)



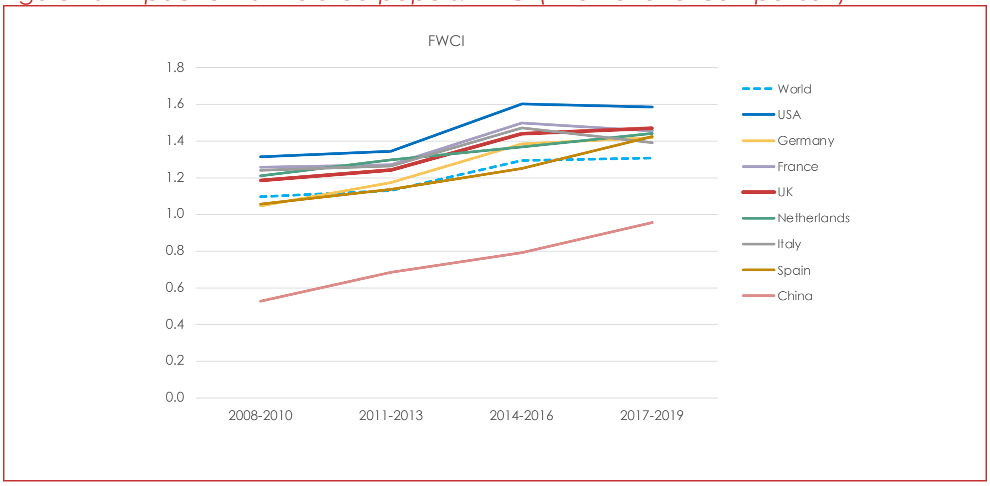
Science-Metrix (2021) / Scopus

Figure 19 Impact of ESA-related papers: HCP (UK and world average)



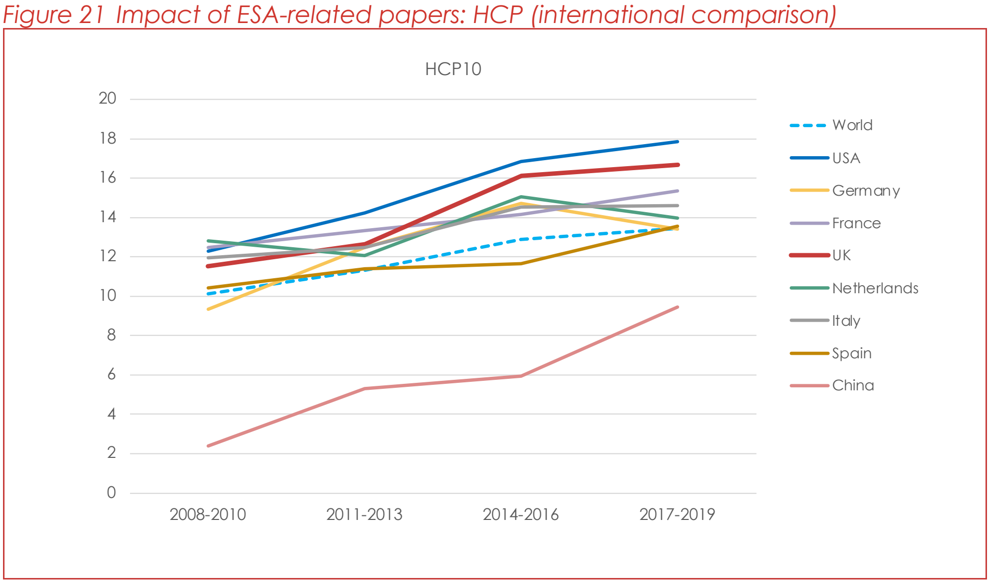
Science- Metrix (Scopus)

Figure 20 Impact of ESA-related papers: FWCI (international comparison)



Science-Metrix (2021) / Scopus

Figure 21 Impact of ESA-related papers: HCP (international comparison)



Science-Metrix (2021) / Scopus

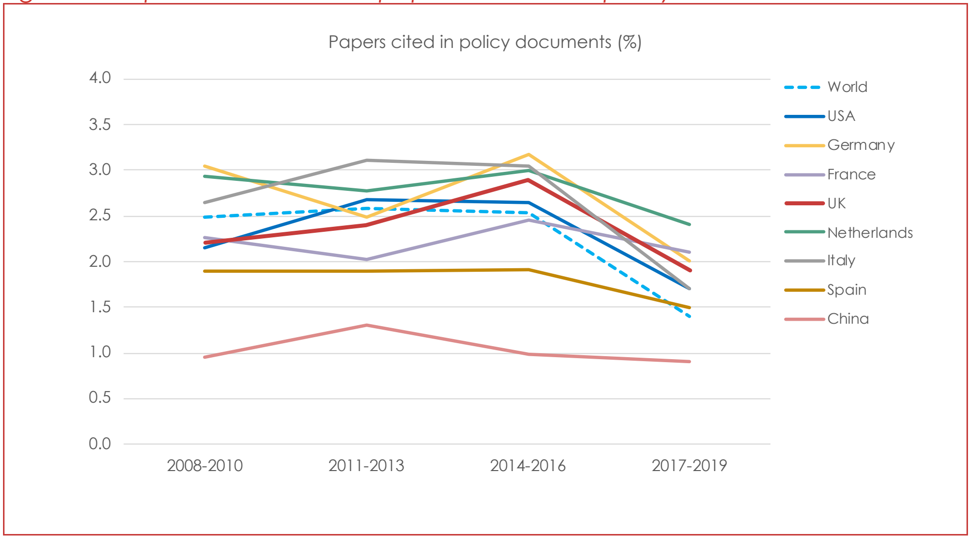
5.3.3 *Wider impact of ESA-related papers*

The knowledge encapsulated in publications is largely scientific knowledge that increases human understanding of the Earth, solar system and universe and knowledge regarding the advanced technologies developed to implement space infrastructures - with both contributing to the stock of knowledge and available to support not only further scientific knowledge but also innovation. The impact of the ESA-related papers is further assessed in terms of the extent to which they are cited in policy documents (Figure 22) and in social media (Figure 23) - as a measure of their contribution and value to public policy and their relevance to public interest. The former provides an indication of one form of spillovers and the latter provides a partial assessment of outreach and interest of the ESA-related papers to the general public.

In terms of policy citations, since 2014 the UK has performed above the world average and above the USA but below that of Germany, Italy and the Netherlands – albeit with a very small proportion, 2-3%, of papers cited in policy documents. In the most recent years (2017-2019) the UK performs also below that of France but above Italy.

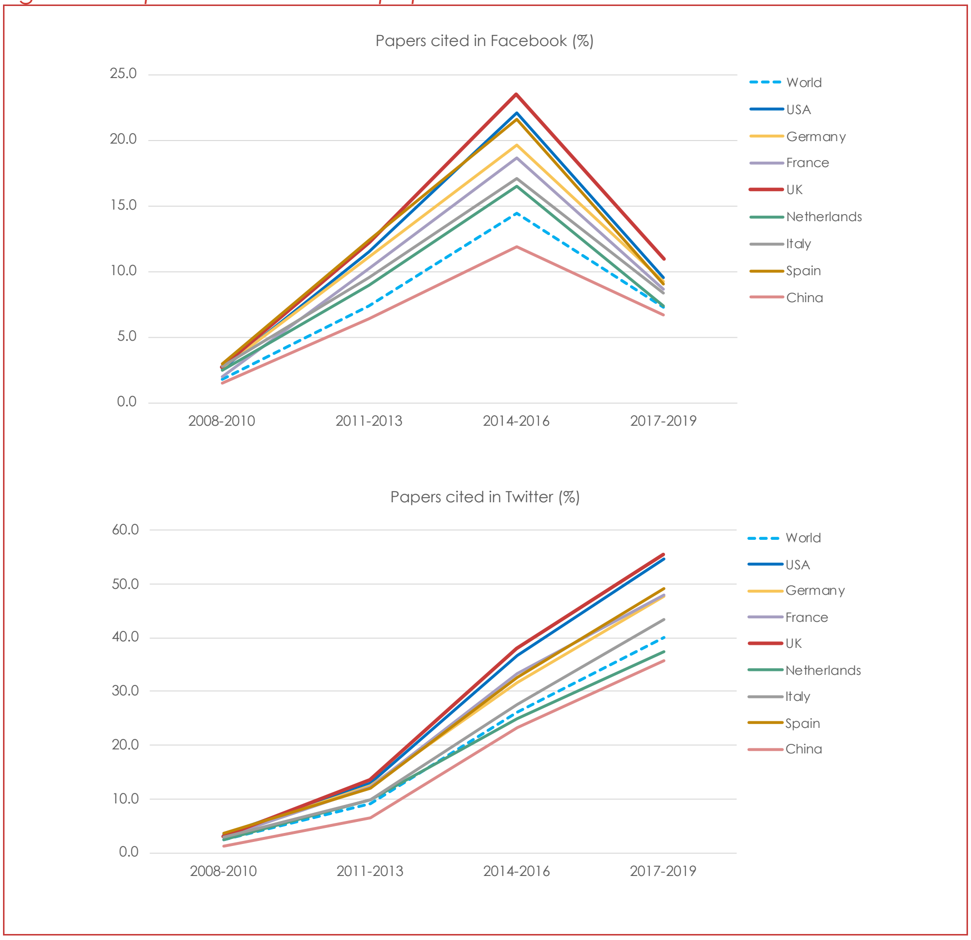
For social media citations, the UK performs better than most of the comparator countries for citations in Twitter and Facebook – with 10-25% of papers cited on Facebook and 40-55% on Twitter since 2014. All countries have followed an upwards trend in citations on Twitter and Facebook (up to 2018) that largely tracks growth in usage of these platforms. It is not clear what has caused the decrease in Facebook citations across all countries in the most recent three-year period. Wikipedia citations are more stable over time, with the UK performing better than its comparators except the USA. With around 10% of papers cited in articles on the platform.

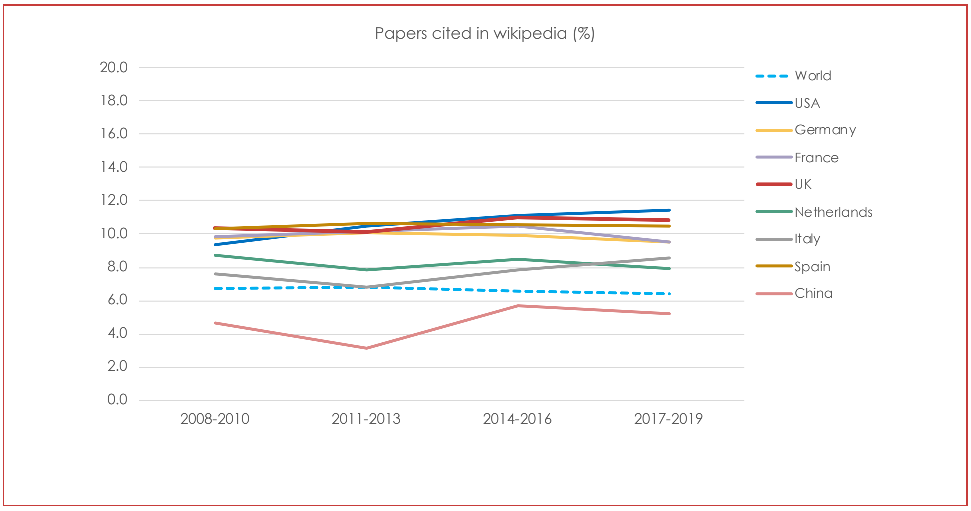
Figure 22 Impact of ESA-related papers: citations in policy documents



Science-Metrix (2021) / Scopus / Overton

Figure 23 Impact of ESA-related papers: citations in social media





Science-Metrix (2021) / Scopus / Plum X

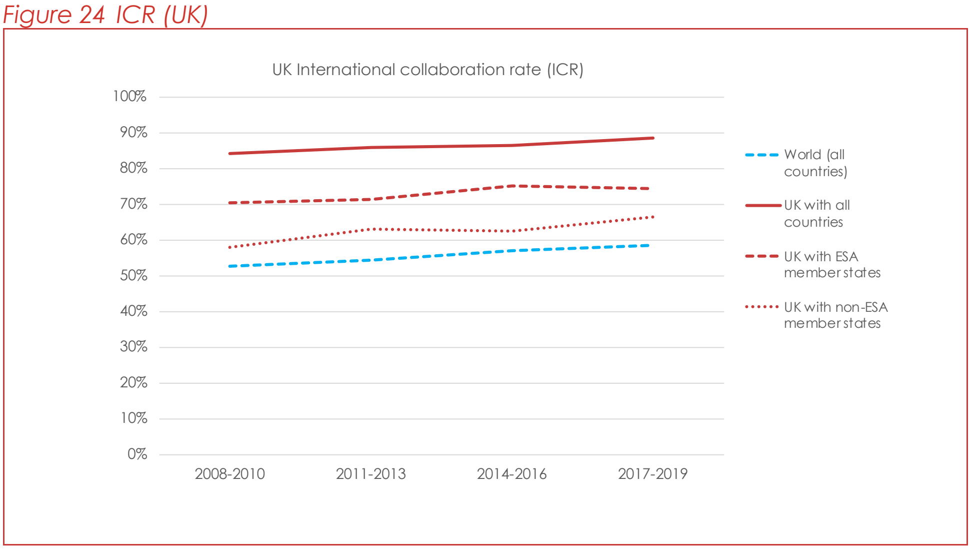
5.3.4 *International research collaboration*

Co-authorship of research papers provides a good measure of collaboration in the research itself. Therefore, the analysis of co-authors affiliated with organisations in different countries can be used to assess levels of international collaboration. As for the previous bibliometric indicators this indicator is provided as a baseline for future M&E activities as there are not, as yet, any papers from CMIN19 to assess.

At a global level, the UK has had a high international collaboration rate for its ESA-related papers, with the majority of its papers (89% in the period 2017-2019) being published with researchers outside the UK (Figure 24). The UK's collaboration rate is slowly increasing following the world average and the trend for the individual comparator countries (Figure 25).

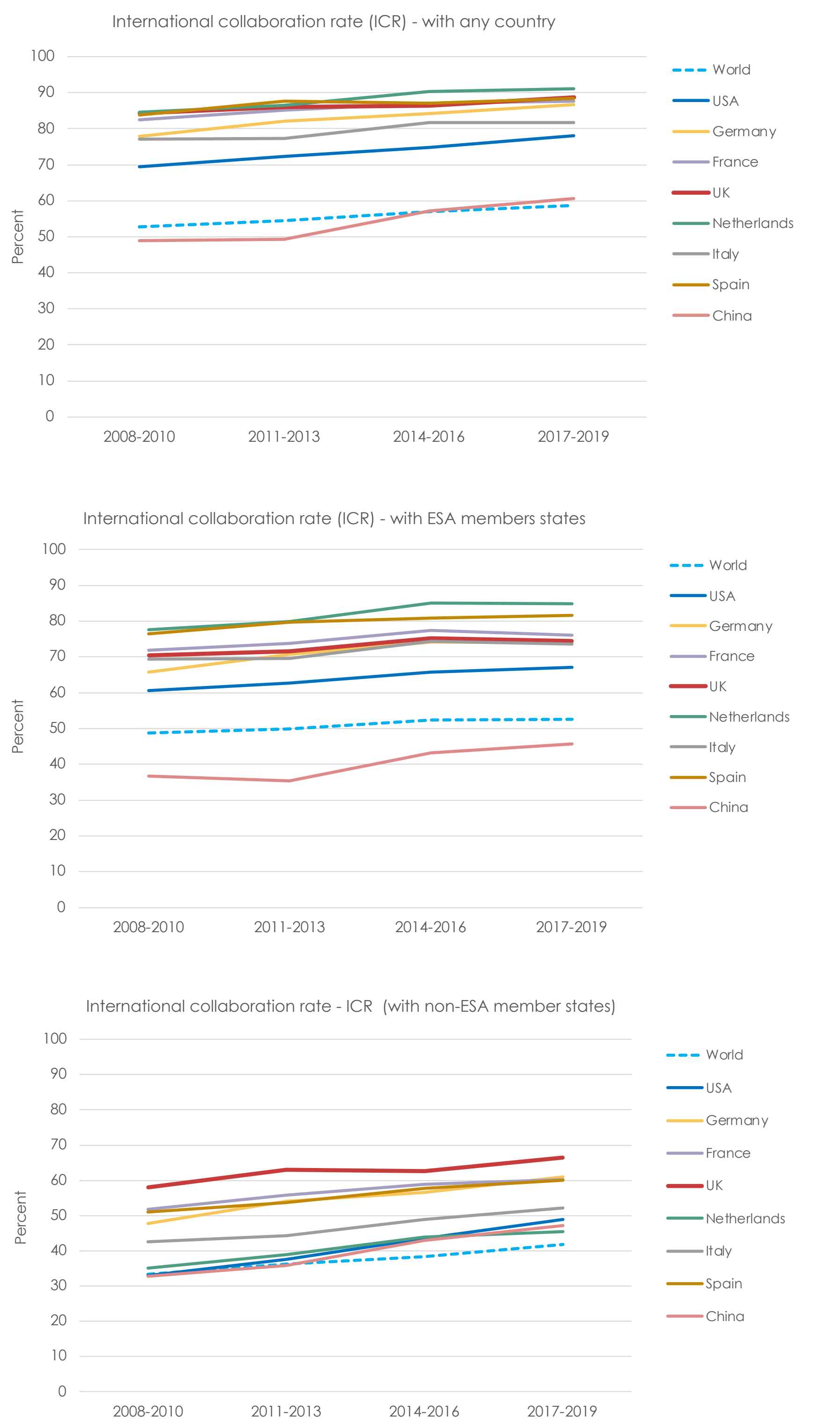
The rate of UK collaboration with ESA member states is higher than for non-ESA countries which might be expected for ESA-related papers. Similarly, the longevity of the UK's ESA membership has resulted in a fairly stable level of collaboration, with a slower growth rate than that for non-ESA countries. Nevertheless, while the UK collaborates with ESA member states at a level on a par with Germany, France and Italy, it collaborates with non-ESA member countries at a somewhat higher level than these comparator countries.

Figure 24 ICR (UK)



Science-Metrix (2021) / Scopus

Figure 25 ICR (international comparison)



Science-Metrix (2021) / Scopus

5.4 Skills

5.4.1 Skills arising from ESA contracts

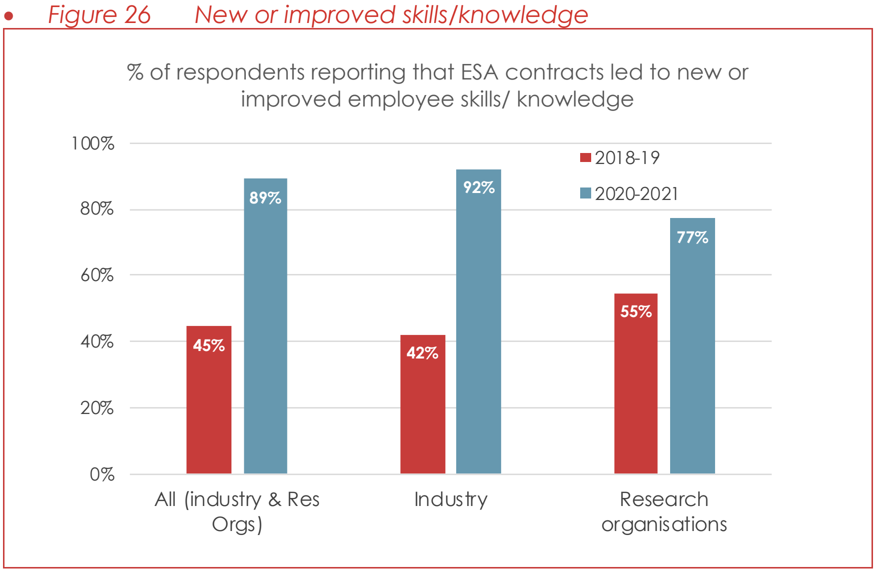
The space industry requires (and develops) a wide range of skills in technology development and engineering, some highly specific to manufacturing, operating and using space infrastructure, and others more generally applicable, but equally high-quality skills, in component design and manufacture and engineering of complex systems.

A little under half of respondents (45%) reported an uplift in skills in the baseline period and 89% in the period 2020-2021 (Figure 26, Table 21), with some small differences between organisation type and programmes (Table 22. We note that the uplift between the two periods should be treated with caution as not all current ESA contractors (the targets for the survey) held ESA contracts in the 2018-19 period.

Respondents provided examples of skills gained. These included space specific skills as well as more general engineering skills but also skills in project management, team work and understanding markets. Various aspects of software design and data science (AI, machine learning, etc) were reported fairly frequently.

- Specific space technologies and capabilities e.g. in propulsion, attitude and orbit control, cooling systems, gyro engineering, electrical ground support system, space electronics, satellite fuelling, oxygen extraction
- Components and technologies used in space and other applications e.g. photonics, antenna, communication technologies, signal processing, receiver design, IoT
- General engineering capabilities: systems design, assembly, integration and test calibration techniques
- Software and data analytics – for controlling autonomous space systems and managing and interpreting space data:
  - Data quality control, processing and management, processing
  - AI, machine learning,
- Skills in project management, working in terms, understanding markets

- *Figure 26 New or improved skills/knowledge*



- ESA contractor survey

Table 21 New or improved skills/knowledge (All respondents, n=110)

% of respondents reporting new or improved skills	2018-2019	2020-2021
All respondents	45%	89%
Industry (n=88)	42%	92%
Academia / Other (n=21)	57%	77%

ESA contractor survey

Table 22 New or improved skills/knowledge by programme (All respondents, n=110)

% of respondents reporting new or improved skills	2018-2019	2020-2021
Science (n=15)	40%	80%
EO (n=30)	57%	90%
HRE* (n=6)	50%	83%
TIA (n=37)	43%	89%
GSTP (n=13)	31%	92%
NAVISP* (n=5)	40%	100%
SSS* (n=4)	40%	100%
CSTS (n=0)	-	-

ESA contractor survey *less than 6 responses

5.4.2 *Inspiration effect*

UKSA, like space agencies worldwide, undertakes dissemination and communication activities to share enhanced understanding about the Earth, solar system and universe with the general public and supports others to do so. This is intended to increase the general scientific literacy of the UK public and inspire young people to consider careers in space science or in the broader range of STEM disciplines. This offers the potential to increase the future availability of skilled scientists and engineers for the space sector and for the wider knowledge-driven economy.

For the *inspiration effect* we present (i) data collected by the UKSA Education and Outreach team on the extent of the reach of space-related outreach to young people and the general public and (ii) data on enrolment of students on relevant higher education (HE) courses.

5.4.2.1 Outreach activities

UKSA's outreach activities which are linked to ESA investments in two ways:

- ESA funding: the educational outreach activities undertaken by the UK national office of ESA's European Space Education Resources Office (ESERO) are part-funded by ESA. The UKSA provides co-funding to UK-ESERO and does so at a level higher than the required 50% matched co-funding required (Table 24. ESERO also develops content and schemes to support national outreach activities[31]

[31] Such as continuing professional development modules for teachers, competitions and activities for school children such as CanSat and Mission X

- The use of ESA missions as content for outreach activities: the scientific findings, novel technologies and skilled people (astronauts, scientists, engineers) provide exciting and informative content for outreach activities

The data for the outreach indicator (Figure 27) represents the activities undertaken by:

- ESERO-UK – funded by ESA and by UKSA national funding
- UKSA Education and Skills Team (and their sub-contractors) – funded by UKSA national funding

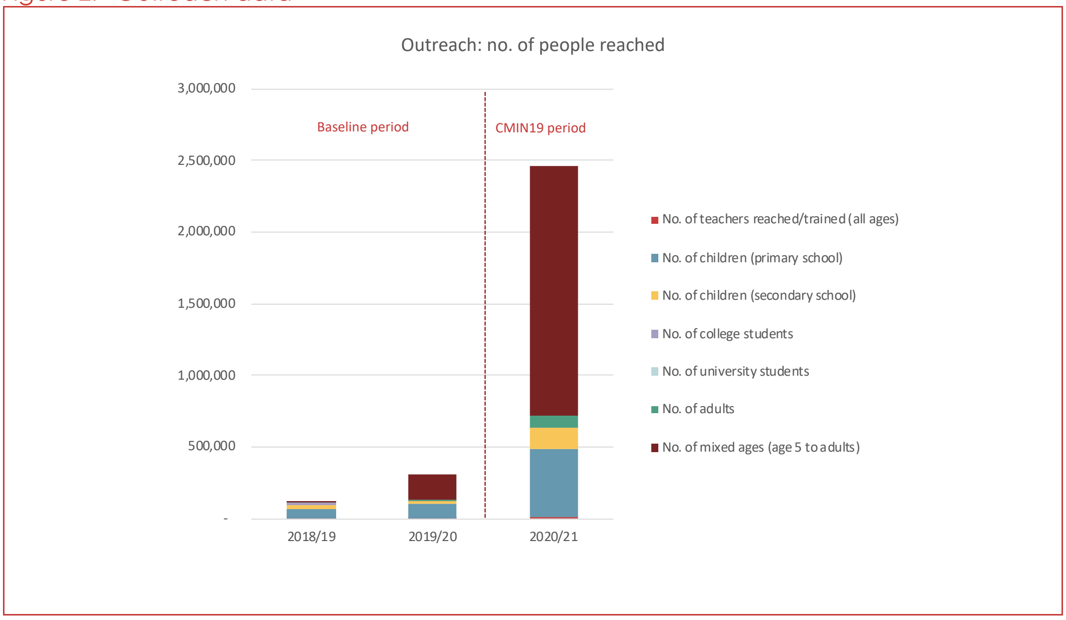
Prior to the pandemic, activities included broad-reach activities such as online materials and lectures (in-person and online), one-to-one /one-to-few conversations at conferences, exhibitions, masterclasses and school visits, to in-depth 'hands-on' activities such as ESERO Mission X and CanSat. Data for the outreach indicator is presented as a table and chart below.

Table 23 Outreach data

Number of people engaged with	Baseline		
	2018/19	**2019/20**	**2020/21**
No. of teachers reached/trained (all ages)	2,156	3,342	5,712
No. of children - primary school	62,306	99,446	477,401
No. of children - secondary school	27,966	17,743	152,801
No. of college students	17,760	2,535	887
No. of university students	719	375	57
No. of adults	1,373	7,133	79,539
No. of mixed ages (age 5 to adults)	6,320	181,566	1,744,728
Total no. of people reached	**118,600**	**312,140**	**2,461,125**

Technopolis (2021)/ UK Space Agency data (Education and Skills Team)

Figure 27 Outreach data



Technopolis (2021)/ UK Space Agency data (Education and Skills Team)

The scale of outreach increased considerably during 2020/21 when activities moved online due to the pandemic. This enabled many more people to attend events (talks, seminars, training activities, etc) but (as reported by interviewees) did so at the expense of more detailed one-to-one and small group interactions and the in-depth 'hands-on' activities. As outreach activities transition back to a combination of in-person and online, numbers may decrease back to a level similar to those before the pandemic. However, this may be counterbalanced by two changes. Firstly, the ESA education department is planning to introduce a new education framework in 2022 that will entail increased outreach activities. Secondly, Tim Peake is expected to make a second mission to the ISS during the CMN19 investment period. UKSA's outreach and educational activities during his Principia mission in 2015/16 reached more than 33 million people and by the start of 2018, at least 2 million young people took part in one or more of the 34 education projects.[32]

The outreach data presented above covers all UK outreach activities. A portion of the ESERO-UK activities are directly funded via the UK contribution ESA, with the reminder of ESERO-UK activities and all other non-ESERO activities funded by UKSA. In total, 19% of activities are funded directly by ESA (Table 24) and therefore, as a minimum, 19% of the outreach levels can be considered to be wholly supported by UK investments in ESA. More broadly, the UKSA Education and Skills Team report that outreach activities use a mixture of content related to ESA (e.g. ExoMars, space science, EO) and UK-funded space initiatives (e.g. spaceports and launch capabilities). They estimate a lower bound of 20% of ESA contribution, via the direct participation of ESA staff, to 75% where ESA activities provide valuable content. Therefore, we estimate that 50% of outreach outputs are attributable to investment via ESA.[33]

Table 24 Budget for UK Space Agency outreach activities for 2021/22

2021/22 budget	**£**	**%**
ESA funding for ESERO activities	159,483	19%
UKSA funding for ESERO activities	251,000	31%
UKSA funding for national (non-ESERO) outreach activities	412,000	50%
Total	**822,483**	**100%**

Technopolis (2021)/ UK Space Agency data (Education and Skills Team)

5.4.2.2 Students enrolling on higher education (HE) courses related to space

HE courses in STEM as defined the Higher Education Statistics Agency (HESA) were assigned to three groups (Table 25):

- **Group 1: space-specific courses** (e.g. space science, satellite engineering): courses directly linked to space science and engineering, where skills developed are directly applicable to space research / space industry and where students might be reasonably be thought to have been influenced by UKSA/ESERO's outreach activities in the preceding years

[32] Impact Assessment: Principia Campaign (Full Report), UK Space Agency https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764882/Impact_Assessment_Principia_Campaign.pdf
Impact Assessment: Principia Education Campaign (Summary), UK Space Agency https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765104/6.5106_Principia_Education_Campaign_Final.pdf

[33] Taking the mid-point between 19% and 75% - 47% - and rounding up to 50%

- **Group 2: space-related courses** (e.g. aerodynamics, astrophysics): a wider group of courses with relevance to space research / space industry and where students might have been influenced by UKSA/ESERO's outreach activities in the preceding years
- **Group 3: all courses in STEM** in the physical sciences and engineering (i.e. biosciences are not included). This groups includes Group 1 and Group 2

Table 25 HESA subjects per group

Group	Subjects	
Group 1: space-specific courses	Space science, Planetary science Astronomy	Space technology Satellite engineering
Group 2: space-related courses	Aerodynamics Aeronautical engineering Aerospace engineering Aerospace propulsion systems Aviation studies Avionics Astrophysics Atmospheric physics	Climate change Climate science Mechanics Meteorology Ocean sciences Surveying Radiation physics Remote sensing
Group 3: physical sciences and engineering *(Group 3 includes groups 1 & 2)*	Physical sciences Mathematical sciences	Engineering and technology Computer science

Technopolis (2021)/ HE2A data **the full list of subjects and classification codes is provided in Appendix G*

Figure 28 and Figure 29 (Table 26and Table 27) and present the annual numbers of students enrolling on HE courses for the three groups

- Numbers of students enrolling on space-specific courses (Group 1) are very low (in the low 100s, representing around 0.01% of enrolments across all HE courses) with a high proportion of these students enrolled on taught postgraduate courses
- There was a large increase in students enrolling in space-specific courses in the academic year 2019/20, however this aligns with the change in the coding HESA used to identify courses and so it is not possible to determine how real this increase is. The HESA data allows the enrolment data to be tracked in future years and this uplift can then be considered in terms of later trends.
- Numbers of student enrolling on space-related courses (Group 2) is of the order of 2,500 and 0.25% of all students. Compared to space-specific courses, a greater proportion of these are enrolled on undergraduate courses.
- The majority of students enrolled on space-specific and space-related courses are male. Female enrolment has been slowly increasing over the period from 24% in 2014/15 to 28% in 2019/20 (Figure 30). These figures align with the findings of the 2020 Space Skills Survey where women represent 29% of employees in the industrial space sector.[34]

The HESA data shows that the majority of these courses are located in the South-East (49%) and London (25%), with the remainder in Wales (10%), the East Midlands (9%) and the North-West

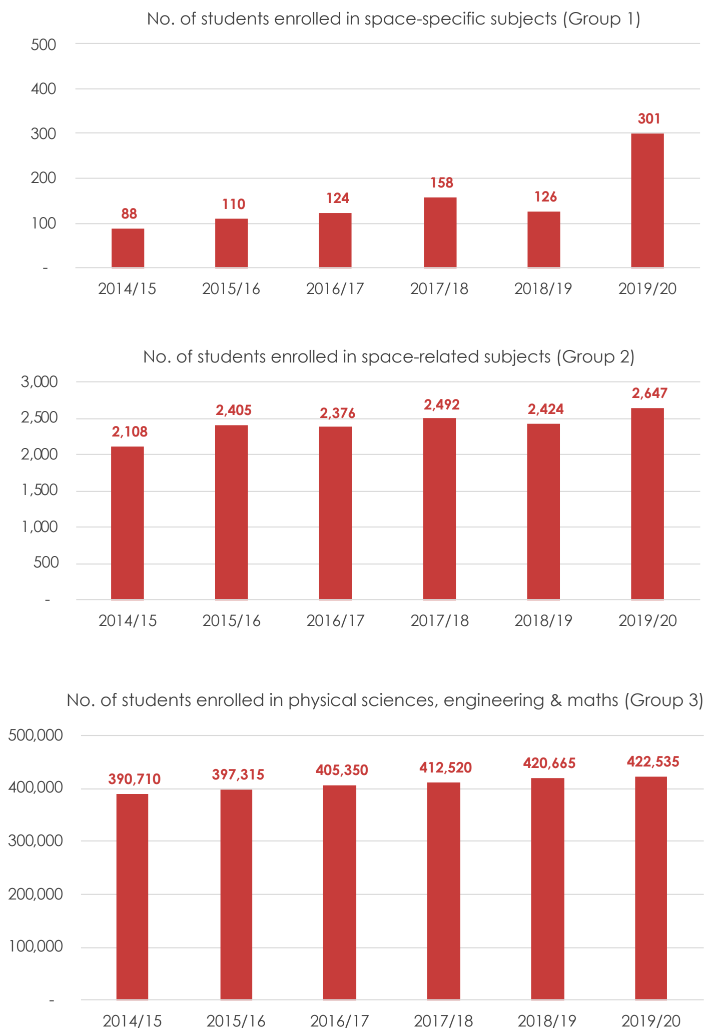
[34] Demographics of the Space Sector, Space Skills Alliance, 2020 https://spaceskills.org/census-demographics#summary

(7%). This aligns with the locations of some of the key departments that conduct space research (such as UCL, University of Surrey, Open University, University of Leicester).

Student demand for space-specific courses, and for space modules in space-related or wider STEM courses, can also be indicated by the number of university departments that are members of the Space Universities Network (SUN). The network aims to enhance the quality of learning and teaching by providing support and resources to the higher education space science and engineering community. Membership currently (as of early 2022) includes 62 departments in 41 institutions (Appendix G).

Interviews with the academic space community report that the ability to use examples of their own research and/or engineering activities on ESA contracts is valuable to demonstrate the availability of careers in the UK in the space industry. In particular to demonstrate that it is not necessary to go to the USA or to other European countries to pursue a career in space. Interviewees provided a small number of examples of PhD students going on to work in space SMEs but also to jobs in data-driven sectors such as logistics and gaming. The challenge of the space sector competing with the finance sector for highly numerate graduates was also raised.

Figure 28 No. of students enrolling on subjects relevant to space



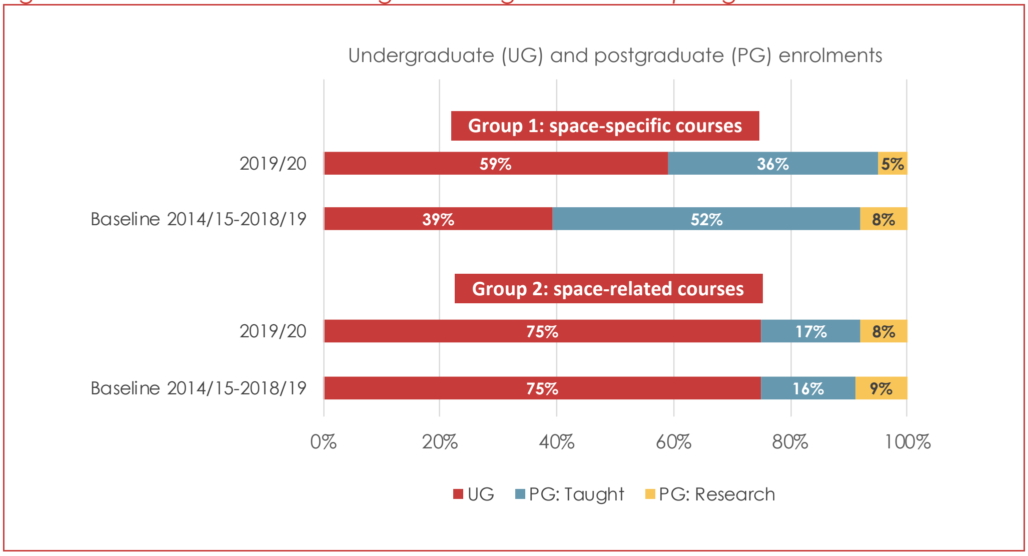
Technopolis (2021)/ HESA data

Table 26 Student enrolments in HE courses

Year	Group 1 Space-specific	% of all enrolments / all subjects	Group 2 Space-related	% of all enrolments / all subjects	Group 3 Physical sciences	% of all enrolments / all subjects
2014/15	88	0.009%	2,108	0.21%	390,710	40%
2015/16	110	0.011%	2,405	0.24%	397,315	40%
2016/17	124	0.012%	2,376	0.23%	405,350	40%
2017/18	158	0.015%	2,492	0.24%	412,520	40%
2018/19	126	0.012%	2,424	0.23%	420,665	40%
2019/20	301	0.026%	2,647	0.23%	422,535	37%

Technopolis (2021)/ HE2A data

Figure 29 No. of students enrolling at undergraduate and postgraduate levels



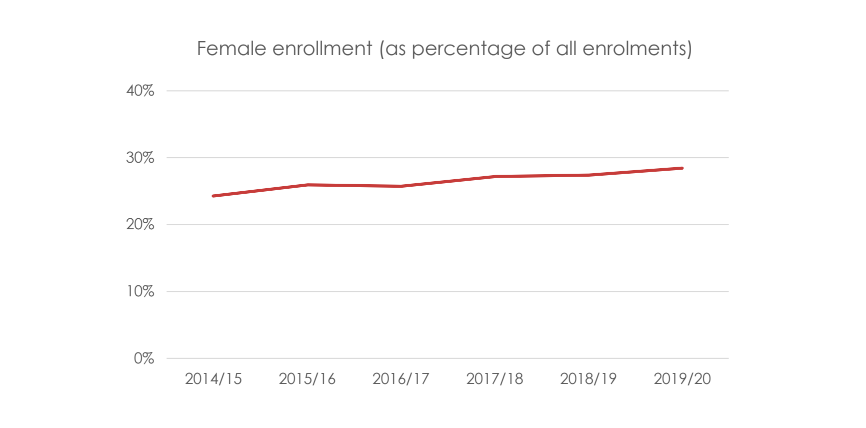
Technopolis (2021)/ HESA data

Table 27 Level of study

	Period	Undergraduate	Postgraduate Taught	Postgraduate Research
Group 1: Space Specific Courses	Baseline 2014/15-2018/19	39%	52%	8%
	2019/20	59%	36%	5%
Group 2: Space Related Courses	Baseline 2014/15-2018/19	75%	16%	9%
	2019/20	75%	17%	8%

Technopolis (2021)/ HE2A data

Figure 30 Female enrolment on subjects relevant to space



Technopolis (2021)/ HESA data

5.5 Attribution and additionality

We consider the extent to which new knowledge about the Earth, solar system and universe, increased skills for space research and the space industry and enrolments in space relevant HE course can be considered attributable to UK investments made via ESA and additional (i.e. the extent to which they might have happened without UK investments via ESA).

Using a theory-based evaluation (TBE) approach, attribution and additionality are assessed qualitatively. That is: the extent to which the outputs and outcomes (evidenced by the quantitative data) are attributable and additional (or likely to be so) is assessed via testing the whether the pathways to impact, identified on the programme ToCs, are valid and reasonable via interviews, desk research and case studies.[35]

New knowledge: outputs

The papers reported as a direct result of activities undertaken under ESA contracts can, in principle, be considered to be attributable to ESA contracts and have high additionality. However, given that the evaluation data was collected two years into the CMIN19 period, it may be that some of the papers reported to date are based on contracts for related activities in prior CMIN investment periods. This highlights the complexities and challenges of evaluating long-term activities to develop missions and technologies over several CMIN periods and the difficulty in assigning specific individual outputs to single contracts. Nevertheless, the data collected provides a baseline indicators for papers arising from directly ESA contracts that can be updated on a regular basis by on-going regular M&E processes

New knowledge: outcomes

Where new knowledge from ESA investments in concerned it is the outcomes that are of most interest and relevance i.e. the new knowledge generated via the data provided from ESA's space infrastructure. For CMIN19 investments these knowledge outcomes are in the future. Nevertheless, the pathway to impact for these expected outcomes were explored in the qualitative research and via desk research. The qualitative data gathered from the interviews, case studies and examination of the programme ToCs at programme level indicated that the pathways to impact are valid and there is the expectation of new knowledge generation in future from the mission under development under CMIN19. In addition, the historic trends in the

[35] The ToC analyses and case studies are reported in Report B

bibliometric data indicate a high level of attribution and additionality of the new knowledge created to UK investments via ESA because:

- The majority of papers published were from the ESA Science programme and were related to the development of instrumentation for missions and use of data from ESA scientific missions. While the funding to support these two activities comes from UKSA (instrumentation development) and UKRI-STFC (space science research), not ESA, the scientific publications are entirely dependent on the operational ESA mission and the data it generates. Therefore, the three funding steams (ESA, UKSA and UKRI) are highly interdependent and the knowledge outcomes are, arguably, attributable to all three sources. However, without UK participation in ESA the other two funding streams are unlikely to exist and therefore we conclude that all the scientific knowledge outcomes (i.e. those related to scientific publications) are attributable to UK investments via ESA.
- Research using space data is, in principle, possible (once openly available) without being a member of the mission's scientific consortium but 'external' non-consortium researchers are at a significant disadvantage: the data is not designed for their specific research needs; there are typically delays in accessing the data; and external researchers lack the deep understanding of the capabilities of mission instrumentation. Furthermore, without ESA, UK researchers would be involved in many fewer mission consortia, so greatly reducing the UK's knowledge outcomes.[36] Therefore, we conclude that there is very high level of additionality of the knowledge outcomes to investments made via ESA. It is not possible to put a precise number on it, however, given that the UK contributes 10% to the ESA total budget and 15% to the Science programme (and this enables the UK to participate across the entire Science programme), we can say that without ESA the UK could only expect to participate in scientific space missions at a fraction of the level that it does currently i.e. 10-15% of its current activity. And so additionality can be considered to be 85%-90% i.e. 85-90% of UK knowledge outcomes would not have happened without investment via ESA.
- There is no reason to consider that the levels of attribution and additionality would be different for the forthcoming knowledge outcomes resulting from missions developed via CMIN19 investments.

Skills: outputs

The survey data (Figure 54 in chapter 6), interview data and examination of the ToCs indicate a high level of attribution of the research and industrial skills acquired to the ESA contracts. Much of the research and industrial RDI activity is highly specific to the space domain and would not be developed via other means. From an industry perspective, there are limited other forms of public support for R&D and innovation activities (RDI) in the space domain.

Skills: outcomes

The skills outcomes achieved via the inspiration effects for CMIN19 investments are in the future. There are long time lags between outreach activities undertaken with CMIN19 (and/or based on CMIN19 funded missions once in flight) and HE enrolment. Outreach activities target all school age groups, from primary to sixth form and so time lags to HE enrolment will range from 2 to 12 years and span several ESA CMIN investment periods. Therefore, any uplift in student numbers in 2019/20 (i.e. within the CMIN19 period) would be attributable to outreach activities undertaken 5-10 years earlier.

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[36] We consider the related question regarding ESA added-value in chapter 9

It is reasonable to expect some level of attribution of student interest in space-specific and space-related subjects to both ESA funded and UKSA (nationally) funded outreach activities. The exact extent is difficult to determine as there are many other (non-ESA/UKSA) STEM outreach activities, some of which will also draw on space as material, as well as other socio-economic factors that underpin student choices. Nevertheless, we would recommend that UKSA considers tracking annual enrolment in the space-specific and space-related subjects both as an M&E indicator but also to support UKSA's wider interest in ensuring availability of skills for the space sector.

6 Impact domain: Prosperity

6.1 Introduction

The indicators for the **impact domain: prosperity** cover:

- Outputs: direct effects for ESA contractors
- Outcomes (spillovers):
  - Subsequent benefits for ESA contractors and the wider space sector
  - Usage benefits
  - Innovation benefits

The indicator data is based on a number of primary and secondary data sources:[37]

- Data for **indicators for the outputs of ESA contracts** comes from the primary data collected via the survey of ESA contractors. The data collected provides an assessment of the position for ESA contracts that started from 1 Jan 2020, providing a value for each indicator as of Q4 of 2021.[38] Wherever possible the data provides a baseline figure for the previous two-year periods (2018 and 2019) and a projection forward, either to the end of contracts or for a period from 2022 onwards. Though as noted on page 23 the baseline data needs to be is problematic.
- Data for the **outcome indicators** comes from a number of sources including primary data from the survey of ESA contractors and the programme of interviews with ESA contractors and stakeholders, secondary data sources including patent and business databases, secondary data provided by ESA, UKSA and the ESA BIC[39] and desk research. **Error! Reference source not found.** provides a more detailed definition and data source for each indicator presented.

6.2 Outputs

The survey data is presented at the level of the portfolio of UK investments in ESA i.e. for all eight ESA programmes together and disaggregated at programme level where it is possible and meaningful to do so.

6.2.1 TRL progression

The first indicator captures the technological development within ESA contracts. The purpose of ESA contracts is to pay for either the development of innovative hardware and software technologies for specific space missions and infrastructure (spacecraft, operations, data management, etc) or the development of novel technologies with the potential to support future space activities.[40] The technology developed is, typically, entirely new or considerably enhanced from previous applications and is often bespoke to a specific ESA mission or infrastructure. The indicator captures progression in terms of Technology Readiness Levels (TRL). This scale was designed by NASA specifically for space missions and is used by space agencies

[37] The indicators and their definitions are provided in Appendix A

[38] The survey was conducted in the last quarter of 2021 and we allowed respondents to estimate values for the full two years 2020 and 2021

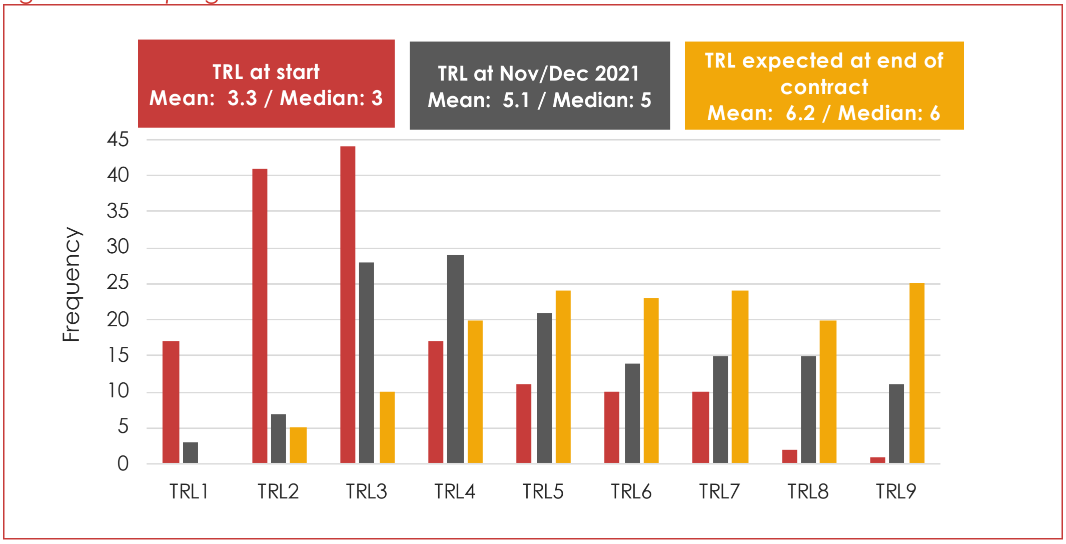
[39] ESA Business Incubation Centre (BIC)

[40] A proportion of contracts will support ESA administration and management

worldwide including ESA.[41] It is a 9-point scale spanning 'basic concept observed and reported' (TRL1 to 'actual system flight proven through successful mission operations' (TRL9).

The indicator is provided as the mean and median TRL progression for the technologies being developed under current ESA contracts as two measures (Table 28): from the start of the contract to Q4 of 2021 (i.e. at the time of the survey) and from the start of the contract to the expected TRL at the end of the contract. The TRL progression is calculated for each individual technology reported and then a mean and median calculated. The range of TRLs is variable (Figure 31) as different programmes and different contracts target different stages of the technology and mission development (Figure 32). Figure 31also presents the mean and median TRL values across all survey respondents for each of the three points in time.

Figure 31 TRL progression



ESA contractor survey

Table 28 TRL progression: mean / median progression across all technologies (n=60-66)

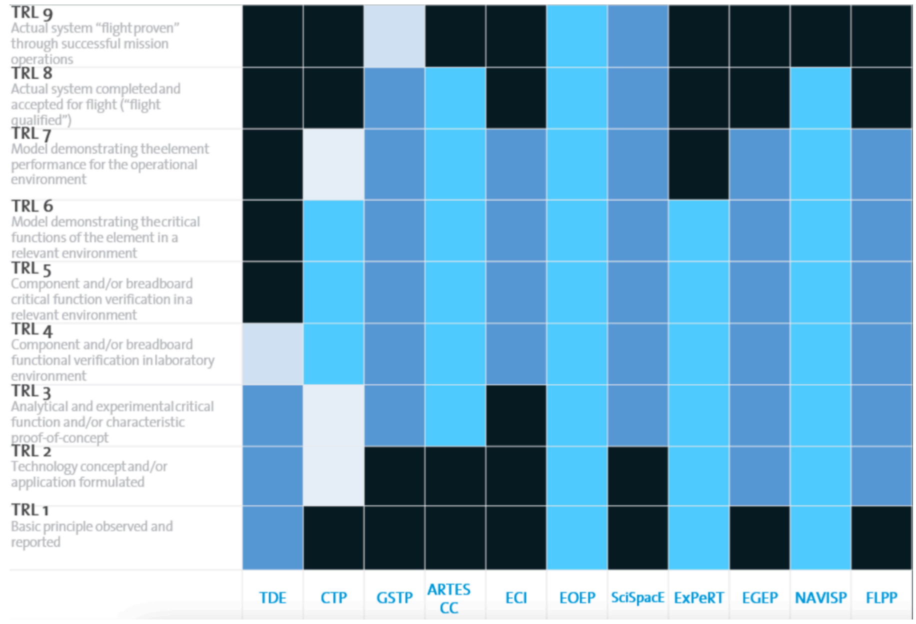
	TRL progression A: from start of contract to Q4 2021	**TRL progression B: from start of contract until contract end (expected)**
TRL progression (mean)*	1.8	2.8
TRL progression (median)*	1	2

ESA contractor survey (*This table presents the mean and median progression of each individual technology reported by respondents)

The mean TRL progression to Q4 2021 is 1.8 (TRL progression A in Table 28) and the median is lower at an uplift of 1. By the end of contracts, the mean expected TRL progression is 2.8 (TRL progression B in Table 28) with a median of 2.

[41] https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/Technology_Readiness_Levels_TRL

Figure 32 ESA TRL matrix



Source: ESA[42]

6.2.2 *Technology contributing to new space infrastructure*

Following on the TRLs, is the extent to which ESA contracts under CMIN19 have led or will lead to operational space infrastructure. Very few respondents reported that their contracts have already led to operational infrastructure, just 10%, but 47% expect to in the future (Table 29). As shown in Table 30 the mean time to operational space infrastructure is 3.1 years with a range from 0-10 years, reflecting the fact that different missions are at different stages development. Contractors reported that benefits of the operational infrastructure will last, on average, 14 years, ranging from 2 to 60 years (Table 30).

That most of the new operational space infrastructure is expected in the future is in line with the activities in CMIN19. The ESA missions under development in Science, EO and HRE and private sector-led missions under TIA are at different stages with launch dates that range from 2020 to the early 2030s and the contractors have a clear understanding of the stage of development of the missions they are contributing to. Technology development programmes such as GSTP are likely to have long timescales to operational infrastructure as they are tasked with developing technologies at low TRLs to provide capabilities for future missions.

[42] TDE - Technology Development Element, CTP - Science Core Technology Programme, GSTP - General Support Technology Programme, ARTES Core Competitiveness - Advanced Research in Telecommunications Systems ECI - European Component Initiative – now part of TDE, EOEP - Earth Observation Envelope Programme, SciSpacE - Science in Space Environment, ExPeRT - Exploration, Preparation, Research and Technology, EGEP - European GNSS Evolution Programme, NAVISP – Navigation Innovation and Support Programme, LPP - Future Launchers Preparatory Programme

Table 29 Key technologies for operational space infrastructure (all respondents, N=110)

% of respondents reporting…	To date	Expected
Key technologies (from CMIN19 contracts from 1 Jan 2020) that have contributed / or are expected to contribute to operational space infrastructure	10%	47%

ESA contractor survey

Table 30 Timing of benefits: papers published (n=48-56)

Timing and duration of applications and benefits from current ESA contracts	Time from start of ESA contract to start of benefit (Mean), Years	Duration of benefit (Mean) Years
Operational space assets	3.1 (range: 0-10 years)	14 (range: 2-60 years)

ESA contractor survey

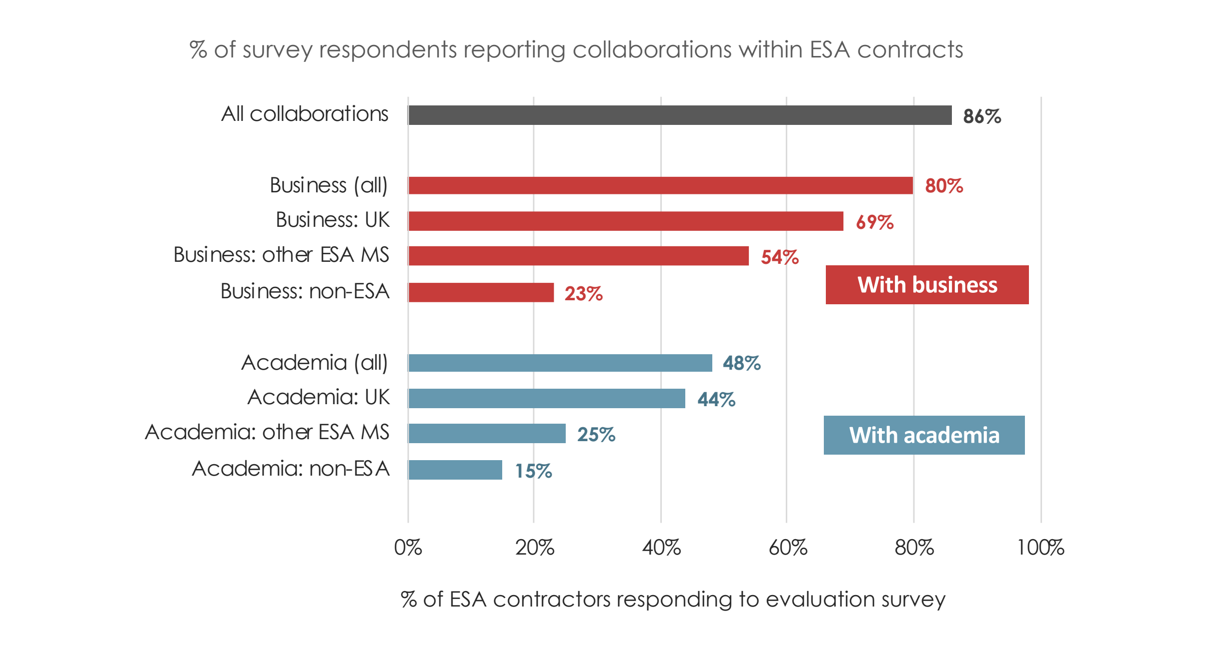
6.2.3 *Collaboration within ESA contracts*

Collaboration within R&D and technology development projects provides opportunities for technology and knowledge transfer between partners and for new ideas and concepts for innovation to arise. This is particularly the case when partners are from different typed of businesses (e.g. large and small businesses, businesses in different parts of the supply-chain), different types of organisations (businesses and universities) and different countries.

The collaboration indicator captures the extent to which the ESA contracts involve collaborations among different partners. Figure 33 presents the data for all contractors.

Collaboration rates are high, with 86% of those responding reporting at least one form of collaboration within their current (2020-2021) ESA contracts Figure 33. Collaborations with industry are high, with 80% reporting collaborations with other businesses; 69% with UK businesses, 54% with business in other ESA member states and 23% with businesses in non-ESA countries. Given that most contractors are from industry the majority of these collaborations are business-to-business collaborations. Collaborations with academia are lower, with 48% reporting collaborations with academia; 44% reporting collaborations with UK academics, 25% with academics in other ESA member states and 15% with academics in non-ESA countries.

Figure 33 Collaboration within ESA contracts (all respondents, n=110)



ESA contractor survey

Table 31 Collaboration within ESA contracts (all respondents, n=110)

Collaboration partners in ESA contracts		**Baseline 2018-2019** % of respondents	**2020-2021** % of respondents
All collaborations		**41%**	**86%**
With businesses	With any business	37%	80%
	In the UK	35%	69%
	In other ESA MS	25%	54%
	In non-ESA countries	12%	23%
With research organisations	With any research org	29%	48%
	In the UK	28%	44%
	In other ESA MS	19%	25%
	In non-ESA countries	9%	15%

ESA contractor survey

Table 32 and Table 33 present the collaboration data disaggregated for survey respondents from industry and academia/ research institutes.

Table 32 Collaboration within ESA contracts (Industry respondents only, n=88)

Collaboration partners in ESA contracts		2018-2019 % of respondents	2020-2021 % of respondents
With businesses	In the UK	34%	74%
	In other ESA MS	22%	58%
	In non-ESA countries	10%	22%
With academia	In the UK	25%	44%
	In other ESA MS	15%	20%
	In non-ESA countries	7%	11%

ESA contractor survey

Table 33 Collaboration within ESA contracts (Research organisations, n=22)

Collaboration partners in ESA contracts		2018-2019 % of respondents	2020-2021 % of respondents
With businesses	In the UK	41%	50%
	In other ESA MS	32%	36%
	In non-ESA countries	18%	27%
With academia	In the UK	41%	41%
	In other ESA MS	36%	45%
	In non-ESA countries	18%	32%

ESA contractor survey

6.2.4 Number of patents

This indicator represents the number of patents (filed and granted in any geographical jurisdiction) arising directly from ESA contracts. The wider patent performance of UK ESA contractors, and the UK in general, in the space domain is presented in section 6.3.3

Table 34 No. of (granted) patents arising directly from ESA contracts

	No. of patents (granted)							
	2018-2019				2020-2021			
Programme	**Industry**	**Academics**	**Other***	**Total**	**Industry**	**Academics**	**Other***	**Total**
TIA	3	-	-	3	2	-	-	2
Total	**3**	-	-	**3**	**2**	-	-	**2**

ESA contractor survey

Very few patents have been reported by ESA contractors in either the baseline or the CMIN19 period (to date) (Table 34).

- Three patents were reported for the baseline period – all from the same company and within the TIA domain
- Two patents were reported for the CMIN19 period – by two different companies and both in the TIA domain. One of these companies was the same one that reported patents in the baseline period. This company noted that they had applied for 17 patents but most had

not (yet) been granted and that, depending on need, patents are applied for in USA, Europe, Israel, China, UK and internationally under (PCT)[43]

- Respondents made a number of comments regarding patents
  - Two noted that patents have been applied for but were not yet granted, and another noted that there is potential for formal IP to arise from current ESA contracts but that it has not yet been reviewed by the company
  - One respondent noted that commercial confidentiality, rather than patents, was their preferred method route to protecting IP
  - Another noted that foreground IP in ESA contracts is owned by ESA
- ESA contractors we asked to report any licence income and the value reported for both the baseline and CMIN19 period was zero.

6.2.5 Commercial benefits

A key effect of both mission development and technology development contracts (i.e. those unconnected to specific missions) is to ensure there is a vibrant and high-quality space industry in the UK and in other ESA member states. The technological capabilities, skills and knowledge gained within contracts are expected to lead to new products and services for commercial and institutional space and downstream markets and entry into new markets (new sectors, new geographical regions) – and subsequent effects on sales and employment.

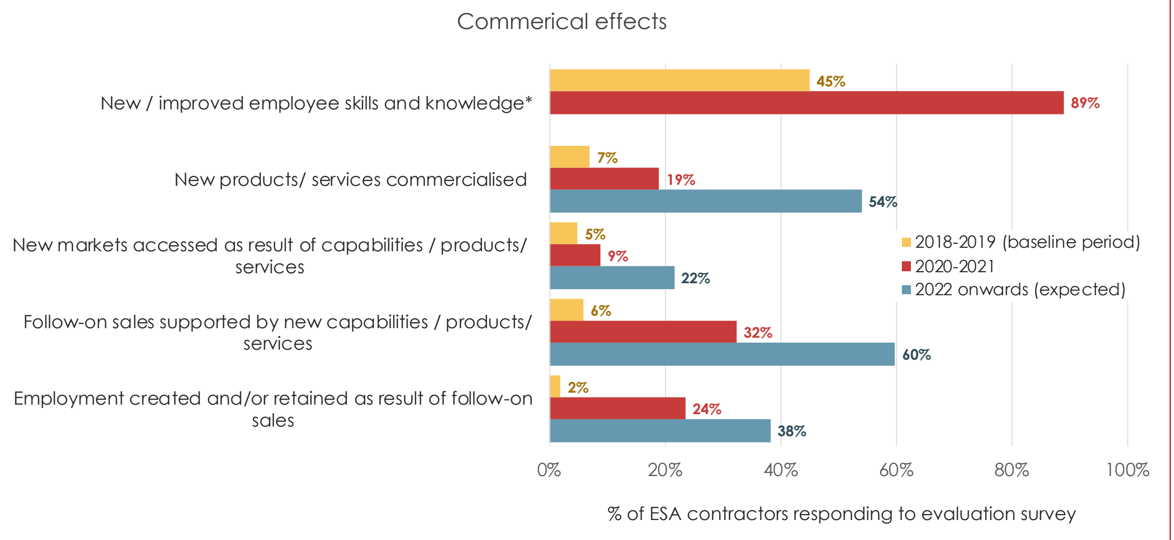
Figure 34 presents the proportion of all respondents that report positive commercial effects arising as a result of ESA contracts in five areas

- The greatest effect to date is in terms of new or improved employee skills and knowledge, 89% of contractors report having already achieved these effects here
- Other positive commercial effects have also already been achieved:
  - 19% have already commercialised new products or services and 54% expect to from 2022 onwards
  - 32% have achieved follow-on sales from their new capabilities, products and services and 60% expect to achieve this type benefit in the future (2022 onwards)
  - 24% have achieved employment benefits as result of follow-on sales and 38% expect employment benefits in the future
  - 9% have accessed new markets to date and 22% expecting to in future

In terms of the ToCs, the follow-on sales and the resulting employment effects are considered outcomes rather than outputs but as the five benefits are inter-related, it is informative to present them together. The next two sections present the survey data on numbers of new products and services and new markets accessed and the timings of benefits and the detailed economic analysis of the value of follow-on sales achieved are presented in section 10.

[43] Patent Cooperation Treaty

Figure 34 ESA contractors reporting commercial effects (N=102-110)*



ESA contractor survey *this question did not include the period for 2022 onwards

6.2.6 *Commercialisation of products and services*

This indicator provides a **count of new products and service commercialised** and expected to be commercialised as a result of ESA contracts, captured from the ESA contractors via the survey.

Table 35 Products / services commercialised

No. of products / services commercialised as a result of ESA contract(s)	2018-19	2020-2021	Expected from 2022 onwards	Total (exc. 2018-2019)
Science*	-	4	11	15
EO	2	8	20	30
HRE	1	2	9	12
TIA	6	24	69	99
GSTP	-	5	14	19
NAVISP	-	-	6	6
SSS	-	-	1	1
CSTS	-	-	-	-
Total	**9**	**43**	**130**	**182**

ESA contractor survey *includes one from OSIP

19% of contractors reported 43 new products and services commercialised to date (2020-201) under CMIN19 and 54% expect to do so from 2022 onwards, with a further 130 products and services expected. In terms of numbers of new commercialised products and services, the majority are reported to occur in the future (from 2022 onwards) – reflecting the fact that contracts are still running and that some further development work may be required post-contract to commercialise products and services.

- The majority of the actual and expected commercialised products and services (54%) reported are within the TIA domain which reflects that fact that it is more directly commercially focused than other programmes
- EO is responsible for 16% of commercialisations and Science and HRE together account for 14%
- GSTP, although a very small programme in terms of budget, is responsible for 11% of actual and expected commercialisations
- All but three respondents reporting were commercialised products and services were from industry.
- Responses to the invitation to provide further detail of the products and services, provided by 80% of respondents, suggests that around half of products and services were for the space market and 40% for downstream applications and the remainder for both (e.g. antennas).

6.2.7 *New markets accessed*

The commercialised products and services can support access to new markets, be that new geographic regions or sectors, and support the growth of the UK space sector. This indicator provides count of the number of new markets accessed as a result of ESA contracts, captured from the ESA contractors via the survey.

Table 36 New markets accessed

New markets accessed	**2018-2019**	**2020-2021**	**Expected 2022 onwards**
No. of new markets accessed (new overseas markets, new sectors)	11	39	196

ESA contractor survey

Table 37 New markets accessed

No. of new markets accessed as a result of ESA contract(s)	**2018-19**	**2020-2021**	**Expected 2022 onwards**	**Total** (exc 2018-2019)
Science*	-	1	25	26
EO	2	8	18	28
HRE	1	4	10	15
TIA	3	13	82	98
GSTP	5	10	50	65
NAVISP	-	3	11	14
SSS	-	-	-	-
CSTS	-	-	-	-
Total	**11**	**39**	**196**	**246**

ESA contractor survey (*includes 23 from OSIP)

9% of contractors reported accessing 39 new markets to date (2020-201) under CMIN19 and 22% expect to do so from 2022 onwards, with a further 196 new markets expected. The majority of new markets (by number) are reported to occur in the future (from 2022 onwards). As for the new products and services they are based on, this reflects the fact contracts are still running and that some further development work may be required post-contract to commercialise products and services and reach new markets.

- The majority of those reporting new market access were contractors in TIA, with 40% of all new markets accessed arising from TIA
- GSTP accounts for 26% of all new markets accessed with two organisations both reporting 20 new markets for their products. One of these is addressing future markets worldwide for manufacturing in microgravity. Another reported five new markets for technologies for 5G and LEO.
- All but three respondents were from industry.

Responses to the invitation to provide further detail of the markets accessed due to their ESA contracts:

- New expected geographical markets include: USA, EU, China, Japan, Singapore, Australia, New Zealand, South Africa, Malaysia and the Middle East and Africa
- New sectors, beyond space, include: automotive, autonomous vehicles, rail, telecommunications and renewable verticals, environmental analysis, critical infrastructure monitoring, agriculture,

6.2.8 Spin-outs

New concepts, technologies and innovations may lead to the creation of new spin-out businesses as a vehicle for their commercialisation. This may occur to explore and exploit new business models and market sectors outside of ESA contractors' core business.

This indicator captures the number of spin-outs arising from activities undertaken within ESA contracts plus the number of employees, revenue and investment achieved and expected.

Table 38 Spin-outs (All respondents, n=23-41)

Spin-outs	2018-2019	2020-2021	Expected 2022 onwards
No. of spin-outs	1	3	8
Total no. of employees working at these spin-outs (FTE)	2	24**	54**
Total investment raised by spin-outs (£m)	£15m*	£11m**	-
Total annual turnover of these spin-outs (£m)	-	-	£1.7m

ESA contractor survey (*the £15m was received by the one spin-out reported in 2018*19. **the £11m comprises: £10m to one spin-out and £1m to another. **Mean no. of employees is 8 (2020/21) and 13.5 (2022 onwards))

The three spin-outs have already been established as a result of contracts in the CMIN19 period, one each from TIA and GSTP one from the Open Space Innovation Platform (OSIP) – a programme funded from the ESA mandatory budget. One spin-out accounts for the majority of the investment achieved by the three spin-outs (£10m of the £11m). This is common in the distribution of investment in spin-outs, where a small number of companies receive large investment and the remainder receive much smaller amounts. This also means that tracking investment in spin-outs and start-ups can vary greatly year to year.

Respondents were invited to provide further details on the spin-outs in an open question. This revealed that the two spin-outs with large investments were the establishment of a UK subsidiary of a national (i.e. state-owned) European space company business and a joint venture between a UK and an overseas company. The future spin-outs are expected by large space companies and SMEs and address space technologies and applications. They are expected to arise as a result of several programmes – Science, HRE and EO in addition to TIA and GSTP.

6.2.9 *Reputational benefits and new strategic partnerships*

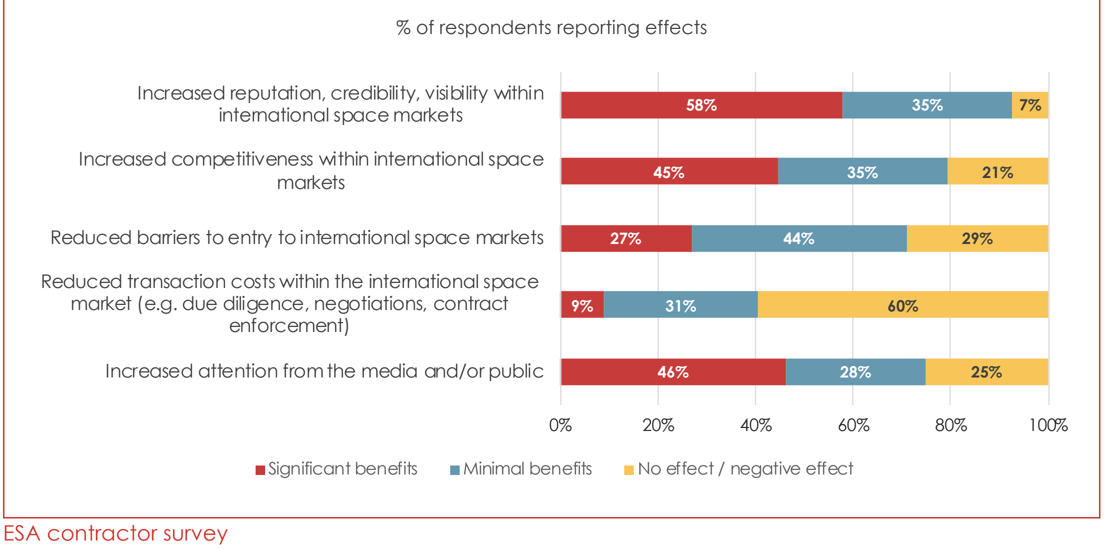
ESA contracts also have direct effects for contractors that are not directly technological or financial. The work undertaken within contracts may lead to new connections and networks and reputational benefits that may result in significant new partnerships – particularly internationally which are key to accessing wider space markets and export-led growth.

Around half of contractors report reputational effects (Figure 35): 58% of contractors report significant reputational benefits in international space markets and 44% report increased competitiveness in international space markets resulting from their CMIN19 ESA contracts. A smaller proportion, 27%, report reduced barriers to entry to international space markets and 46% report increased attention from the media and public

These reputational effects may lead to important new international partnerships with, for example customers and suppliers in space markets and with space agencies beyond the UK and ESA. 53% of contractors report gaining, or expecting to gain, new significant strategic international partnerships as a result of their ESA contracts in CMIN19 (Figure 36). 34% have achieved new partnerships to date and 37% expect from 2022 onwards. The majority of these partnerships are with other ESA member states.

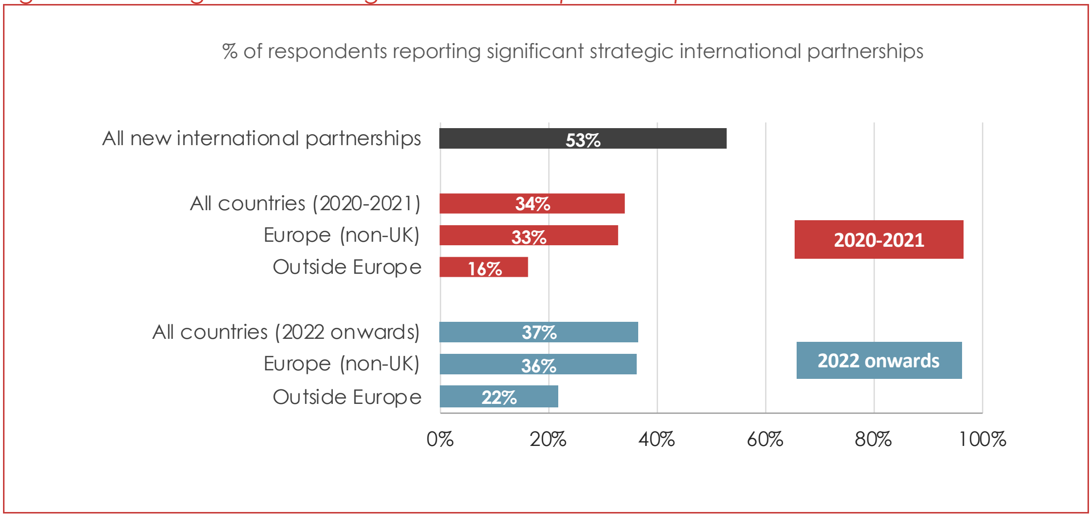
The additional details provided by respondents indicate that the majority of the new international strategic partnerships are commercial partnerships with customers within the supply-chain, so suggesting a high potential for future exports. One or two respondents reported new partnerships with academics, international NGOs and one with a non-UK space agency.

Figure 35 Reputational effects (N=76-78)



ESA contractor survey

Figure 36 New significant strategic international partnerships



ESA contractor survey

Table 39 provides details on the number of new international strategic partnerships achieved (or expected) with the majority arising from TIA and EO – the programmes with commercial opportunities and/or growth potential and commercially focused supply-chains. Importantly, this shows that although fewer contractors reported new international partnerships outside Europe, they reported higher numbers of new partnerships. Therefore both indicators are important.

Table 39 Number of new strategic partnerships by programme (n=43-56)

No. of new significant strategic international partnerships from ESA contracts since Jan 2021	**In Europe (non-UK)**		**Outside Europe**	
Programme	**2020-2021**	**Post-2021**	**2020-2021**	**Post-2021**
Science	17	7	1	0
EO	13	22	27	35
HRE	6	4	1	4
TIA	25	60	13	54
GSTP	6	10	5	10
NAVISP	2	3	-	1
SSS	2	6	-	3
CSTS	-	-	-	-
Total	**71**	**112**	**47**	**107**

ESA contractor survey

6.3 Outcomes (baseline)

Data for outcome indicators comes from a range of secondary data sources (plus some further indicators based on the ESA Contractor Survey) and captures effects at two levels. Firstly, the wider and longer-term effects for ESA contractors themselves and secondly, effects for the wider UK space sector. Comparing the data for both groups (where both are available) enables us to consider the extent to which sector level performance can be attributed to UK investments via ESA, if, for example, the scale of the effect for ESA contractors is similar in scale to sector level effects then sector level effects are likely to be attributable to ESA. In addition, we use the qualitative data from interviews and case studies to assess the attribution of outcome effects for the ESA contractors.

The data presented provides a baseline for the outcomes of CMIN19 for two reasons: because it is too soon for outcomes of CMIN19 to have been generated (see for example section 6.3.1); and because there are time lags in secondary sets i.e. it takes time for the dataset owners to collect data and make it available.

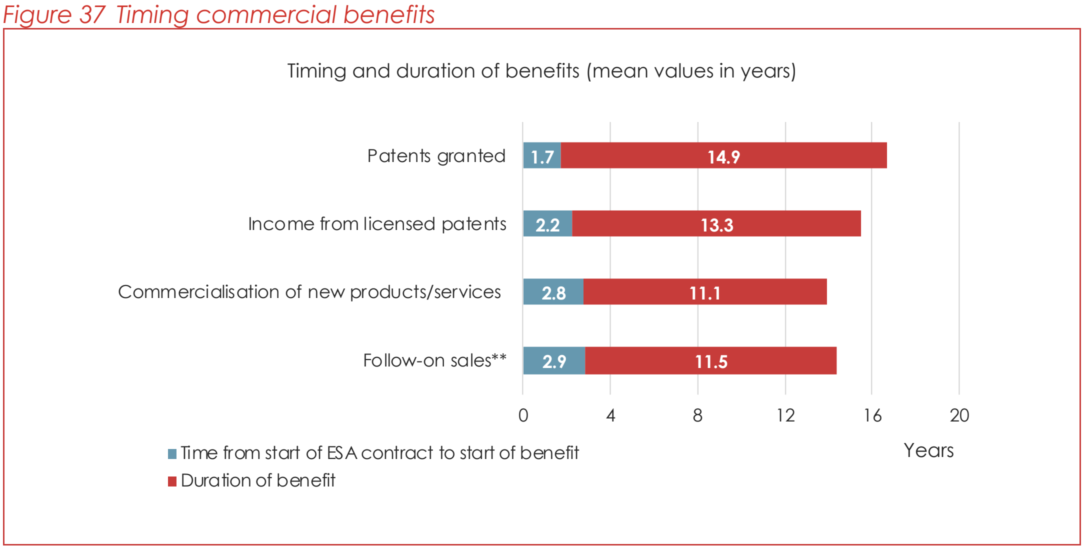
The data is presented at the level the portfolio of UK investments in ESA i.e. for all eight ESA programmes together. Data from secondary sources cannot be disaggregated at programme level as many space companies participate in more than programme and therefore any effects for individual companies, or collections of companies, would be the collective effect of all their ESA activities.

6.3.1 *Timing of commercial benefits*

We start this section with a consideration of the timescales to /duration of outcome benefits

- Commercialisation of products and services and follow-on sales occur, on average, just under 3 years from the start of a contract and last for around 11 years. The range of values reported is quite large, from 0-12 years for benefits to start and 2-50 years for duration (Figure 37). **This means that for current CMIN19 contracts, on average, the commercial outcomes will commence in 2023-2024 and, therefore some will start during the CMIN19 period but will continue into the next CMIN22 period and beyond.** Furthermore, many CMIN19 contracts have been let yet and will commence between 2022 and 2024, and therefore their outcomes will arise later still, not starting until 2027 at the earliest.
- Granted patents occur a little more quickly, on average 1.7 years from the start of contracts, with licensing following around six months later and benefits lasting, on average for 13-15 years. Again, the range of values reported is quite large, from 0-5 years for patents and 0-10 years for licensing benefits to start and 2-25 years for the duration of both. Given that it can typically take 2-3 years for a patent to be granted once the R&D work has been completed these timescales appear to be rather the low, suggesting patents may have been assigned to the current (and most recent) ESA contracts even though their development may have been supported, in part, by earlier ESA contracts. The patent and licensing benefits last for around 13-15 years, somewhat less than the maximum patent protection period of 20 years.

Figure 37 Timing commercial benefits



ESA contractor survey *Time from start of ESA contract to start of benefit **responses from industry only

6.3.2 *UK patents in the space domain (baseline)*

As shown above, patents will arise at various timescales after the start of ESA contracts. Here we present data on UK patenting activity[44] in the space domain for the ESA contractors and for the UK more widely for the period 2008 to 2019. To ensure the trend data is more representative of the pool of typical UK ESA contractors we included all companies with ESA contracts active in 2020 and up to Q2 2021 (that were identifiable as such in the ESA geo-return datasheet). This is a larger group of companies than those with ESA contracts starting after 1 Jan 2020. This data provides a baseline trend for patenting activity and not an assessment of the effects of CMIN19 investments.

ESA contractors were granted 10-30 space-related patents[45] a year in the period 2008-2019 (Figure 38) with the majority of these belonging to Airbus Defence and Space Ltd (82%) – the UK's largest space company and the recipient of 21% (by value) of the ESA contracts let to date under CMIN19. As a group, ESA contractors account for half (49%) of all space-related patents granted to UK organisations across the time period 2008-2019. While this does not mean that all patents are being generated from ESA contracts, it does indicate that ESA contractors are likely to be the innovators within the space industry. With 2-3 patents a year reported as due to ESA contracts (Table 34), these contracts may account for 5-10% of annual UK space-related patents. (This figure can only be taken as indicative as (i) the number of patents reported from ESA contracts is very small - one or two patents more or less would make a significant difference to the percentage (ii) and the wider trends in patent numbers are also variable.) Nevertheless, the knowledge, skills and capabilities developed under ESA contracts add to the stock of knowledge and enhance the level of capabilities in the space sector. They may also contribute to patents granted at a later date within the wider pool of patents granted to ESA contractors - but with no direct line of sight to the contracts themselves.

Worldwide, the UK accounts for 3% of space-related patents, ranking 7th behind the USA (which accounts for 52% of patents granted), Japan, China, Germany, France and the Republic of Korea (Figure 39). Patent numbers reached a fairly stable 40-50 patent families[46] per year during the period 2011 to 2015 followed by decline in 2016 to 2019, despite a peak in patent family applications. The drivers for this particular pattern is not known. However, where the decline in recent years is concerned, it is important to note that there is a considerable time lag between a patent application and its first appearance in the PATSAT database such that the most reliable data for is that up and including to 2017.[47] There is also a delay of 2.5 – 3 years (and sometimes longer) for a patent to be granted and therefore the data for granted patents in earlier years may also change in the future.

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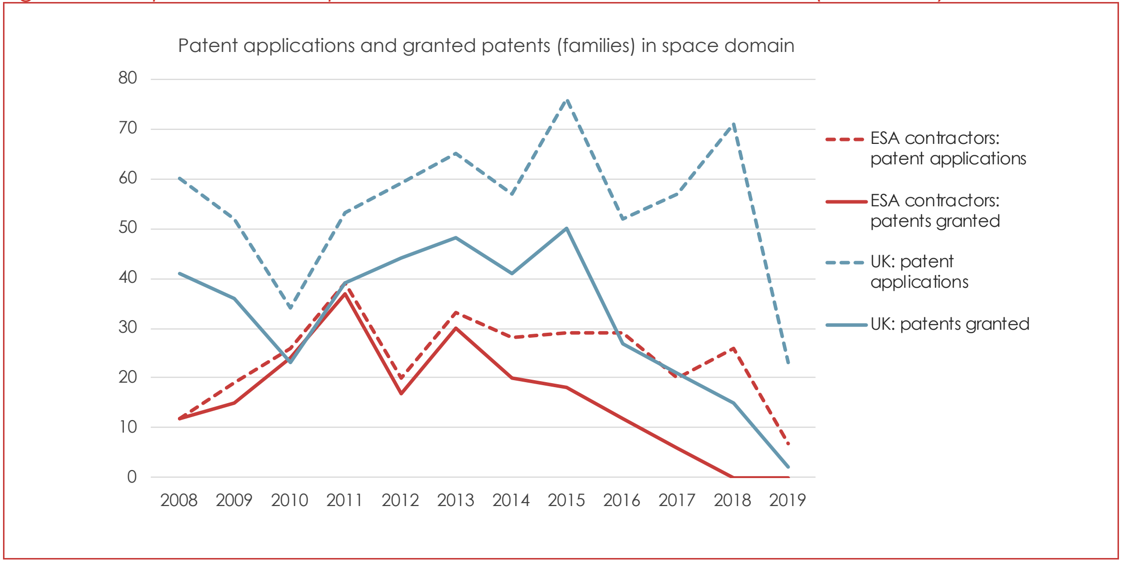
[44] "UK patenting" refers to patents applied for by, and granted to, UK organisations. The patents themselves may be filed in any geographical jurisdiction worldwide

[45] "Space-related patents" were identified by a combination of keyword searches and selection of relevant Cooperative Patent Classification (CPC) categorisations defined by the European Patent Office (EPO) and the US Patent and Trademark Office (USPTO)

[46] Data on patents and patent applications is reported as "patent families: rather than as individual patents or patent applications. A patent family is a series of patent applications related to the same technical content and the applications of a patent family are linked to each other through priority claims. Counting families is a better indicator of number of inventions than counting individual application/patents numbers.

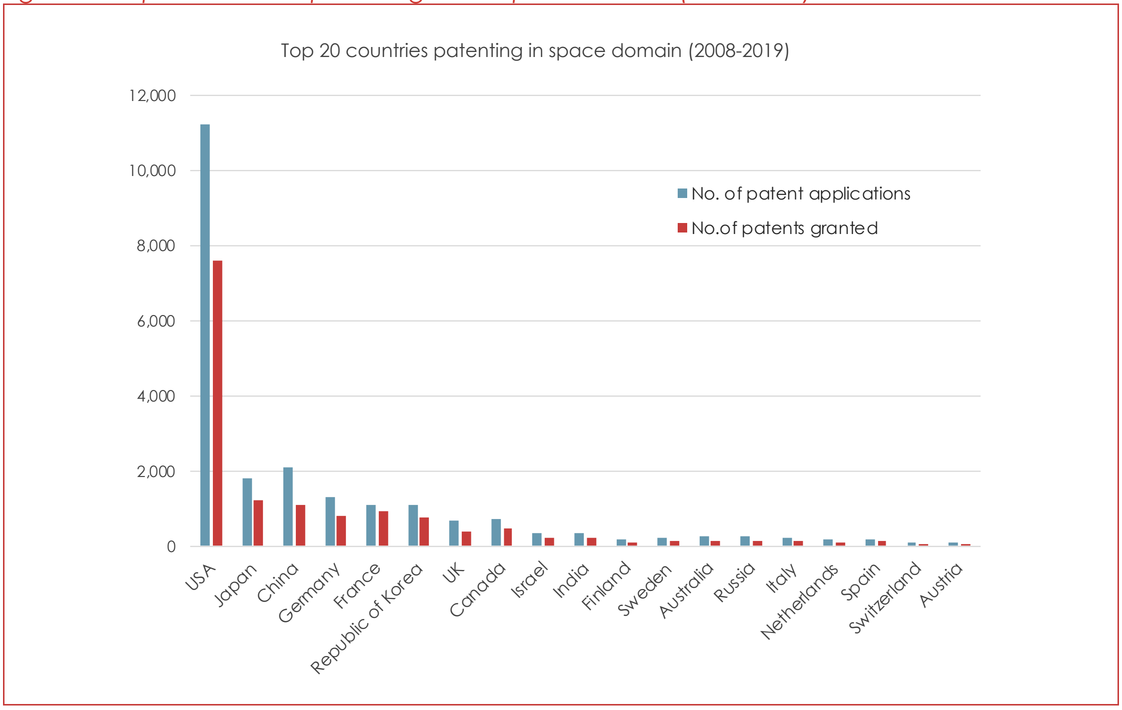
[47] There is a delay between the filing and publication of a patent application by patent offices. At the EPO this is 18 months, and 30-31 months for applications made through the PCT process. Once published, an application (and the subsequent patent) is dated in the database with their filing date. In addition, the PATSAT database is updated periodically; the data for this study was extracted in summer 2021 using the PATSAT Autumn 2020 edition

Figure 38 UK patents in the space domain: ESA contractors and all UK (2008-2019)



Science-Metrix (2021) / PATSAT

Figure 39 Top 20 countries patenting in the space domain (2008-2019)



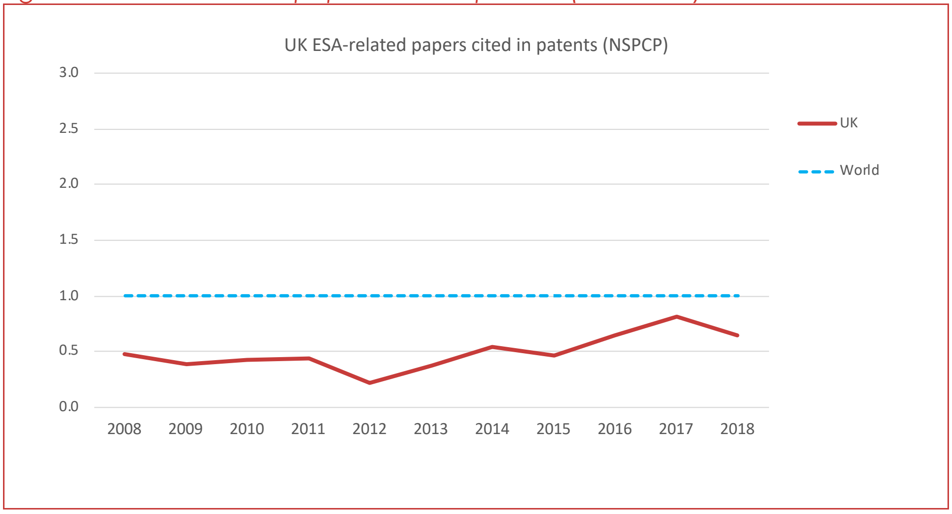
Science-Metrix (2021) / PATSAT

6.3.3 *ESA-related papers cited in patents in the space domain (baseline)*

The extent to which papers (in peer-reviewed journals) arising from ESA activities are cited in patent applications provides an indication that research outputs can be considered to be technology-relevant and have commercial potential and that knowledge transfer may have occurred or has the potential to occur. <u>This data is based on papers published from 2008-2018 and based on prior ESA investments and therefore the data provides a baseline trend for papers cited in patents and not an assessment of the effects of CMIN19 investments.</u>

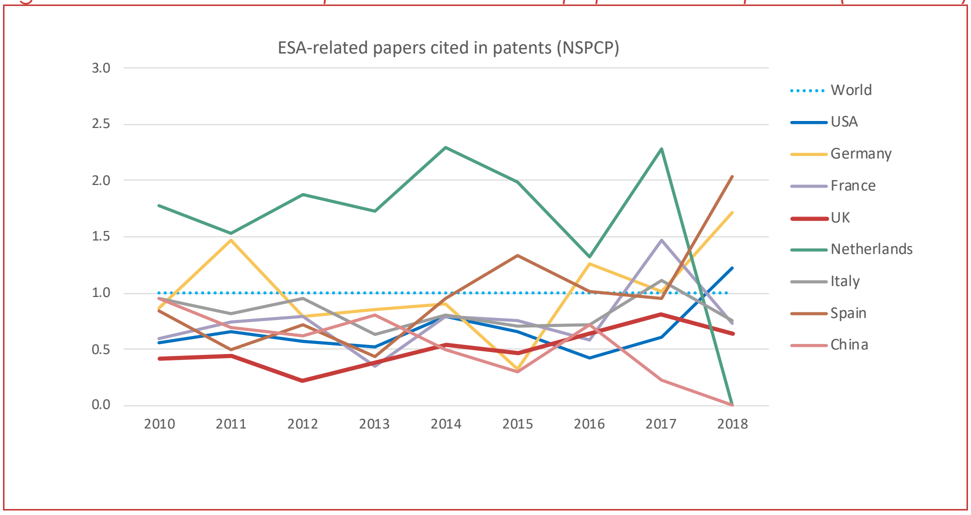
The UK performs below the world average in terms of its ESA-related papers cited in patents (Figure 40). Other key space nations such as USA, France and Italy also perform below the world average, with only the Netherlands (which includes the ESA ESTEC facility) consistently performing above it (Figure 40). The Netherlands has low number of patents, ranked 16th internationally, indicating that its papers are being utilised by other countries rather than in-country organisations.

Figure 40 UK ESA-related papers cited in patents (2008-2019)



Science-Metrix (2021) / Scopus / PATSAT

Figure 41 International comparison: ESA-related papers cited in patents (2008-2019)



Science-Metrix (2021) / Scopus / PATSAT

6.3.4 *Investment and growth (baseline)*

ESA contracts are expected to support the growth of space businesses through increased investment as well as via direct effects on revenue. The intention being that successful UK space businesses will be attractive to UK and overseas investors and a successful UK space sector will be an attractive location for subsidiaries of foreign-owned business.

We present data on investment in ESA contractors from the survey and from the business database Pitchbook.

6.3.4.1 Survey data on investment and growth

Just under half of two-thirds of survey respondents from industry (68%) reported investment and growth events in the past five years. Just over three-quarters of these were driven from within the UK (Table 40) and almost a quarter by driven by foreign direct investment (FDI). These types of events were more frequently reported by participants of the TIA, EO and GSTP programmes. These types of events are relatively infrequent and therefore a five-year time period was set to for the data. This means that some of the investment events may have taken place during the CMIN19 period and others during CMIN16 and therefore this data should be used as a baseline figure – ideally set to capture and present data for a rolling five-year period.

Table 40 Investment and growth events driven from UK

In the last 5 years, has your organisation...*	Respondents reporting effect (%)
Expanded its UK operations	39%
Received investment from UK sources (not including that from parent company or owner)	14%
Total UK-driven investment and growth activity	**52%**
Established a UK subsidiary	6%
Received investment from non-UK sources (not including from parent company or owner)	5%
Moved to the UK from abroad	6%
Total investment and growth activity driven by overseas sources (FDI)	**16%**

ESA contractor survey *only one response was allowed to this question

6.3.5 *Investment in ESA contractors*

The Pitchbook database provided data on investment activity for ESA contractors. Pitchbook captures data on all forms of investment deals and corporate financial activity. The database contains data from 2014-2021 (although the 2021 data is unlikely to be complete at this point in time) and is therefore is presented predominantly as a baseline. Investments made in 2020 and 2021 may have some attribution to CMIN1 investments and this is considered below.

To ensure the baseline is representative of the pool of typical UK ESA contractors we included all companies with ESA contracts active in 2020 and up to Q2 2021 (not just those starting in that time period). This is a larger group of companies to those with ESA contracts starting within the CMIN19 period. The data is presented in the figures below for four groups:

- All ESA contractors identified as holding active contracts in 2020 and up to Q2 2021[48] and divided into two sub-sets[49]
  - Upstream space companies - those manufacturing and operating space infrastructure and providing ancillary services
  - Downstream space companies – those providing products and services using space infrastructure and data

[48] Using ESA geo-return datasheet as of 2021 Q2

[49] We note that some companies do not neatly fit into 'upstream' and 'downstream' categories (e.g. companies procuring and operating new constellations and selling data services). Each company was assigned to one of the two categories on a case-by-case.

- Data is presented for all three groups (all contractors, upstream, downstream)

- We provide a further analysis for start-ups supported via the ESA Business Incubation Centres (BIC). These companies are not direct recipients of ESA contracts but receive ESA funding indirectly via the support and grants provided by the BICs

For each group we provide the total number and value of deals[50] and investment for

- Venture capital investment
- Private equity investment
- Corporate mergers and acquisitions
- IPOs
- Debt
- Grants

We also provide a separate chart of the venture capital investment as this is an important indicator for a healthy community of start-ups. The companies with the highest levels of VC investment are presented.

When interpreting the data it should be noted that Pitchbook database captures data for businesses with offices in the UK (whether they are UK or non-UK owned) and captures investment from any source and does not record geographical location of the investment.

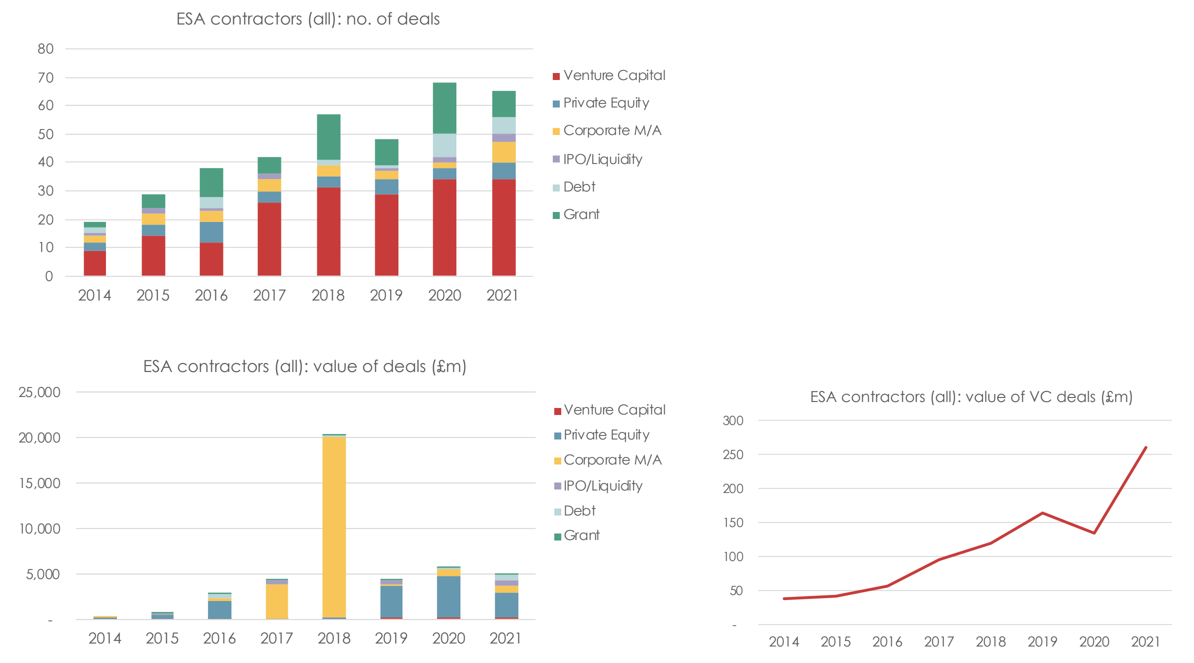
There has been a general upward trend in the number of deals over the period with an exception in 2019 when deal numbers declined. 2021 is currently a little below that of 2020 but the Pitchbook database will not yet have captured all activity in 2021 (Figure 42). It is important to note that the total value of deals is typically skewed by one or two large deals, often a single large private equity investment or corporate merger. The large spike in the data in 2018 in Figure 42 for example is largely due to a single £18m corporate merger. These deals involve large UK businesses that are active both in space and non-space sectors (e.g. BT, Atkins, BAE Systems, Rockwell Collins) as well as space businesses such as Inmarsat, OneWeb and MDA. The venture capital investment is more focused on space start-ups and SMEs. While downstream applications businesses have more deals across the time period than upstream businesses, the deals tend to be smaller in size than for the upstream companies (Figure 43).

The interviews suggest that some investments are linked, at least in part, to winning ESA contracts. This tends to be the case for smaller and younger companies where, as reported in section 6.2.9, winning an ESA contract provides a reputational gain and contributes to developing investor confidence. However not all investments will be a result of ESA contracts neither will a single investment be wholly attributable to ESA contracts as investors take many factors into consideration. Nevertheless, timing-wise, reputational gains from winning CMIN19 ESA contracts in 2020-21 may have contributed to some of the investments made in 2020 and 2021, while other investments may arise after contracts have delivered new capabilities and technologies. **Therefore, it is reasonable to consider data from 2020 onwards as partially relevant to CMIN19 and, in the longer-term, investment can the captured and tracked annually for CMIN19 and subsequent CMIN periods.** Data for the earlier years (2014-2019) provides a baseline.

[50] Where the term 'deal' is used to cover all types of investment and corporate activity

All ESA contractors

Figure 42 Investment ESA contractors (all)



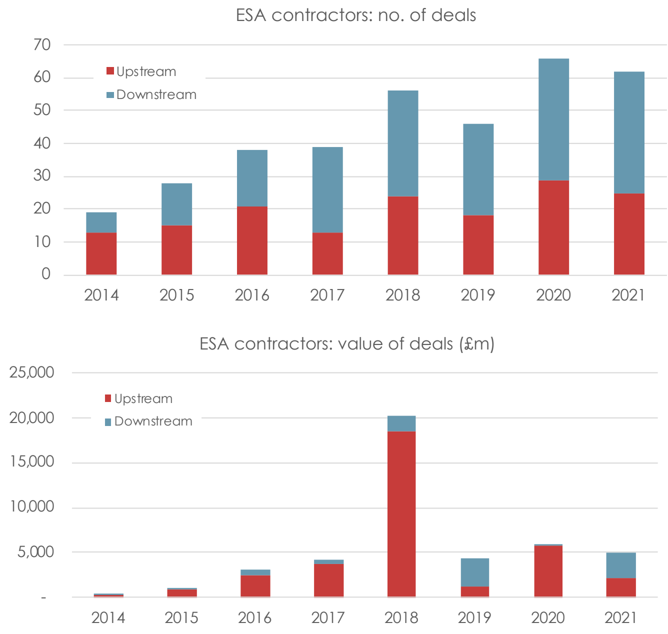
Technopolis (2021) / Pitchbook

Table 41 Deals over £500m (2014-2021): all space companies

Company	Year	Deal type	Value (£m)
Collins Aerospace	2018	Corporate M&A	18,207
Cobham	2020	Private equity	4,000
Atkins	2017	Corporate M&A	2,732
Inmarsat	2019	Private Equity	2,637
BT Group	2021	Private Equity	2,200
Interoute Communications	2018	Corporate M&A	1,663
OneWeb	2016	Private Equity	1,355
	2019	Private Equity	951
	2020	Corporate M&A	763
MDA	2020	IPO/ Private equity	615
	2021	Private equity	690
Teledyne e2v	2017	Corporate M&A	625

Technopolis (2021) / Pitchbook

Figure 43 Investment ESA contractors (upstream & downstream)



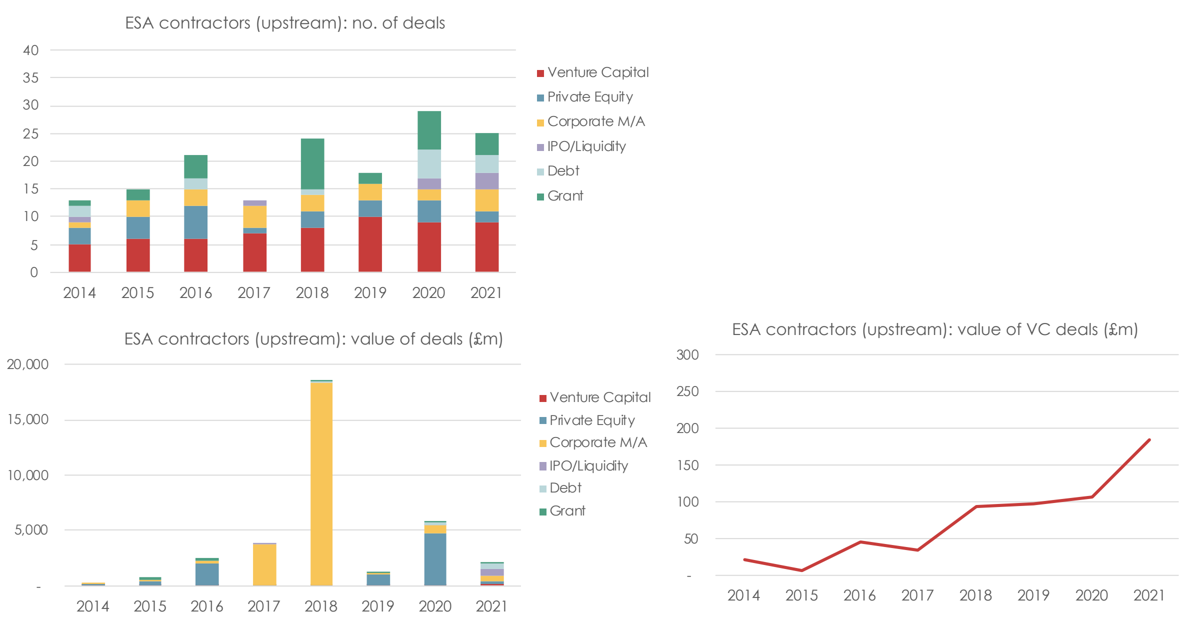
Total number of deals (2014-2021)	
Upstream	158
Downstream	196

Total value of deals (£m) (2014-2021)	
Upstream	34,742
Downstream	8,799

Technopolis (2021) / Pitchbook

ESA contractors: upstream

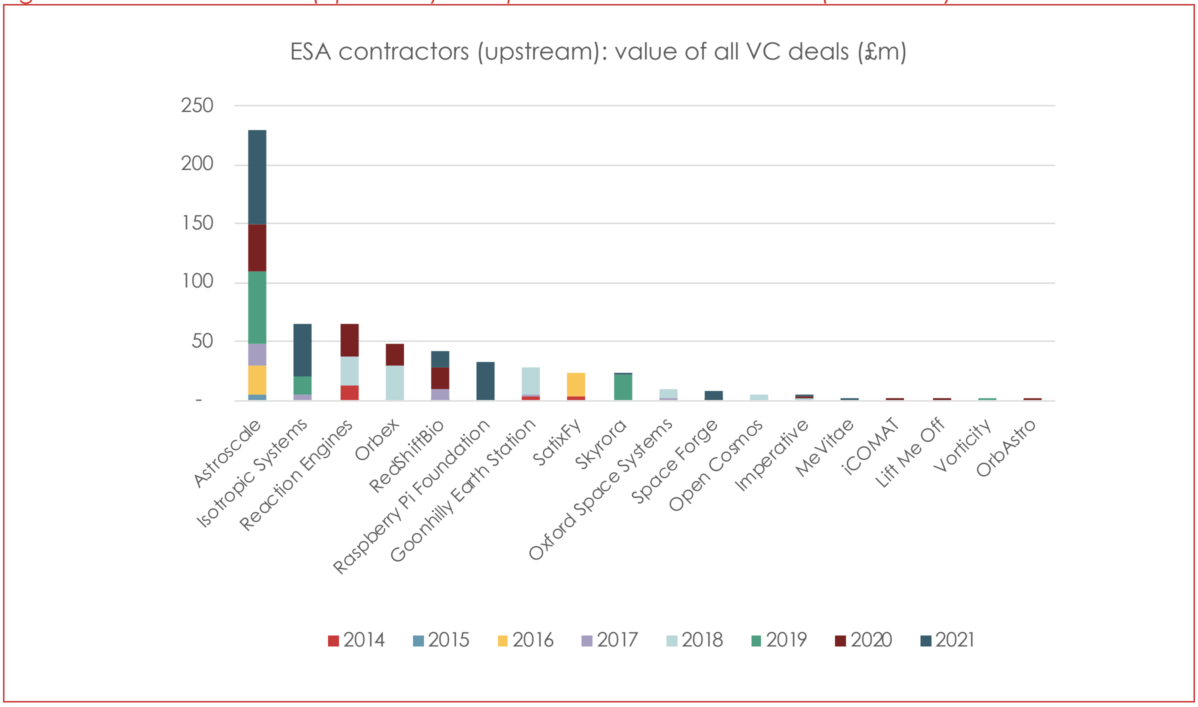
Figure 44 Investment ESA contractors (upstream)



Technopolis (2021) / Pitchbook

Figure 45 provides details of the companies receiving investment.

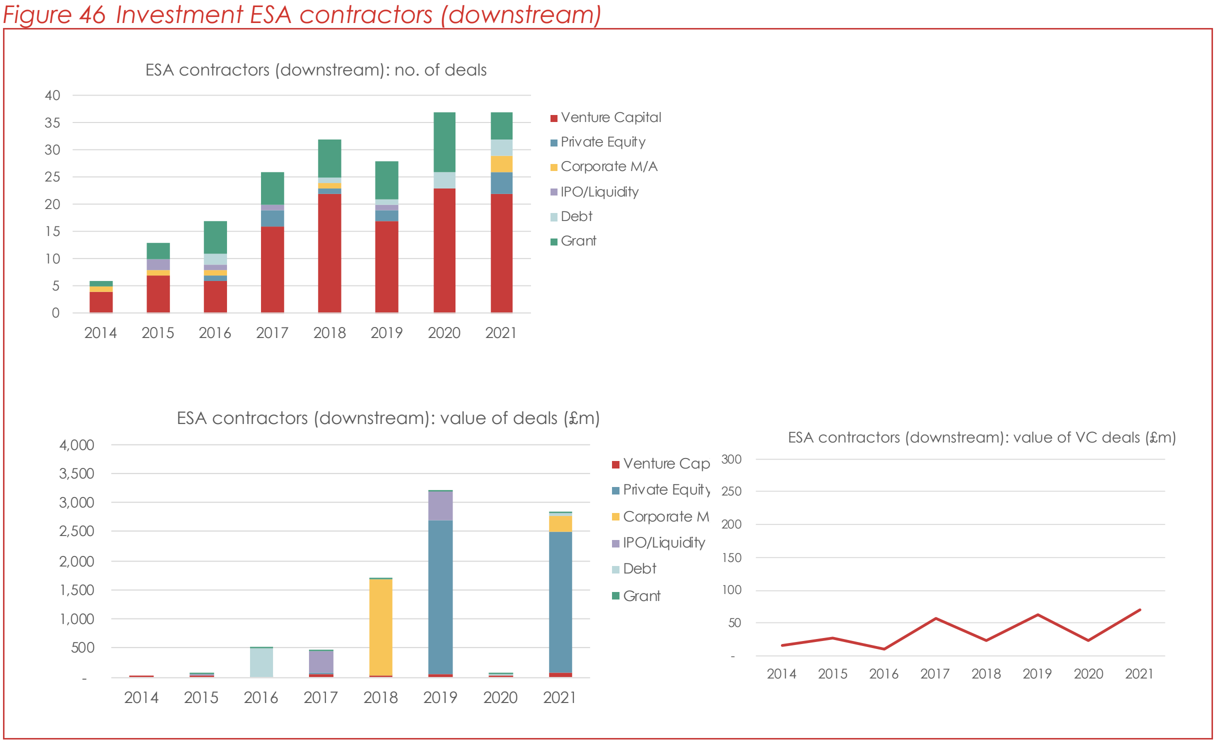
Figure 45 ESA contractors (upstream): companies with VC investment (2014-2021)



Technopolis (2021) / Pitchbook

ESA contractors: downstream

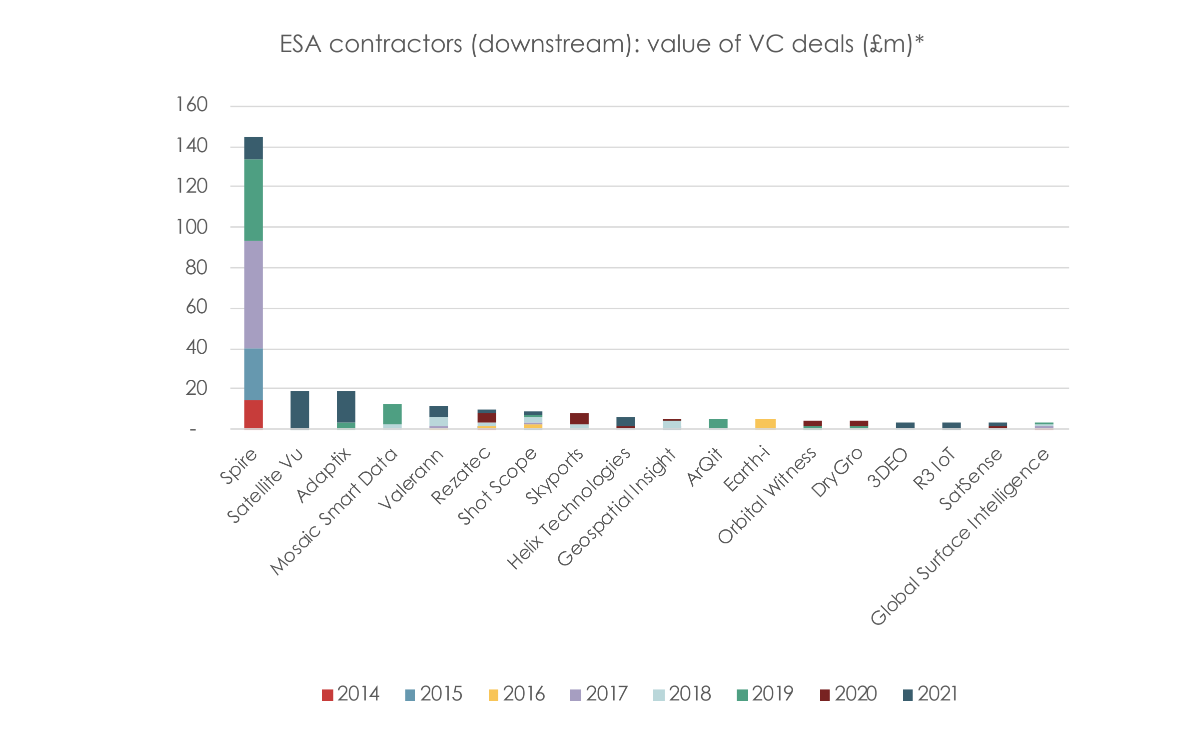
Figure 46 Investment ESA contractors (downstream)



Technopolis (2021) / Pitchbook

Figure 47 provides details of the companies receiving investment.

Figure 47 ESA contractors (downstream): companies with VC investment (2014-2021)

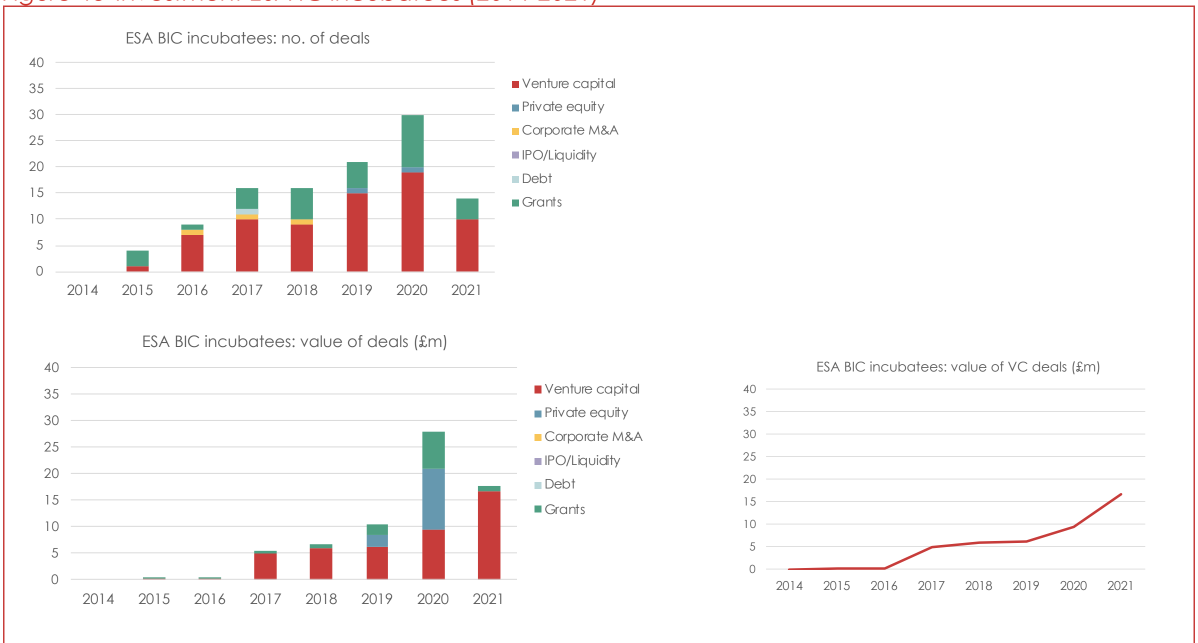


Technopolis (2021) / Pitchbook

ESA BIC incubatees

The figure below presents the investments for young companies that have been supported by the UK ESA BICs between 2014 and 2021.

Figure 48 Investment ESA IC incubatees (2014-2021)



Technopolis (2021) / Pitchbook

We were unable to make a robust comparison between investments in ESA contractors and investments in the wider UK space sector to determine the role and scale of ESA-related investment activity in the sector as a whole. There is no direct comparator source of investment data for the UK space industry – because there is no definitive definition of the 'space industry' (it does not have its own SIC code and many companies active in space are also active in other sectors) and therefore cannot be readily identified in datasets. Space investment trackers (e.g. the UKSA commissioned Size and Health of the UK Space Industry Reports, the Seraphim SpaceTech Venture Capital Index, know.space's tracker) use different data sources and methodologies to capture data and analyse data. And as one large investment will significantly skew the total investment figure, comparisons between the data sets are not robust.

6.3.6 *Effects on R&D investment (baseline)*

It is expected that public investment in R&D activities will crowd in private expenditure[51] and we asked ESA contractors to scale the influence of ESA funding on their internal R&D activities. Over 80% of respondents from industry provided information on R&D, with just over two-thirds of them (68%) reporting a significant effect on both the level of investment in, and content of, their R&D. Academics reported a slightly lesser effect on the content of their R&D. This question was intended to capture the current views of ESA contractors and provides valuable information in its own right – that ESA contracts have a considerable effect on R&D decisions - and can also be used as a baseline figure and tracked into the future. Where the former is concerned, the space sector is a high investor in R&D – the 2020 report on the Size and Health of the UK Space Industry,[52] reported £702m investment in R&D by the sector in 2018/19 and that 52% of this (£365m) and it is likely that some of this figure reported may refer to R&D supported by ESA contracts but this was not explored in this study.

Table 42 Influencing R&D investment

Have your ESA contracts influenced your internal R&D activities?		**To a significant extent**	**To a small extent**	**No effect**	**Negative effect**
Industry	Level of internal investment (n=82)	68%	22%	10%	-
	Content of R&D activities (n=80)	68%	23%	10%	-
Research organisations	Content of R&D activities (n=16)	56%	44%	-	-

ESA contractor survey

6.4 Usage and innovation benefits

Space infrastructure is intended be used for a wide range of commercial and social purposes, both thee uses intended from the outset (scientific research, meteorology, environmental monitoring, communications, navigation, etc) and innovative (downstream) applications using space data that are unknown when infrastructure is designed. Further innovation effects are generated when technologies and capabilities developed for space are transferred and used

[51] *The relationship between public and private R&D funding*, BEIS Research Paper Number 2020/010 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/897470/relationship-between-public-private-r-and-d-funding.pdf

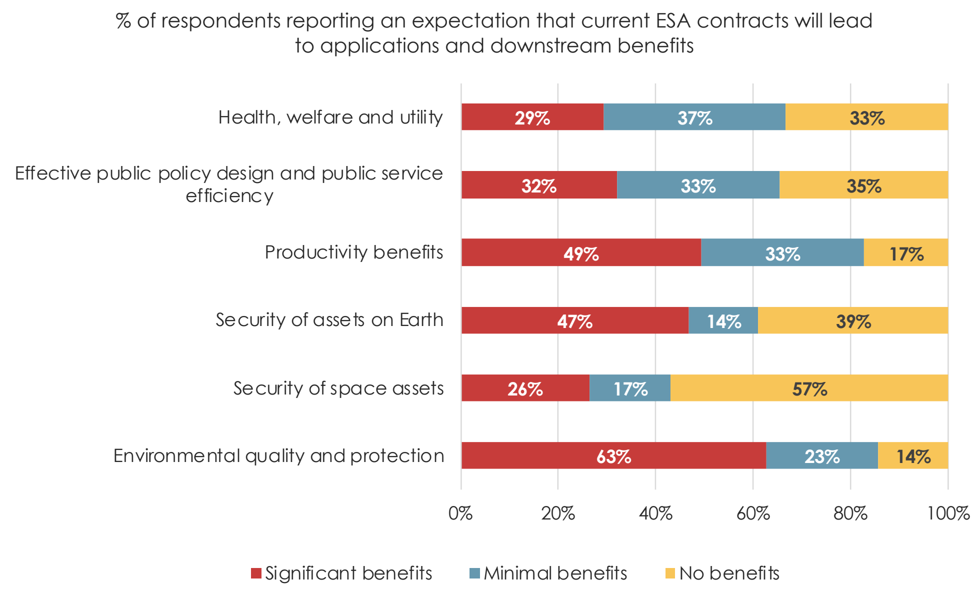
[52] UK Space Industry: size and health report, 2020, know-space for UKSA https://www.gov.uk/government/publications/uk-space-industry-size-and-health-report-2020

in other sectors. It is these usage and innovation spillover effects that generate the large returns from the public investments in space, but their very breadth and 'unknowability' in advance makes then a challenge to identify in their entirety.

By definition, usage benefits happen after missions are launched and operational and, for CMIN19 investments, benefits will occur on different timescales as the new ESA funded space infrastructures are at different stages of development. Some missions will be launched during CMIN19 (e.g. Solar Orbiter, Euclid, EarthCARE), some in the late 2020s (so in the next CMIN period and later) (e.g. TRUTHS, ARIEL) and others are still at the very early design stage (Athena, LISA). Commercial satellites (in SatComs mainly, but increasingly in EO) generally work on shorter timeframes but may make use of ESA technology development funding from several years earlier. Interviewees were consistent in their views that most space investments are long-term endeavours with considerable time lags to the generation of benefits. In addition, only 20-25% of the expected contracts in the CMIN19 period have been let, and so the majority of CMIN19 funding has yet to start generating outputs, and therefore outcomes and impacts are even further into the future.

This does not mean that there is not a high expectation of impacts in the future and ESA contractors provided information on the type of usage benefits they expect their contracts to lead to (Figure 49). 64% of respondents reported significant expected applications and downstream benefits in at least one of the benefit categories, with environmental protection the most frequently reported, followed by productivity benefits, security of assets on Earth.

Figure 49 Usage: expected applications and benefits (n=75-83)



ESA contractor survey

Table 43 Timing of outcomes benefits: new downstream applications

Timing and duration of applications and benefits from current ESA contracts	**Time from start of ESA contract to start of benefit (Mean) Years**	**Duration of benefit (Mean) Years**
New downstream applications	2.5 (range: 0-8 years)	8.9 (range: 3-20 years)

ESA contractor survey

ESA contractors reported a range of timescales to, and duration of, these benefits (Table 43), with a mean time to the start of outcome benefits (from the start of contract) of 2.5 years (range 0-8 years) and a duration of 8.9 years (range 3-20 years). The range of start dates reflects the fact that some applications are already being supported under the TIA Business Applications and Space Solutions (BASS) programme while others require missions to be launched. The BASS programme invests in the development of innovative applications (and demonstrates the potential) of existing operational space infrastructure and therefore provides an opportunity to explore the innovative downstream uses.

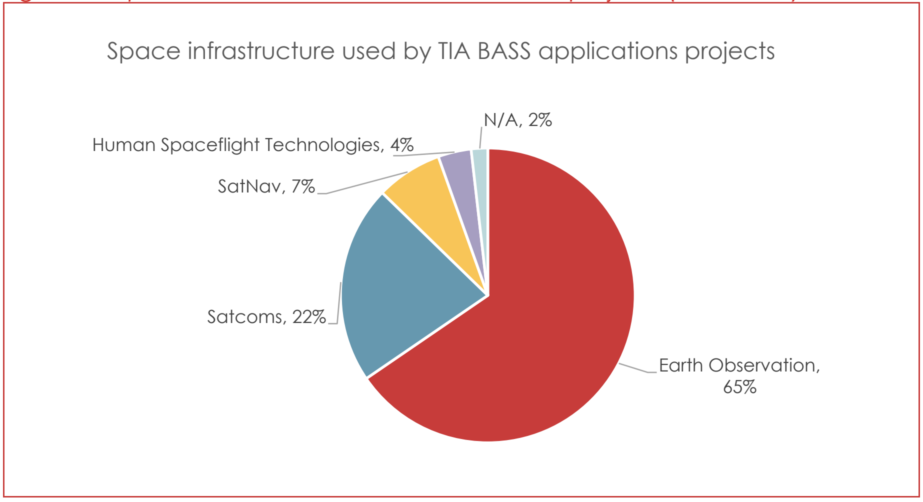
To date, under CMIN19, 59 BASS applications projects have been led by a UK organisation. BASS supports projects at different points in the innovation process and of the 59 projects, just under a quarter (22%) feasibility studies and half were demonstration projects looking to develop working prototypes. Another 19% of the projects were ‘kick-start activities’, exploring how space technology can link with or enhance online digital and data products by introducing new features and/or functionality to end users.[53]

- The majority of the applications projects (65%) are based on the use 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 (Figure 50)
- The products and services under development address a wide range of application areas (as identified and defined by ESA) (Table 44). 29% were focused on infrastructure and smart cities, 25% on environment, wildlife and natural resources, 15% in health, 14% in energy and 10% in food. Other projects have developed applications for areas from media to transport and finance.
- All projects were reviewed to identify the type of impact they can be expected to generate once deployed by intended users (Figure 51). All projects are developing products or services targeting economic impact, but many are also targeting environmental and wider social (health, improved public services, welfare benefits) impacts. Given the high usage of EO data it is unsurprising that environmental impacts feature highly.

Most of the benefits of BASS projects are in the future as the innovative products and services under development have not yet reached the market or have only reached one or two early adopters. Furthermore, as innovation projects not all will be commercially successful. Nevertheless, the BASS projects provide illustrations of the type of downstream products and services possible and will themselves reflect just a portion of the wider usage and innovation benefits.

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

Figure 50 Space infrastructure utilised in TIA BASS projects (2020-2021)



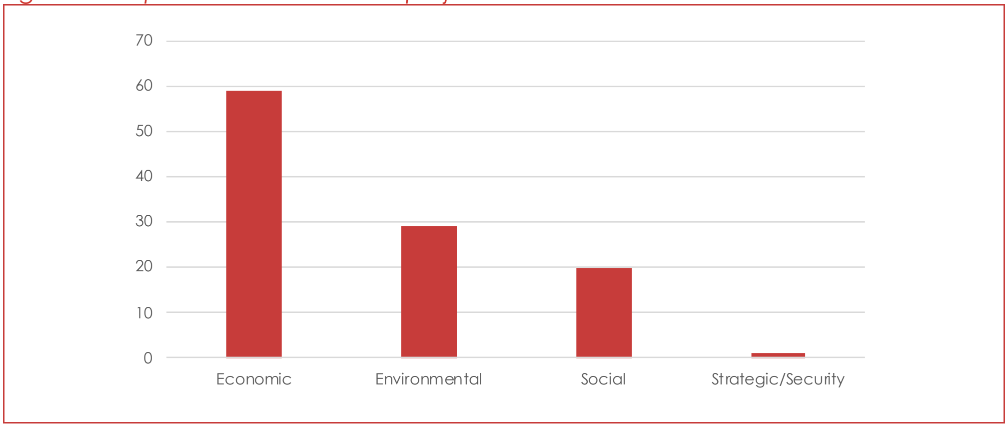
Technopolis (2022): Analysis of ESA website TIA applications case studies

Table 44 Thematic areas covered by TIA applications projects during CMIN19

Application area	No. of projects in application 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%

Technopolis (2022): Analysis of ESA website TIA applications case studies (n=59)
*each BASS project can address more than one thematic area

Figure 51 Impact domains of BASS projects



Technopolis 2022: ESA TIA data

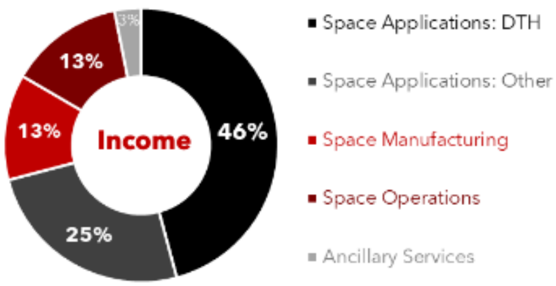
Taking a broader perspective on downstream applications, in 2018/2019 space applications generated revenue of £11.7bn in the UK - two-thirds of this comes from direct-to-home (DTH) broadcasting and the remainder from a wide range of application products and services (Figure 52). The non-DTH applications make a greater contribution to applications-related GVA than DTH (representing 35% of the applications income but 41% of GVA (Figure 53)). Some of these applications, but no means all, will be using ESA space infrastructure and technological developments and therefore attributable to prior ESA investments. Currently much, if not the majority, of EO data will be provided by satellites developed under the auspices of ESA so there will be a strong link back to the ESA investments. Satcom services on the other hand are largely provided on a commercial basis but may have benefited from ESA's support for satcom technology development. Understanding the extent scale of attribution would require some very detailed retrospective studies of current applications to historic ESA investments which was not the purpose of this study.

The data presented in Figure 52 also illustrates the scale of the value of applications compared to the manufacture and operation of space infrastructure.

Figure 52 UK space industry income by segment 2018/19

Segment	**2018/19 £m**
Space Applications	11,659
- DTH broadcasting	*7,533*
- Other applications	*4,126*
Space Operations	2,216
Space Manufacturing	2,052
Ancillary Services	514
Total	**16,440**

Source: know.space analysis



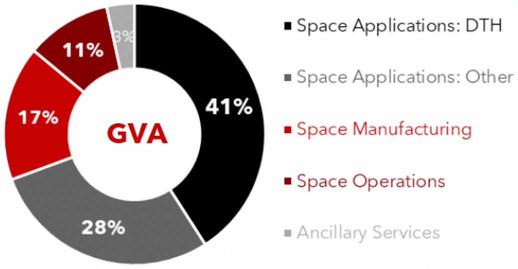
know.space (2020)[54]

[54] Size & Health of the UK Space Industry 2020, know.space, report for UKSA

Figure 53 UK space industry GVA by segment 2018/19

Segment	2018/19 £m
Space Applications	4,554
- DTH broadcasting	*2,679*
- Other applications	*1,864*
Space Manufacturing	1,090
Space Operations	690
Ancillary Services	225
Total	**6,559**

Source: know.space analysis



know.space (2020)[55]

6.5 Attribution and additionality

Innovation: outputs

The outputs reported by ESA contractors are in line with the expectations put forward in the portfolio and programme level ToCs and are a direct result of the activities undertaken within contracts and so are attributable to ESA contracts.

The mission-focused contracts are undertaking well-defined work for specific ESA purposes – i.e. ESA is procuring the development of spacecraft – and therefore the outputs generated have high additionality. The outputs would not be generated without ESA contracts and funding and there are currently no alternative sources of funding for this work and its outputs.

Where the longer-term, and more innovative and speculative, technology development work for future missions and commercial space activity is concerned, it might be considered that businesses might fund this work themselves or seek alternative public sources. However, the interviewees were clear that this work is either: targeting capabilities for future ESA missions and therefore would not be undertaken without ESA support; or is sufficiently risky RDI activity that they would need to seek alternative sources of public support. In the latter case, UKSA support (albeit at a lower level) is currently available and there is the potential to route all support for, for example, TIA-type activities via UKSA rather than ESA. However, this would reduce the more intangible outputs such as reputational benefits and networks and new collaborations, gained via working through ESA.

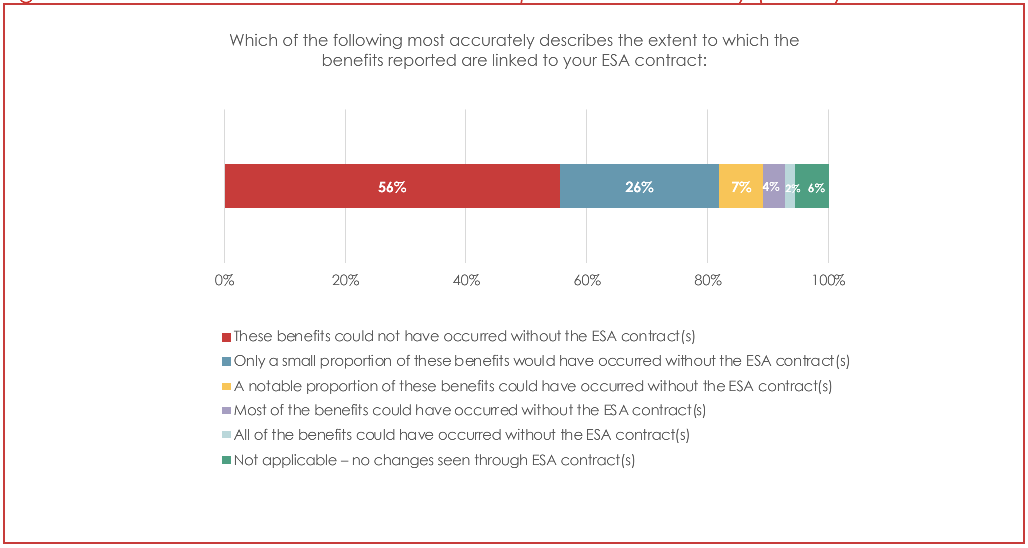
Innovation: outcomes

While there is some evidence **early outcomes for ESA contractors**, in the form of early sales of new products and services arising from ESA contracts and new markets accesses, the majority of innovation outcomes of CMIN19 investments are in the future. ESA contractors were able to estimate future outcomes in terms of sales and employment. They were asked to consider the extent to which these outcomes would have occurred without ESA investments (Figure 54). The self-reported approach revealed a high level of attribution and additionality to ESA investments. 56% reported that the benefits could not have occurred without the ESA contracts and a further 26% that only a small proportion of the benefits would have occurred without the

[55] Size & Health of the UK Space Industry 2020, know.space, report for UKSA

ESA contracts. This was corroborated by the interviews with ESA contractors - from an industry perspective, there are limited other forms of public support for RDI in the space domain, giving them limited alternative options to work on space technologies and applications. Interviewees noted the small scale of national funding for space activities whether from UKSA or other sources such as Innovate UK. As for the outputs, non-mission focused RDI activities could, in principle, be routed entirely via UKSA but interviewees were clear of the limitations of doing so – in particular the decreased opportunities to collaborate with ESA member states to acquire skills and capabilities, the lack of access to ESA technical and project management capabilities and reduced reputational benefits. (The issue of 'ESA added-value' is covered in more depth in chapter 9).

Figure 54 Views of UK ESA contractors: self-reported additionality (n=110)



ESA contractor survey

The majority of the wider innovation and usage outcomes and impacts - those based on the innovative products and services that make direct use of ESA space assets - are in the future. The pathways to impact for these expected outcomes and impacts were explored in the qualitative research. The qualitative data gathered from the interviews, case studies and examination of the programme ToCs at programme level indicated that the pathways to future innovative uses of ESA space infrastructure developed (in part) via CMIN19 are valid and the attribution of these outcomes and impacts to ESA investments will be variable and they will not be wholly additional.[56]

- Innovation products and services based on data generated by ESA space infrastructure are highly attributable to ESA investments in that they would not exist without access to the data and capabilities ESA provides. However, their development and commercialisation will be a result of a range of private and public investments and, in many cases, will integrate data from a range of sources, not just ESA assets, and so additionality will be partial.
- Innovation products and services whose development was funded by ESA or rely on commercial space capabilities whose development was supported by ESA (e.g. satellite communications) will have some attribution to ESA but again, their development and

[56] The ToC analyses and case studies are reported in the Impact Evaluation Report B

commercialisation will be result of a range of private and public investments and therefore their additionality to ESA investments will be partial.

- Wider economic or social impacts will arise (or are expected to arise) as a result of the use of innovative products and services discussed above. The intended end-users, be they businesses, consumers, public service providers or policy-makers, will have to expend further resources to adopt and utilise them. The use cases are expected to be highly varied from monitoring and tracking physical assets to precision-agriculture and monitoring climate change and biosystems.

While all the products and services and their applications will be ESA, the level of additionality will be highly dependent on the specific example and will depend for example, to the whether the ESA data being used are available are in the public domain or only to ESA member states, the relative scale (and value) of ESA data inputs compared to other data inputs, the relative scale of ESA support to the development of the capability/product/service. A selection of future applications of space infrastructure developed via CMIN19 investments will need to be case studied in detail to determine the extent of attribution and additionality.

7 Impact domain: Security and protection

7.1 Introduction

Participation in ESA is expected to provide the UK with increased security and protection via

- 'Security in space' in terms of access to space, a good regulatory environment, a resilient space sector and secure and resilient space assets in space especially where they provide critical national infrastructure (CNI)
- Enabling the design and delivery of effective public policy and efficient public services

This chapter presents the findings against the features above followed by a summary of the findings for the Space Safety and Security Programme (SSS) and Commercial Space Transportation Services (CSTS) programmes as these support key activities in security and protection.

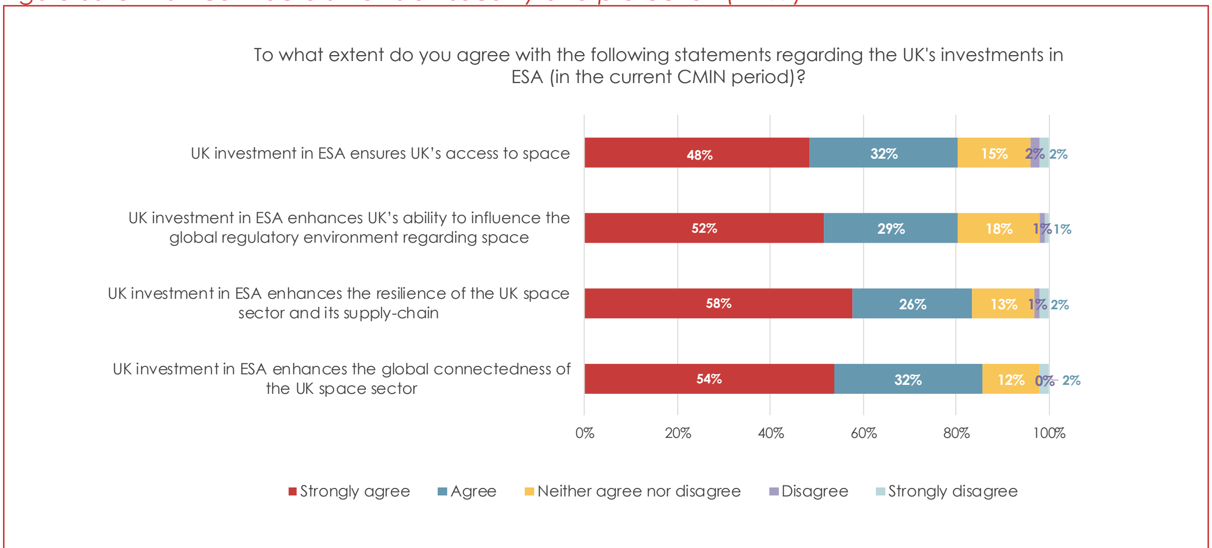
7.2 Outputs and outcomes

7.2.1 Access to space

Our interviews and survey found that the great majority of stakeholders consider that UK membership of ESA has assured UK access to space, through Europe's spaceport in French Guiana. While the UK has not separately funded ESA's big launcher programmes (e.g. Ariane), membership has provided direct access to this launch capability as well as a stronger basis from which negotiate competitive prices with other launch providers.

Under CMIN19, the UK has made a relatively significant new investment in the ESA CSTS programme, with a view to giving the UK launch industry improved access to technology, partners and international markets (section 7.4).

Figure 55 UK ESA contractors views on security and protection (N=97)



ESA contractor survey

7.2.2 Influencing the global regulatory environment

Our interviews and survey found that the great majority of stakeholders consider that UK membership of ESA has given greater weight to UK arguments / ambitions to extend and improve standards and regulations relating to space. Much of this success relates to technical standards, and contributors take the view that the work being performed through CMIN19 contracts continues to support these on-going activities.

The feedback also makes clear the UK is just one of many contributors in an increasingly important area of international cooperation and dialogue, and that this will remain an important line of activity in future, both within ESA and through the UN and various thematic and bilateral collaborations among governments, space agencies and leading institutions

ESA has been actively promoting European and international standardisation across most areas of technology development, operations and data for many years. It has helped create various overarching committees and the UK has been involved with the coordinators (deciding what to prioritise) and the individual technical committees working to define specific standards. Indirectly, and in the background, there is other work occurring through United Nations Office for Outer Space Affairs (UNOOSA) and even nationally, such as the UK space industry regulations 2020, that are looking to developing a more comprehensive legal framework for the use of space.[57][58]

The PWC review of main trends and challenges (2020)[59] suggests there will be competition between countries around the efficiency / stringency of national space laws (they suggest some countries will set a low bar, e.g. for licencing, so as to achieve a major competitive advantage). They also flag issues around the militarisation of space and the incompatibility of such developments with the main overarching international law, the Outer Space Treaty 1967 or the 2010 UNOOSA space debris mitigation guidelines. They suggest there is a need for new laws relating to human spaceflight and the colonisation of celestial bodies.[60] These are important concerns for the coming years and the UK plays a role at national level, however UK's level of influence in these regulatory activities is in part due to its role as leading member of ESA and its participation in, for example, debris removal and human spaceflight activities.

7.2.3 Resilience of the UK space sector and its supply chain

Our interviews and survey found that the great majority of stakeholders consider that UK membership of ESA has contributed to the resilience of the UK space sector.

All ESA programmes have provided substantial funding over many years to the UK's major space companies and their supply chains, attracting inward investment, retaining key actors and more generally catalysing an expansion in the national space economy of overall. CMIN19 investments are continuing to provide this baseload of technological development, supporting established markets and supporting the emergence of new industries in fields such as space weather forecasting and commercial launchers.

On the question of supply chains beyond the space sector, in 2020, ESA set up an TIA funding call relating to the convergence between satellites and 5G, initiated on behalf of the UK

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[57] The UK published an updated national space law (2020) - as have several other countries (e.g. Australia, Portugal in 2019) - and the UN (UN Office for Outer Space Affairs) published guidelines (soft law) in 2019 and the ITU world radiocommunication conference is also advocating new or enhanced standards to deal with the challenges of 5G or satellite coordination (for large constellations).

[58] The proceedings of the UN Committee on the Peaceful Uses of Outer Space (COPUOS) annual conference 2019 show the UK was one of several members involved in a discussion about long-term sustainability.

[59] Main Trends & Challenges in the Space Sector 2nd Edition, Dec 2020, PWC https://www.pwc.fr/fr/assets/files/pdf/2020/12/en-france-pwc-main-trends-and-challenges-in-the-space-sector.pdf

[60] There is a lot of space-related regulatory activity going on, mostly national but some international (https://www.twobirds.com/en/news/articles/2019/global/space-alert-review-of-the-key-legal-developments-for-the-space-sector-in-2019).

government (closed 29 January 2021).[61] Space-enabled technologies have the potential to improve the resilience of global supply chains by combining satellite communications, satellite navigation, and EO-derived services (e.g. weather forecasts) in order to increase supply chain connectivity and visibility on the one hand and optimising routing and cross-modal logistics. These qualities are increasingly important in a global world and can improve a system's ability to cope with sudden shocks or longer-run disruptions (like COVID).

7.2.4 Global connectedness of the UK space sector

Feedback from stakeholders was less clear cut on the link between ESA membership, CMIN19 and the improving global connectedness of the UK space sector.

Our desk research and case studies suggest that membership of ESA has had a positive impact on other spacefaring nation's perceptions of the UK space sector at governmental, industrial, and scientific levels. This is stronger in some areas than others: space science, satellite communications and EO, historically; however, the UK has taken a global lead in space weather and is collaborating closely with the US as well as with other ESA member states; and CMIN19 is expected to be an important bridgehead for international cooperation in the commercial launch markets.

7.2.5 Effective public policy and efficient public services

ESA invests heavily, particularly via the EO programme, in the development of infrastructure, data and services related to climate change, environmental protection, disaster mitigation and weather forecasting, and CMIN19 commitments are ensuring the UK's many regulators and environmental protection agencies are getting access to new applications and tools to improve their forecasts, planning, emergency response, etc. Past ESA-supported scientific and technological developments (in earlier CMIN periods) have been incorporated in various operational (rather than research) satellites and services, and perhaps most obviously the various Copernicus Services, such as the Copernicus Atmosphere Monitoring Service (CAMS) or The Copernicus Climate Change Service (C3S), both of which services are run by the ECMWF in Reading. Interviewees expect investments under CMIN19 to lead in the future to enhance existing policy-relevant services and capabilities and create new ones with these outcomes dependent on the launch of new space infrastructure.

Effective public policy in the UK also includes addressing the security of space and terrestrial assets in terms of the effects of space weather (an item on the BEIS risk register) and from space debris. These are specifically addressed by the ESA SSS programme reported below.

7.3 Space Safety and Security (SSS)

7.3.1 The Space Safety and Security (SSS) programme

The Space Safety and Security (SSS) programme is an optional ESA programme with three 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).

The UK has participated in the SSS programme since its inception in 2009 and safety and security issues have become more important in the interim, with the current SSS programme addressing several key objectives of the UK's National Space Strategy, including helping to address the

[61] https://business.esa.int/funding/invitation-to-tender/space-and-5g-convergence-transport-logistics

space weather risks outlined in the National Risk Register and improving debris mitigation and collision prevention.

The UK's contribution to the SSS programme, agreed at CMIN19, was €96.8m, representing nearly 13% of total UK investment in ESA for the period and 22% of the SSS programme budget making the UK the biggest contributor, ahead of Germany (€85.5m). The UK is participating in the programme's core activities and in three of its four cornerstone missions (Vigil, ADRIOS/CleanSpace-1, and CREAM), reflecting the relatively greater likelihood of major space weather or debris-related events. The UK chose not to participate in the planetary defence mission (HERA), because of the much lower risk of a severe asteroid impact.[62]

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,[63] and UK divisions of debris-removal companies Astroscale and ClearSpace have each won national funding to perform feasibility studies for a UK debris-removal mission.[64] In 2022, the UKSA has also committed £1.7m for 13 new projects to bolster the UK's national capabilities in the tracking and removal of debris.[65] Across ESA, the UK also participates in missions in other programme that have spillover impacts on space safety, particularly in the Science programme, such as 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).[66] Both these missions explore the Sun's impact on Earth. Astroscale UK also received £2.5m in funding from the TIA Sunrise programme.[67]

The outputs and outcomes detailed in the next sections are therefore best understood as pieces of the larger puzzle of realising the UK's space safety ambitions, to which SSS participation plays an important role.

7.3.2 SSS benefits

7.3.2.1 Space Weather

Because of the delay to Vigil, (formerly known as the Lagrange mission) most of the outputs from the CMIN19 space weather commitments are some way in the future. However, there are already-realised reputational gains for the UK within ESA and worldwide, and in further strengthening of the Met Office's pioneering space weather operations.

Vigil is expected to help maintain the UK's strong capabilities in this field, which track back to its involvement in building the instruments that feature on the STEREO and SOHO space weather missions. For the Met Office, ESA space weather funding is supporting their strategic commitment to be one of the key global players in space weather forecasting services.[68] Contractors such as the Met Office, RAL Space and others expect to see an increase in income – and employment – relating to space weather, as a result of CMIN19 contracts. The UK's commitment to space weather has led to the UK having increased influence over the space

[62] UKSA SSS business case

[63] https://gtr.ukri.org/projects?ref=104193

[64] https://spacenews.com/uk-funds-studies-to-remove-two-spacecraft-from-leo/

[65] https://www.gov.uk/government/news/new-funding-to-support-sustainable-future-of-space

[66] https://www.thalesgroup.com/en/worldwide/space/press-release/thales-alenia-space-signs-contract-european-space-agency-design

[67] https://astroscale.com/astroscale-uk-signs-2-5-million-agreement-to-develop-space-debris-removal-technology-innovations-with-oneweb/

[68] UKSA Business Case

weather agenda within ESA. Furthermore, Vigil will strengthen the UK's relationship with NASA and the NOAA.

Vigil will provide a substantial upgrade to space weather forecasting capability globally, which should result in additional commercial benefits – with the UK Met Office being one of the leaders in this market – and improved protection of assets and avoided losses. 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.[69,70]

Once Vigil has launched, there will also be a significant scientific output from exploiting the data from the mission. As a point of reference, the space weather mission STEREO has supported over 400 publications in the 15 years since its launch in 2006.[71]

7.3.2.2 Debris & clean space

SSS also covers debris removal and clean space and CMIN19 investments are expected to deliver a range of different types of outputs, with ESA income helping UK-based specialist contractors expand their capacity and capability in this new and emerging market. The CMIN19 projects will support the progression of debris-removal technologies across the TRL spectrum, from proof of concept to fully demonstrated systems. Successful demonstrations of these novel technologies should trigger user interest and improve the potential for UK companies to address the global active debris removal and in-service services (ADR/IOS-M) market that is forecast to reach £3.2bn by 2030.[72]

Current CMIN19 debris-removal contracts awarded to UK companies should help to consolidate and extend UK leadership in the emerging ADR/IOS-M market.

Other contractors developing collision avoidance technologies with CMIN19 investments have led to the creation of new employment and are expecting to progress their solution system to a point that they can begin to look at selling the technology. They are projecting significant levels of sales of the collision avoidance technology on future satellite launches.

The ESA contracts are useful signals for investors and should improve the prospects for UK based companies to raise investment finance and build a stronger market position more quickly. Companies this domain have already raised investment and are continuing to do so.

Because of the risks from space debris to satellite services, there are major benefits to be realised by operators from improved 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.[73] Other satellite services that the UK rely on, such as satellite-based meteorological observations (possibly worth between £670m and £1bn annually)[74] could lose efficiency. Finally, there may be wider sustainability benefits of the UK's debris & clean space activity, supporting the transition to a more sustainable, circular space economy.

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69 https://www.youtube.com/watch?v=xc50DEr_GfU&t=52s

70 UK Space Safety Community Meeting: Part 1

71 https://www.stereo.rl.ac.uk/Documents/STEREO_publications.pdf

72 https://sa.catapult.org.uk/wp-content/uploads/2021/05/Catapult-Astroscale-Fairspace-Platform-for-Growth-report-final-27-05-21.pdf

73 https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/12/SDC8-paper12.pdf

74 https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/12/SDC8-paper12.pdf

7.4 Commercial Space Transportation Services (CSTS) / Boost!

7.4.1 Introduction

The UK has not traditionally invested in ESA launch programmes due to the considerable cost of programmes like Ariane and Vega. However, the key objective for the CSTS programme is much more in line with UK priorities - supporting the emergence of commercially viable, privately-led initiatives for space transportation services. As such, the UK has taken a leading position in CSTS from its inception at CMIN19. 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.
- Gaining technical assistance and expertise from ESA and participating member states to support the development of its national launch capabilities.
- Our discussions with UKSA also highlighted a core aim of the UK's subscription to the programme at CMIN19 is to ensure that US payloads are permitted to launch on UK launchers.

At CMIN19 the UK subscribed €15m into CSTS, representing just over a quarter (27%) of the total budget for CSTS. The UK is the second largest contributor to the programme after Germany (contributing 52%) and far ahead of Italy (3rd largest contributor, €5M). Moreover, UKSA expect leveraged private investment to at least match the CSTS public investment, providing a combined investment of more than €30m.

There are positive outputs already being seen where CSTS has played a role. These include:

- In terms of commercial progress, companies supported have raised $10s million series A VC funding and report that the CSTS contracts have played a key role to securing the capital
- Similarly, all of the CSTS contractors have hired relatively aggressively since receiving the ESA contracts, with tens of new employees, and expectations for hundreds more
- CSTS is also making an important contribution to levelling up, where new facilities and jobs are being created in Wales, Scotland and 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

7.4.2 CSTS benefits

Increased global influence

Participation in CSTS is already helping to raise the profile and influence of the UK. The UK wants to use UK launchers for ESA missions, and the UKSA is using its voice in CSTS to push that agenda. Being part of 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.

The programme was described to us as "win-win" for both the UK and ESA. For the UK, it develops competences, attracts investment and develops resilience, while for ESA there will be benefits for the wider space ecosystem if it brings launch costs.

Increased prosperity & scientific knowledge

For ESA contractors there is a stamp of approval 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, helping attract new business.

Companies have plans for new product and service offerings, which could have strong commercial benefits, with CSTS funding enabling this. The programme is expected to help grow the UK space industry through its role as part of the national launch endeavour helping to deliver new, high-skill jobs and economic activity.

The programme could have significant benefits in terms of global connectedness through improved access to US and European markets. This market access point is an underpinning rationale for UK involvement in the programme at CMIN19.

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 and fast return to Earth. 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.

Users, adopters, and the wider space community

CSTS funding is expected to ensure UK launch emerges as a functional system – in turn enabling the wider benefits through better/cheaper services from space once launch capabilities are established. Recent analysis of the UK launch market 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.[75]

In the longer term, CSTS is expected to come together with other national launch activities to deliver defence and security impacts whereby an indigenous launch capability has strategic value for military and other institutional purposes (e.g. CNI resilience), reducing reliance on other countries. Lastly, there are also expected sustainability impacts whereby CSTS solutions may create the ability to return assets from space and re-launch, rather than having to manufacture from afresh.

7.5 Attribution and additionality

The UK's ability to ensure security of our space assets and protect terrestrial assets is highly attributable to UK's participation in ESA. The problems and solutions of space weather, space debris and environmental protection are global and the UK's ability to protect itself is part of a collective effort at the European and global level. UK's leadership in space weather to date is highly dependent both on the skills, capabilities and reputation of key UK organisations (such as the Met Office) and on our participation in ESA. It is too costly to develop a space weather mission alone and UK leadership would be lost without ESA backing. The entrepreneurial clean skies businesses benefit not only ESA funding, which could be directed to them without ESA, but also on the ESA 'brand', it's seal of approval for technical and professional quality. This gives them credibility with investors and with international markets.

While the UK is developing its own national launch capability, this will not provide access to space for all our space priorities. Space missions, some EO missions, exploration activities and even the space weather Vigil mission require the capabilities of ESA's spaceport or international equivalents. And access to the CSTS programme, while not essential to national efforts, provides access to considerable technical knowledge and experience and helps to accelerate the development UK's capabilities.

[75] Know.space & NSR (2021), *UK Satellite Launch Market Study*

8 Impact domain: Global influence

8.1 Introduction

Participation in ESA is expected to provide the UK with international reputation and influence within the international space community (both in Europe and globally) with its position as a technologically advanced, leading space-faring nation contributing to the UK's reputation and influence in wider international relations and commerce.

Issues of reputation and influence are subtle and nuanced and not readily measured or quantified, therefore the thematic strand of the ToC is treated largely qualitatively based on evidence from desk research, secondary sources and primary research from interviews and case studies.

8.2 Outputs and outcomes

8.2.1 Political Leadership in ESA

As the fourth largest investor in ESA (among 22 full MS) contributing 10% to the total ESA budget, the UK has considerable influence within ESA. It is among the small number of countries that are home to space primes able to manufacture and/or operate the large-scale complex spacecraft for science, EO and HRE missions and satellite communication capabilities and home to a strong scientific community that is highly active in designing, proposing and leading scientific activities – which provides the technical and commercial knowledge to have its views heard and appropriately influence decisions.

The UK is represented by a UKSA member of staff on all the relevant ESA Plenary and Programme Boards where strategic and financial decisions are made (Table 45). It has specific leadership roles as chair of the Industrial Policy Committee (IPC) and chair of the sub-group 'Exploration and Utilisation Board' of the Programme Board for Human Spaceflight, Microgravity and Exploration (PB-HME).

The IPC is responsible for defining, implementing and monitoring ESA's industrial policy including geo-return, supporting SMEs, monitoring industrial trends and approving contract proposals submitted to it (such as those under the applications programme within TIA). It also performs a number of co-ordination and harmonisation tasks between European and national space activities.

UK influence is further extended through former UKA staff taking senior leadership roles within ESA (David Parker the former CEO of UKSA is the ESA Director of Human and Robotic Exploration) and other senior roles (e.g. a former Innovate UK staff member becoming Head of Space Solutions at ESA). Of course, people are recruited into these roles based on their individual skills and experience and are ESA employees and not UK representatives but nevertheless they bring deep knowledge of the capabilities and ways of working of UK space industry and the UK's public and private RDI ecosystem. Interviews reported that the UK's commercial culture and acumen is generally highly regarded within ESA, and its focus on commercial imperatives and operational efficiency may be challenging on occasions but are important. Reflecting this, the UK contributes 25% of the total budget of the TIA programme – the most commercially focused ESA programme – and as a large contributor has considerable influence.

Table 45 UK leadership role on ESA's decision-making bodies

ESA decision-making bodies	UK leadership
Plenary committees	
Science Programme Committee	UK co-chair of the science strategy development committee - for Voyage 2050 (UK academic)
Administrative and Finance Committee	
Industrial Policy Committee	Chaired by UK (UKSA staff member)
International Relations Board	
Programme Boards	
Joint Board on Communication Satellite Programme	
Launchers Programme Board	
Programme Board for Earth Observation	
Programme Board for Human Spaceflight Microgravity and Exploration	Sub-group: Exploration and Utilisation is chaired by UK (UKSA staff member)
Programme Board for Satellite Navigation	
Programme Board on Space Situational Awareness	
Programme Board for Space Transportation	

ESA/UKSA[76]

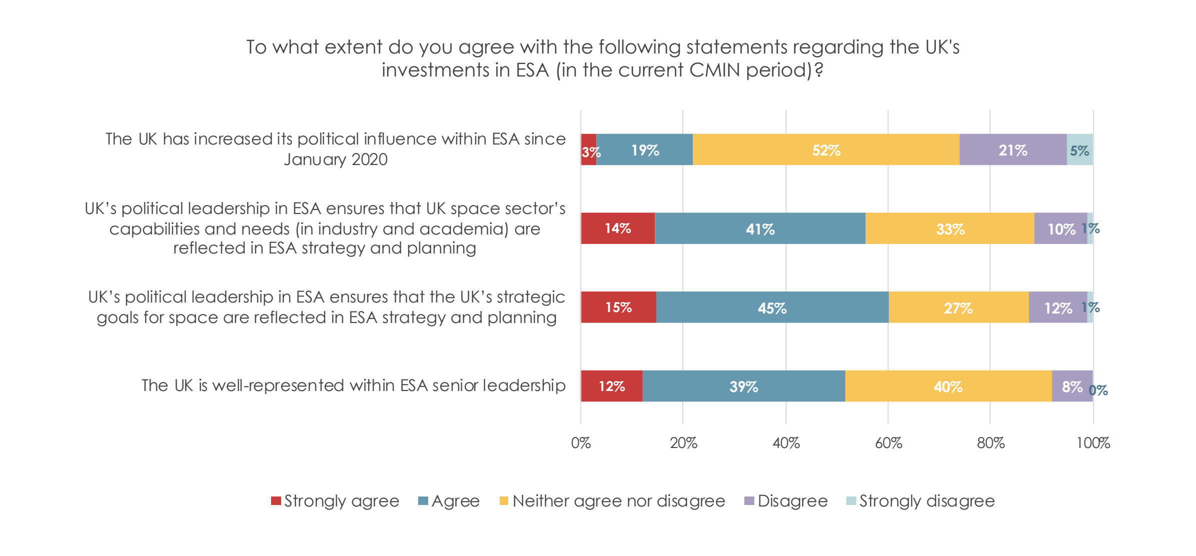
ESA contractors were asked for their views on UK's influence within ESA focused on the current CMIN investment period (Figure 56)

- 52% agreed or strongly agreed that the UK is well-represented within ESA senior leadership
- 56% agreed or strongly agreed that UK's political leadership in ESA ensures that the UK's space sector's capabilities and needs (in industry and academia) are reflected in ESA strategy and planning
- 60% agreed or strongly agreed that UK's political leadership in ESA ensures that the UK's strategic goals for space are reflected in ESA strategy and planning

Fewer respondents (22%) agreed or strongly agreed the UK has increased its political influence within ESA since January 2020. This is unsurprising as change in level of influence changes rather slowly particularly in the positive direction. Some interviewees expressed concern about Brexit effects, particularly regarding the Copernicus elements of the EO programme where the uncertainty about UK's participation is causing, not so much (as yet), a reduction in political influence, but a risk averse attitude amongst industrial partners in ESA MS being reluctant to partner with the UK on Copernicus related contracts.

[76] https://www.esa.int/About_Us/Law_at_ESA/ESA_s_organs_and_functioning

Figure 56 Views of UK ESA contractors: UK political influence (n=95-99)



ESA contractor survey

8.2.2 *Knowledge and technology leadership*

The UK is very well-regarded in knowledge and technology terms

- The bibliometric analysis in section 5.3 demonstrates the UK's strong scientific performance, with the highly cited papers (HCP) index providing a key comparator for the quality of our scientific knowledge. The UK outperforms all our European competitors for ESA-related papers considerably at the HCP10 level (papers in top 10% of highly cited papers) and marginally at the HCP5 level
- The UK plays a strong and often leading role in developing concepts for science missions and playing a leading role once selected, both in terms of designing the research and designing and building scientific instrumentation. In terms of CMIN19 UK researchers are principal investigators (PIs) or Co-investigator (Co-I) for the ARIEL (PI) and PLATO missions (Co-I) and built four of the 10 instruments on Solar Orbiter and is the lead for the TRUTHS EO mission
- A UK researcher was selected as co-chair of the ESA Voyage 2050 Senior Committee (Dr Chris Arridge of the University of Lancaster) tasked with developing ESA new strategy for space science diving ESA's science missions from 2035-2050. In an open call for members of the senior committee's Topical Teams, the UK fared extremely well in the selection processes, with 25% of the members (3 out of 12) on the sub-committee for Solar and Space Plasma Physics, 20% (3 out of 15 members) in Planetary Science and 30% (3 out of members, including the co-chair) in Cosmology, Astroparticle Physics and Fundamental Physics (Appendix H), suggesting that the UK's expertise and research interests will be well-catered for in the mandatory space science investments for many years to come.
- On the ESA advisory committees: the UK has three members (of 12) on the Space Science Advisory Committee (SSAC); two members (of 12) on the ESA Solar System and Exploration Working Group (SSEWG); two (of 10) on the ESA Human Spaceflight and Exploration Science Advisory Committee (HESAC); one (of 12) on the ESA Astronomy Working Group (AWG)
- A UK academic (Prof. Chris Rapley) chairs the European Space Sciences Committee (ESSC)

- At the industrial level, the UK is home to a large space manufacturing prime (and others are emerging) and a vibrant supply-chain that continuously develop new skills and capabilities to meet UK and ESA's needs, as well as an active innovative 'new space' community developing novel satellites and services for commercial purposes. Specific examples include the new in-situ resource utilisation and re-fuelling capabilities being developed for exploration and the UK lead in at least a third of TIA partnership projects being developed or planned from 2020-2023[77]
- However, the UK fares less well against the comparator countries in terms of patenting in the space domain (Figure 39)

ESA contractors were asked to report any international positions they hold on relevant committees or working groups. Very few were reported (most, where they did report, reported UK positions), the key instance of note being an academic who is a member of the AI Technical Committee of the Frontier Development Lab – public-private partnership with NASA and ESA and commercial organisations such as Google, IBM, Intel and challenge partners such as Lockheed Martin and the Mayo Clinic

8.2.3 Standards and regulation

As a leading space nation the UK is represented on relevant standards and regulation bodies:

- At an international level the UK is represented on, and was a founder member of, the UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) – established to govern the exploration and use of space for the benefit of all humanity: for peace, security and development and responsible for debate regarding international Space Law
- The UK has a voting position on the steering board of the European Cooperation of Space Standardisation along with France, Germany Italy, the Netherlands, ESA, and four industry representatives (Eurospace members).[78] The UK also has Technical Area responsibilities (both held by a UKSA member of staff) for two of the 30 technical areas (PA management and Quality assurance)

While these activities are the result of the UK's long-standing space activities and capabilities and not specifically related to the UK's investments in ESA or CMIN19 in particular, the UK voice has added weight with through its leading role within ESA. In the future, the UK's role in space weather and clean-space activities (via the ESA SSS programme and national activities) and its launch capabilities may increase its influence in standards and regulation.

8.2.4 International partnerships (institutional and commercial)

ESA contractors provided details of numerous new international strategic partnerships (section 6.2.9) in Europe and beyond Europe. The majority of these were commercial partnerships with customers within the supply-chains and just one reporting a new relationship with a non-UK space agency.

At the mission level, working with ESA, the UK is engaging with other space agencies such as SMILE with the Chinese National Space Administration and Lunar Gateway with NASA and JUICE with JAXA.

At a strategic level the UK is developing bi-lateral relationships beyond ESA, with Canada, Australia, the US and Japan (as listed in section 9.2).

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[77] https://artes.esa.int/partnership-projects

[78] https://ecss.nl/organization/steering-board/

8.3 Attribution and additionality

UK's global reputation and influence within European and within ESA itself is highly attributable and additional to UK's participation in ESA. UK positions within the ESA governance structure and in the delivery of contracts and operational space infrastructure provide a central 'meeting ground' for interaction and collaboration. Nevertheless, the UK's reputation is also built on the successful innovative and entrepreneurial space industry eco-system in the UK. These two factors are very closely entwined and have developed in tandem over decades, including via ESA funding, and cannot be readily disentangled. Similarly on the wider international stage, given that the majority of UK's public civil space budget has been directed via ESA, our collaborative activities with agencies such as NASA and JAXA are, in the main, undertaken within ESA missions with bilateral interactions in a very few cases only.

9 ESA added value

9.1 Introduction

This section presents an overview of ESA added value, focusing on our qualitative research in the main when describing the principal benefits that motivate membership and have been reported repeatedly by all stakeholder groups.

Our interviews, surveys and literature reviews confirmed there is widespread agreement regarding the principal types of added value that derive from the UK's national membership of ESA. This is in comparison with the alternative of a larger, UK national space programme with more targeted international collaboration delivered through selected bilateral or multilateral missions with other national space agencies.

We have looked at issues of scale (indivisibility and affordability) replicability (technical capability and capacity) and industrial dynamism (inward investment and local agglomeration effects).

9.2 Scale and indivisibility

From the UK perspective, the first point of ESA added value relates to the scale of public investments in space and what economists refer to as the indivisibility of civil space. Individual space missions are developed over many years (10-20 years) and have development budgets running into the billions, before reaching an operational phase.

The already substantial costs of designing, developing, and operating individual space missions cannot be viewed in isolation, as they are reliant upon decades of capability development and wider capital investment in the coordination structures, facilities and infrastructure. These are large, cumulative investments that would be hugely costly to replicate at a national level, and such a strategy could take 10-20 years to implement fully and with questionable value for money in comparison with other national infrastructure priorities.

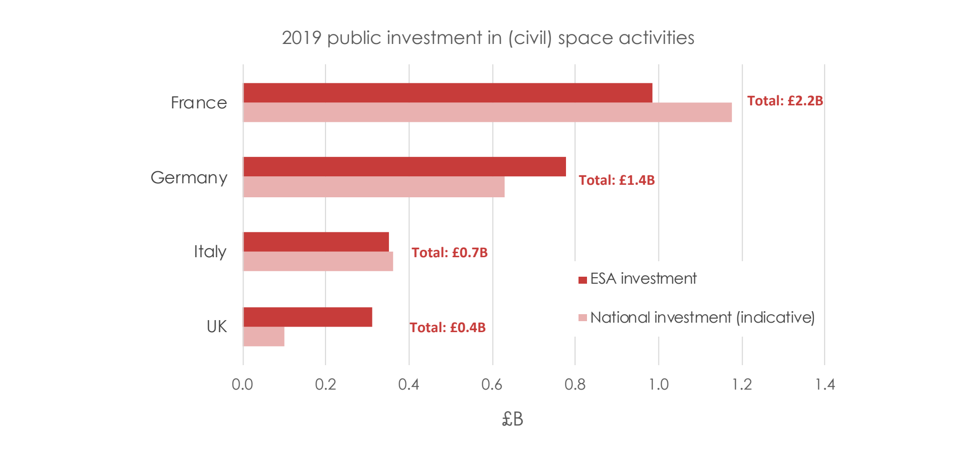
The large, minimum scale of space programmes is revealed in the size of the budgets of the major national spacefaring nations, whether that is NASA's $20bn annual budget or the China National Space Administration's (CNSA) $10bn annual budget. While NASA and ROSCOSMOS have been investing at scale for decades, there are several newer players that perhaps give a clearer sense of the scale of investment required to establish a globally significant national space agency: the Indian Space Research Organisation (ISRO), employed more than 17,000 people in 2021 and had an annual budget of around $1.8bn.[79]

Figure 57 compares the annual civil space budgets for the four biggest spenders in Europe, all of which are founder-members of ESA; with a longstanding commitment to international cooperation in space. Within this analysis, France stands apart from all other member states, even Germany, with an annual civil space budget of around €2.6bn, split 55% ESA / 45% national. CNES remains fully committed to ESA for both economic and strategic (i.e. independent space launch capability to protect Europe's sovereignty) reasons.[80]

[79] This scale of investment is all the more noteworthy when one considers that India is classified as a Low and Middle Income Country (LMIC) by the OECD Development Assistance Committee (DAC) making it eligible to receive official development assistance (ODA) from DAC members, including the UK (e.g. the FCDO provided around £100m in aid to India in 2021).

[80] https://france-science.com/en/cnes-in-2022-60-years-serving-french-and-european-space-sights-firmly-set-on-new-spaces/

Figure 57 Indicative national / ESA budgets for top 4 ESA contributors (2019)



Technopolis (2021)[81]

The withdrawal of the UK from the EU on 31 January 2020 has created a new strategic dynamic, that does challenge these largely economic considerations about scale. While ESA is not an EU institution, the EC has come to play an ever more important role in determining the agency's strategic priorities, which is impacting on UK participation in the Agency's Earth Observation and Navigation programmes. These two programme areas have a high degree of overlap with the EU's two flagship space programmes, Copernicus and Galileo, where ESA operates as the development and implementing agency. In the case of Copernicus (€5.8bn of the €14.8bn, 7-year EU space programme) the UK had agreed to participate in the programme as part of the EU-UK post-Brexit Trading and Cooperation agreement, however, the funding for Copernicus, together with the UK's participation in the Horizon Europe research programme, has since been blocked by the dispute over the Northern Ireland Protocol. For the EU navigation programmes, BREXIT brought an immediate exclusion and the UK no longer participates in the EU Galileo or EGNOS programmes.

These flagship EU space programmes provide a window onto the likely costs of establishing equivalent national space programmes, and the challenge such programmes would pose to stretched public finances. The UK government's initial plans to replace Galileo's Public Regulated Service — the encrypted part designed to guide missiles and plan military operations — with a domestic global alternative was estimated to cost £3bn-£5bn. The government launched the UK Global Navigation Satellite System (GNSS) pilot, which ended in September 2020 with the government deciding, it would be more cost-effective to continue to look at bilateral collaborations (e.g. including US GPS technology in UK satellites) and to explore new avenues. Specifically, the UK Space-Based Positioning Navigation and Timing Programme is exploring 'new and alternative ways' to deliver Position, Navigation and Timing services (PNT).

The various statistics on agency and programme funding suggest the UK's current levels of investment in civil space would need to increase several times over if the UK government were to decide to leave ESA and instead establish an internationally significant national space programme with sufficient breadth to fulfil national interests across the board, from space science to civil security.

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[81] ESA: https://www.esa.int/ESA_Multimedia/Images/2019/01/ESA_Budget_2019
National space budgets are provided as indicative figures only. They are from space agency annual reports and articles and may not be exactly comparable

While there are other possible permutations, our surveys and interviews suggest that membership of ESA remains the very best strategic option for UK international cooperation in space. There is a general sense that the UK will do more outside ESA in future, but that these more extensive activities will be additional and complementary to the UK's contributions to various ESA programmes. Moreover, ESA provides the UK with a route to global space missions, with China, Japan, Russia and the USA (e.g. the International Space Station; the Lunar Gateway; SMILE[82]). This is similar to the strategy followed by Italy, which has a more balanced funding profile across ESA and non-ESA programmes. Our interviewees suggested that Italy has lost ground in terms of its international standing in space, over the past 20 years in part as a result of this proportionately lower level of commitment to ESA.

This ESA-plus strategy was confirmed in the National Space Strategy. The UK Space Strategy 2021 is expected to be delivered through four pillars,[83] one of which is international collaboration. ESA remains at the centre of the country's global partnerships, as does the EU Space Programme under Horizon Europe, however there is also a commitment to expand selected additional bilateral and multilateral cooperation with Australia, Canada, Japan and the US. Most of these collaborations are small and exploratory in nature, involving budgetary commitments that are a tiny fraction (<1%) of UK investments in ESA:

- In October 2021, the UK signed a Memorandum of Understanding with the Canadian Space Agency, committing to working together on using space in vital and urgent areas, including helping to fight climate change, and setting up a framework for future collaboration on space science and exploration
- In February 2021, the UK and Australia signed a new 'Space Bridge' partnership to increase knowledge exchange and investment across the two countries' space sectors, with five collaborative research projects receiving a total of £250,000 from SmartSat CRC and the Satellite Applications Catapult, with the projects due to be completed by the end of June 2022[84]
- In 2020 the UK was one of eight countries to sign the Artemis Accords, a NASA-led initiative committed to returning humans to the Moon by 2025. The UK has reaffirmed its support for activities to develop the Lunar Gateway[85] and sending astronauts back to the Moon over the coming decade. Though it should be noted that UK's participation in the Lunar Gateway is undertaken via ESA
- The UK's International Bilateral Programme within the pathfinder National Space Innovation Programme has committed funding to projects directly with partners such as NASA and the Japanese space agency, JAXA

Lastly, another option would be to scale back support for various ESA optional programmes in order to help finance UK national space programmes that are more closely aligned with UK strategic priorities. As an aside, the UK and all other member states work together within the context of ESA's committees and programme boards to develop strategies, programme concepts, roadmaps and activities that reflect the interests of the whole community and not individual member states. This is true of any intergovernmental scientific organisation, and not just ESA: the UK government can no more write the strategy for the European Southern

[82] SMILE is a joint mission between ESA and the Chinese Academy of Sciences which aims to build a more complete understanding of the Sun-Earth connection

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

[84] https://www.gov.uk/government/news/successful-first-year-for-uk-australia-space-bridge

[85] Lunar Gateway - a small space station in lunar orbit intended to serve as a support hub for long-term return to the moon

Observatory (ESO) or European Molecular Biology Laboratory (EMBL) than it can the ESA EO strategy. It is a joint undertaking with negotiation and compromise. This is the trade-off for any single member state investing at 10% of the overall scale of investment necessary to set up and run the facilities and their associated science and technology programmes.

There are several downsides to a leaner strategy, which was the approach pursued in previous years, under the British National Space Centre (BNSC). The first difficulty is that the basic membership cost – for the basic operation of ESA and access to its various mandatory programmes – is high, and the UK would need to achieve a social return through a very much narrower programme window, dominated by science. The second and related challenge, would be the loss of the financial and capability-leverage realised through support for the main optional programmes, in areas of key strategic interest to the UK, from EO to SatComs and Safety. Moreover, the national commitments to the optional programmes would fall a long way short of what might be needed to create a national alternative. Overall, to pursue this more bespoke strategy, the UK government may have to increase the overall budget for the UKSA by a factor of two or more.

A third challenge is a loss of influence more generally in contributing to discussions about overall ESA priorities as well as the more immediate reduced access to programme-specific discussions. While many ESA (and other) space-related data are increasingly being made available through public access databases and free-of-charge services, the potential social value of such unpaid or under-paid access is likely to be compromised by an inability to direct ESA research to questions of particular interest to the UK scientific and industrial communities. UK science may struggle particularly with this outsider status, missing the opportunities to win the right to define key science projects and build instruments that reflect UK scientific agendas. Without the big missions, it is likely that the main science funders – STFC, NERC, EPSRC – would begin to prioritise other national research communities, possibly undermining the sustainability of UK space science broadly defined. This vulnerability would not easily be overcome by international cooperation either; there is very little prospect that NASA would give scientific leadership on key instruments to its partner countries, unless they were investing heavily and at an equivalent scale to the US.

9.3 ESA in-house coordination and technology capability

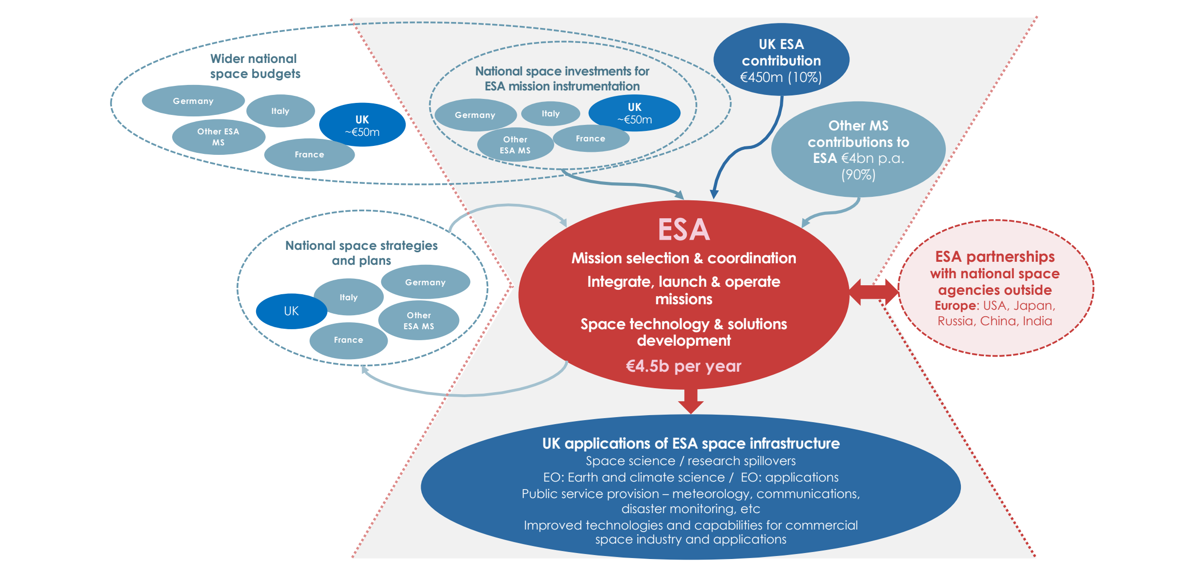
The second major source of added value relates to the strategic coordination and technical capability and capacity within ESA,[86] which far exceeds the capacity one might expect to establish in the UK.

ESA has established a series of coordination structures, planning protocols and strategic units that ensure it is able to draw up exciting, long-range programme proposals, medium term roadmaps and rational short-term programme priorities and investment plans. This capacity to coordinate and direct member states in the pursuit of a vision and related missions far exceeds anything any other European country has in place. It is value adding and takes substantial pressure of national space agencies, including UKSA. It would be challenging to replicate these international mechanisms within a national agency.

[86] ESA employs c. 2,500 staff around the world, most of whom are based at its main centres of excellence in Europe: ESA Headquarters in Paris; ESTEC (technology) in Noordwijk; ESRIN (Earth Observation) in Frascati; ESOC (operations) in Darmstadt; ESAC (astronauts) in Villanueva de la Cañada; ECSAT (Satcoms) in Harwell; and ESEC in Redu, Belgium. ESA staff are also based at several ground stations, offices and outposts worldwide, including Kouro in French Guiana (Europe's spaceport).

ESA's scientists and engineers are active participants in various development programmes, running major in-house projects as well as working in collaboration with the scientists and technologists working at its many contractors or based in the universities and research institutes of its member states. The expertise – both technical support and in support managing complex projects - is highly value by the UK space stakeholders. Our consultations also revealed the value provided by ESA in connecting and linking UK contractors with expertise and potential partners in other ESA member states. The agency is procuring solutions at the boundaries of what is technologically possible, and its model of in-house collaboration with world-class external contractors, enables it to work on many fronts, while integrating new solutions and systems in a working whole. This level of engagement also means that the procurement exercises deliver competitively priced goods and services that are more likely to have a successful outcome than would a research grant or SBRI-style award.

Figure 58 Schematic overview of ESA added value



Technopolis (2022)

The use of competitive procurement models even for basic technology has also meant ESA is able to fund companies' development of cutting-edge technologies in full (in many cases), whereby the cost-plus contracts de-risk private sector development efforts to a greater extent than typical industry research grants (typically cost-shared, and pre-competitive in order to comply with the EU state aid rules and those of the WTO). The higher levels of funding intensity for individual projects, along with the close engagement with ESA mission customers and technologists is also thought to give a boost to both the relevance and quality of the resulting project outputs. Programmes like GSTP have been especially beneficial in this respect, given it allows companies to come forward with proposals for technological developments they believe could be relevant to ESA missions and which align with their local strategic interests.

Our interviews also underlined the benefits of membership in terms of access to ESA centres of excellence and facilities (e.g. technology teams in ESTEC; lunar environment lab in Cologne; NASA-JPL facilities in the US, via the ESA ExoMARS programme).

There are downsides to ESA membership too, as compared with a national programme, including a reduction in national purchasing power and less control over strategic priorities. Member state investments made through ESA attract a 15-20% surcharge to pay for the operation of ESA's HQ and various technology centres and ground stations. There is also a loss of strategic directionality. While the biggest member states may wield more influence than smaller countries, in recognition of their larger investments and more extensive national capabilities, ESA goes to great lengths to ensure its strategic priorities secure wide-ranging support and are of mutual interest to all.

Overall, however, there is a presumption that ESA contracts deliver more and better technology advances than would the equivalent national investment, because of the level of technical support, user engagement and international networks of excellence. The issue of directionality is less easily addressed. ESA's use of optional programmes allows some degree of national influence over priority setting at programme level, assuming countries invest heavily in those programmes. And several of its mainstream programmes include smaller calls that support national capacity building and give member states greater say in which strategic priorities to support.

9.4 UK space economy

UK membership of ESA has underpinned growth in the UK space economy, with the additional national investment in ESA championed by successive science ministers (David Sainsbury and David Willetts) for example being used to persuade ESA to switch some of its technical support activities from ESTEC at Noordwijk in the Netherlands to the newly created European Centre for Space Applications and Telecommunications (ECSAT) in Harwell. This decision and the investment that followed has brought new investment into the UK, with 10-20 EU headquartered space companies opening offices in Oxfordshire in part because of the establishment of this new centre of excellence on the Harwell Campus and close to one of the UK's leading international centres of excellence, RAL Space.

Reducing investments in ESA may have a similarly highly leverage impact on the UK, but in the opposite direction.

While contract income from ESA amounts to a small share of the total UK space economy, a many of the key players are EU-headquartered businesses that maintain subsidiaries in the UK in part to maximise their access to ESA contracts. This is true especially for the upstream space sector, which is largely responsible for building and operating ESA funded spacecraft and operational infrastructure. These foreign-owned businesses account for a majority of R&D investment and innovation in the space sector (itself a high investor in R&D) and while they have long-standing ties to the UK – accessing key local labour markets, supply chains and centres of excellence – any reduction in UK investment in ESA would be likely to lead to a switch in new investment from the UK to the EU and a gradual downsizing of these 'anchor' businesses, and a likely erosion of UK-based networks and supply chains. The expansion in the number and output of UK-based businesses developing or making use of space applications may offset some of these losses, however, these areas of 'new space' remain challenging and highly contested. As a case in point, the UK is not alone in Europe in its growing commitment to commercial spaceports, and while it enjoys certain territorial advantages and has put in place relevant regulatory systems, it may be many years before such endeavours would make up for the departure of a key upstream player like Airbus or Thales.

10 Economic assessment

10.1 Introduction

In this section, we explore the economic effect of ESA spend for CMIN19 via four routes (as illustrated in Figure 2 in chapter 2):

- **Direct effects of ESA funded activities** (CMIN 19 contracts) i.e. benefits to ESA contractors
- **And indirect effects of the activities of ESA contractors**, i.e. on CMIN19 suppliers
- **ESA-derived activities** i.e. any additional 'ripple effect' in terms of follow-on sales leveraging the capabilities developed by ESA contractors
- **ESA-derived spillover benefits,** wider socio-economic effects from ESA-derived activities, including:
  - Innovation benefits: Benefits to users (consumers, organisations, society) of space-derived goods and services.
  - User benefits: Benefits to users (consumers, organisations, society) of space-derived goods and services.
  - Coordination benefits: Benefits from coordination, standardisation and achievement of a critical mass of innovation adopters

10.2 Direct and indirect economic activity generated by ESA funded activities

We estimate the indirect effect of ESA contracts by looking at the economic activity generated in the wider economy (supply chain) as a consequence of UK ESA contractors implementing their contracts.

These estimates are based on a macro-econometric modelling, using Cambridge Econometrics E3ME model. A brief description of the model is presented in Appendix F.

The model baseline provides one possible counterfactual of the economic outturn in the absence of ESA spending on UK commitments.

We take as inputs to the model, projected ESA spend in the UK over 2020-25 broken down by sector (i.e. the sectors where ESA contracts are placed).[87] This is modelled as a boost to gross output (via the ESA spend in that period) for these UK sectors and the Type I only impacts (i.e. direct and indirect effects) are then estimated for the period 2020-30.

In addition, by only modelling ESA spend in the UK and not ESA spend in other countries, the modelling does not capture the impact of ESA spending in other countries on demand for UK exports. Our analysis also assumes that the ESA spending is funded through an expansion of the UK government budget, with no assumption of an offsetting increase in government revenues.

The inputs for the model are those described in Appendix F. We estimate that in total, £1.69bn (in 2020 prices) is expected to be spent on UK contracts at the portfolio level (i.e. across all ESA

[87] The principle of geo-return within ESA means that there is a target to return all of UK's commitment to ESA to UK organisations - minus the UK's contribution to the overhead costs of operating ESA. Therefore the ESA spend in the UK is the UK commitment to ESA Obligations" minus the overhead charged per programme be ESA as this is funding that does not come to the UK. The data for UK commitments/ ESA spend in the UK is based on the data in the "ESA Report on Contributors' Financial.
The sector distribution of funding is based on historic trends of contract holders and contract values per programme in the "ESA geo-return datasheet".

programmes) over 2020-2588. Furthermore, we also show that the Science, EO and TIA programmes are each projected to receive 21-24% of the total £1.69bn spend (between £355m-£405m each). The HRE programme is scheduled to receive a smaller share of the ESA investments, at just 11% (£192m).

Finally, we also find that, around 27% of the £1.69bn is expected to be spent on contracts with firms in the Other Transport Equipment sector (this corresponds to SIC 30 Manufacture of other transport equipment, which includes the manufacture of spacecraft), making this sector the largest recipient. The next largest recipients are the Electronics (16.4%) and Telecommunications sectors (12.1%). Collectively, these three sectors account for 55% of ESA spend in the UK.

The next section provides a brief description and analysis of the modelling results, focusing primarily on the portfolio level.

10.2.1 GVA Impacts

The main results from the modelling analysis are shown in Table 46. The ESA spend in the UK represents the input assumption for each modelling scenario. The total GVA[89] outcome is calculated endogenously in the model and is compared to GVA outcomes for a baseline scenario in which no ESA spending had occurred: the differences between the baseline and scenario outcomes are presented in the table as the 'total GVA impact'.

At the portfolio level, and as stated above, ESA commits £1.69bn over 2020-25 to contracts with UK organisations (predominantly firms) for the provision of goods and services. In producing these goods and services, the firms must purchase inputs from domestic and foreign suppliers. This creates knock-on effects along the domestic supply chain as these suppliers must then purchase their own inputs. **We estimate that this knock-on (indirect) effect in the supply chain is £625m (at the portfolio level).**

Those inputs that are imported from overseas producers represent a leakage of the initial spend outside of the UK economy and have no subsequent impact, except where they generate demand for UK exports as inputs. **Once the firms have paid for the inputs into the production of the goods and services, they are left with £827m – the direct GVA.**

Combining the direct and indirect GVA impacts gives a total GVA impact of £1.45bn over 2020-30. This is less than the £1.69bn because some of it leaks out of the economy through imports. **The direct and total GVA impacts imply a GVA multiplier of 1.75 at the portfolio level** (i.e. that a direct effect of £1m leads to a total effect of £1.75m, =£1.45bn/£0.83bn).

Since our analysis has excluded consideration of (Type II) induced demand effects[90] and does not consider the impact of ESA spending (on the same programmes) in other countries on demand for UK exports, we can expect that these results underestimate the total macroeconomic impact of the ESA programmes.

Across the four major programmes the total value of spending ranges from £192m in HRE to £404m in TIA, and the results with regard to subsequent GVA impact, relative to the initial spend,

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[88] Note that this differs from the figure presented in Section XY since here we present the figures in pounds and deflated (using 2020 prices). The figures also exclude overheads.

[89] GVA is the part of turnover (output) retained once the cost of inputs has been deducted and is composed principally of labour income (wages and salaries) and capital income (profits). It is thus a measure of income retained from the contract once input costs have been accounted for; some of that income is profits.

[90] And as requested by the USKA Research and Analysis Team

are broadly similar (with some variations due to the varying sectoral distribution of spending within each programme). Notable results are:

- The relatively lower GVA multiplier for the Science programme (compared to that for the portfolio): 1.64. The scale of total impact compared to the initial spending by ESA is in line with the portfolio as a whole. However, compared to the portfolio as a whole, a slightly higher share of the spend is retained by the recipients of the initial ESA spend and a slightly lower share goes to the supply chain, i.e. the direct impact is slightly larger and the indirect impact slightly smaller. The result is a slightly lower GVA multiplier.
- The relatively higher GVA multiplier for the HRE programme: 1.89. This is because, compared to the portfolio average, a markedly lower share of the spend is retained by the recipients of the initial ESA spend. The share that goes to the supply chain is also lower than for the portfolio, but by much less. As a result, the direct impact is noticeably weaker, and the indirect impact is just about in line with the portfolio. The result is a larger GVA multiplier. But it is worth noting that the scale of total impact compared to the initial spend is the lowest of the four programmes, indicating greater import leakage under this programme.
- The multipliers for the TIA and EO programmes are in line with the portfolio average. In the case of EO, the distribution of the direct and indirect impacts is virtually identical to that for the portfolio. In the case of TIA, the shares of the spend retained by the recipients of the initial ESA spend and that go to the supply chain are higher than for the portfolio (because the scale of total impact compared to the initial spending by ESA is markedly higher), but their relative weighting is similar to that for the portfolio. Hence, a similar multiplier.
- At £378m, the total impact of the TIA programme is around 94% of initial spend. This is the highest across the programmes and indicates that just 6% of the spend leaks out of the economy through imports. At 83-84%, the Science and EO programmes are in line with the portfolio average. The HRE programme sees the highest leakage through imports, with just 74% of the spending under this programme remaining in the economy.

Table 46 ESA spending inputs and GVA impacts

2020-2030 (cumulative)	ESA spending (£2020 million)[1]	GVA Impact (£2020 million)			GVA multiplier
		Direct[3]	Indirect[4]	Total[2]	
Science	355.0	180.8	115.7	296.4	1.64
EO	382.3	179.6	136.8	316.4	1.76
HRE	192.4	75.2	66.6	141.8	1.89
TIA	403.5	217.0	160.8	377.8	1.74
Other activities[91]	357.6	174.9	144.7	319.8	1.83
Total (Portfolio)	**1,690.8**	**827.5**	**624.6**	**1,452.2**	**1.75**

The direct GVA impact of ESA spending is calculated by applying the GVA share of gross output for each sector to the estimated output impact. The indirect impact is the difference between the total impact and direct impact. Dividing the total GVA impact by the direct GVA impact gives us the Type I GVA multiplier

Note(s): 1. E3ME modelling input assumption; 2. E3ME modelling output; 3. Off-model estimate based on direct spending by sector (1) and GVA share of output in each sector receiving funds; 4. Estimate based on (2) & (3)

Source(s): E3ME and additional data analysis; CE analysis of ESA Contributors' Financial Obligations report dataset

[91] This includes Launch, Navigation, Technology, Space Safety, Basic Activities (part of Mandatory Activities), and the Guiana Space Centre (also part of Mandatory Activities).

10.2.2 *Employment*

Across the portfolio, the projected spend of £1.69bn is expected to generate 10,485 person years of employment over 2020-30. A substantial share (70%) of this employment is generated among the initial recipients of the ESA spending (direct employment), while a smaller share is generated along the supply chain. This is because many of the sectors that receive the largest share of ESA spending initially are also those that have the largest employment impacts (as they are more labour intensive). At the same time, the sectors that make up the supply chains of the main recipient sectors have much lower employment impacts. Hence, the lower share of the indirect employment impact. Given this total impact and the direct impact estimated at 7,308 person years, this implies an employment multiplier of 1.43. As a result, at the portfolio level, each £1m of spending is expected to generate 6.2 person years of employment.

Table 47 ESA spending inputs and employment impacts

2020-2030 (cumulative)	ESA spending (£2020 million)[1]	Employment Impact (FTE)			Employment multiplier
		Direct	Indirect	Total	
Science	355.0	1,738	825	2,563	1.47
EO	382.3	1,769	806	2,575	1.46
HRE	192.4	708	460	1,167	1.65
TIA	403.5	2,079	751	2,830	1.36
Other activities[92]	358	1,014	335	1,350	1.33
Total (Portfolio)	**1,690.8**	**7,308**	**3,177**	**10,485**	**1.43**

E3ME and additional data analysis; CE analysis of ESA Contributors' Financial Obligations report dataset.
Note(s): 1. E3ME modelling input assumption

As with GVA impacts, the employment impacts relative to the initial spend are broadly similar across the programmes with some variations due to the varying sectoral distribution of spending under each programme and the labour intensity of sectors. Notable results are:

- Across the four main programmes, the total employment impact increases with the level of ESA spending. The largest total employment impact is projected to be in the TIA programme, which is the largest recipient of funding. The lowest employment impact is in the HRE programme, which receives the lowest funding.
- The employment multipliers for all programmes vary a little from the portfolio average. TIA has the largest employment impact, but because proportionately more of that is a direct impact, it has a noticeably lower employment multiplier.
- The opposite is true for HRE. It has the lowest total employment impact, but because proportionately more of that is indirect employment, it has a markedly higher employment multiplier.
- The split between the direct and indirect impacts, and thus the employment multipliers, for the Science and EO programmes are broadly in line with the portfolio average.
- Although the TIA has the lowest multiplier, each £1m of spending is expected to generate 7.2 person years of employment, i.e., more than the portfolio average. In contrast, the HRE has the highest multiplier, but each £1m of spending is expected to lead to just 6.1 person

[92] Ibid

years of employment, although that is in line with the portfolio average. For the Science and EO it is 7.2 and 6.7 person years, respectively.

10.2.3 Sectoral impact

Table 48 presents the estimated GVA and employment results, disaggregated and ranked by sector, for the total portfolio spending commitment.

Looking at how the impacts break down across sectors, as expected, GVA impact is more dispersed than initial spending. Whereas nearly 95% of direct spending across the portfolio is concentrated in the 10 largest beneficiary sectors, the 10 most important sectors by GVA impact only account for 68% of the portfolio GVA impact. This can be explained by the flow of the initial spending through industrial supply chains, which allows the final economic impact to be spread across a much wider spectrum of the economy than the narrower focus of ESA programme spending would immediately suggest. Nonetheless, most of the impact is still felt in the high-value manufacturing and knowledge-intensive services that make up much of the space sector, with a range of administrative and other professional services in support.

The final employment impacts show a similarly even distribution: the top 10 sectors account for 70% of total employment impact, although they are concentrated in different sectors. As might be expected, some of the largest employment impacts are in sectors that saw the largest GVA impact (e.g. Electronics, Engineering Services, Other Transport Equipment, Other Professional Services, Computer Services). The difference in the order of their ranking reflects differences in their labour intensity. For example, Other Professional Services, which includes the provision of other professional scientific and technical services, such as specialised design services, is only the seventh ranked for GVA impact, but is top ranked for employment impact, reflecting its relatively greater labour intensity. A similar story can be told for the Security & Admin[93] and Metal Products sectors, both of which sit just outside the top 10 for GVA impact but are well within the top 10 for employment impact. The GVA impact for Hotels & Catering is small but the labour-intensive nature of that industry means that is sees a relatively stronger employment impact.

Table 48 Portfolio GVA and employment impact by sector

2020-2030 (cumulative)	Total GVA impact			Total Employment impact	
	£2020 million	% of total		FTE years	% of total
Electronics	165.0	11.4%	Other prof. services	1,093	10.4%
Other transport equip.	133.9	9.2%	Security & admin.	895	8.5%
Telecommunications	127.8	8.8%	Electronics	885	8.4%
Computer services	112.3	7.7%	Engineering services	868	8.3%
Engineering services	104.8	7.2%	Other transport equip.	794	7.6%
R&D activities	99.9	6.9%	Computer services	659	6.3%
Other prof. services	74.8	5.2%	Public admin. & def.	593	5.7%
Public admin. & def.	61.6	4.2%	Metal products	574	5.5%
Legal, account. etc	57.8	4.0%	Legal, account. etc	519	4.9%
Construction	55.1	3.8%	Hotels & catering	445	4.2%
Others	459.2	31.6%	Others	3,160	30.1%
Total	1452.2	100.0%	Total	10,485	100.0%

E3ME and additional data analysis; CE analysis of ESA Contributors' Financial Obligations report dataset.

[93] This includes the provision of security-related services and facilities support services.

10.3 ESA derived activities

ESA funded activities are also expected to generate additional 'ripple effect' via follow-on sales through leveraging the capabilities developed in an ESA contract, which materialises in terms of additional income and / or employment.[94]

Data for these 'ripple effects' was collected via the survey of ESA contractors. 89% of contractors reported an increase in capabilities. Furthermore, 19% of contractors from industry have already commercialised products and services as a result of their ESA contracts and 54% expect to do so in the coming years (from 2022 and onwards). 55% of respondents reported projected values of the follow-on sales from these new capabilities, products and services.

This income is expected to materialise 2-3 years after contracts are in place (with some organisations experiencing more immediate gains) and is expected to be accrued over a decade.

Based on the responses to the ESA contractors survey, we estimate that in 2018-2021 (4 full years) companies have already generated income totalling £146.1m from new capabilities, products and services supported by ESA contracts (£48.2m in 2018-2019 and £98.0m in 2020-2021). Furthermore, those organisations expect this income to equate to approximately £1.2bn in the coming years.

Taking into account the value of contracts reported by those organisations (from 2018-2021), we estimate that each £1m in value of ESA contracts generates a total of £7m in additional income (see Table 49). These organisations also estimate that these benefits will last approximately 11.5 years, so this equates to approximately £607k per annum (=£7m/11.5).

Respondents were also asked to reflect on the extent to which the benefits expected from ESA contracts (including additional income) are linked to ESA contracts, with some indicating that their benefits could not have occurred without the ESA contracts (55%) and, at the other end of the spectrum, others indicating that most benefits would have occurred anyway (only 2% of respondents). Using these responses, we estimate an 'additionality score', to arrive to a net value of benefits, and **estimate that each £1m in value of ESA contracts generates a total of £4.9m in *net* additional income (i.e., after accounting for additionality).**

These figures are based on the additional income reported by all organisations, including those that have contracts in 2018-2019 (for a given programme), i.e., prior to CMIN19, and are aggregated this way to take into account that ESA contracts offer, in many cases, opportunities to make incremental changes to existing technologies / solutions and that benefits accrue overtime (and often as a result of consecutive contracts). This group also offer a larger pool of responses to draw from.

To further isolate the effect of CMIN19 contracts we proceed to focus only on organisations that have had contracts in 2020-2021, but not prior to 2020 (for a given programme). For these 'new entrants' we estimate that their ESA contracts (and resulting new capabilities, products and / or services) will deliver a total additional income of £10.6m, in 2020-2021, with a further £355.3m expected from 2022 and onwards. Compared to the value of their contracts in 2020-2021, this would mean that **each £1m in value of ESA contracts generates £8.1m in *net* additional income** for those organisations (i.e., after accounting for additionality) (see Table 49). This higher return on investment might be explained by the fact that these new entrants

[94] Note that the estimates presented in this sub-sections rely fully on primary data collected via the ESA contractor survey and do not make use of other assumptions or ratios from secondary data sources.

exclude well-stablished, big operators (such as Airbus and Thales) whose major developments will probably lead to further sales or contracts to institutional buyers like ESA, while new entrants are likely to operate in other commercial markets, with larger (expected) opportunities for follow-on sales.

Taking into account the *net* return on investment across all organisations (i.e., 1:4.9), we estimate that the total value of ESA contracts for the period of analysis (2018-2020), £580.2M (based on geo-return data), has led to a total of £2.8bn in *net* additional income. **Furthermore, if we take into account the total projected spend for the CMIN19 investment period (£1.69bn) we estimate a total projected *net* additional income of £8.2bn, for the period 2020-2036 (i.e., £0.72bn per annum).** As a reference the total UK space industry income reached £16.4 billion in 2018/19 and had an annual growth rate of 2.8%[95] (i.e., grew approximately £0.44bn in one year). If contractor's projected estimates prove to be correct, this means that the ESA investments could support a substantial grow in the years to come.

There is a high degree of variability in results across organisations, with some reporting figures for projected follow-on sales generated (to some extent) as result of ESA contracts, even after excluding some clear 'outliers'.

In fact, we estimate that the return on investment on contracts is 1:22 for the top 25th percentile, and 1:09 for the remainder. This is consistent with the 'pareto distribution', a principle usually applied in the technology and innovation arena, where 80% of the results are expected to materialise from 20% of the investment.

Finally, and in other to arrive to a global figure of impact, we also estimate that the return of investment in terms of GVA is 1:2.5, taking into account a GVA/turnover ratio of 51%. This ratio is calculated as the weighted average of the GVA/turnover ratio across the sectors identified in our estimations of GVA impact (shown in Section 0 above). Taking into account the total projected spend for the CMIN19 investment period (£1.69bn), this means a total impact of £4.3bn in GVA.

[95] Know.Space (2021) UK Space Industry: size and health report, 2020

Table 49 ESA derived activities – Income generated from new capabilities / products / services (£m)

	Period	All organisations (Group 1) (n=72) (£m)	Organisations with no contracts prior to 2020 (Group 2) (n=35) (£m)
Total Value of contracts (£m)	In period 2018-2019 (2 full years)	82.3	NA (organisations with contracts prior to 2020)
	In period 2020-2021 (2 full years)	104.9	30.0
	Total [A]	**187.2**	**30.0**
Total Income generated by new capabilities /products / services (£m)	In period 2018-2019 (2 full years)	48.2	NA
	In period 2020-2021 (2 full years)	98.0	10.6
	Expected from 2022 onwards (excl. outliers) *	1,158.3	355.3
	Total [B]	**1,304.5**	**365.9**
Total Income per value of contract	**[A]/B]**	**7.0**	**12.2**
	[C]	**0.7**	**0.7**
	Net value (after accounting for additionality) ([A]/B]*[C])	**4.9**	**8.1**
Gross-up (net) estimate	Based on contract values of £580.2m for the period 2018-June 2021 (based on geo-return data)	**2,824**	
	Based on ESA spend 2020-2025 (£1.69bn)	**8,230.9**	

Source: Technopolis (2021). Based on ESA Contractor Survey. * Excludes 4 outliers in Group 1, and 1 outlier in Group 2. Outliers were identified as those with an estimated expected income that was 1 standard deviations of the mean. The outliers excluded provided estimates that are 9-10 times of the ones presented in the table. The study team take the view that the values provided are not robust (and may even been provided mistakenly). As such they have not been carried forward to produce ranges or sensitivity analysis.

We find a high degree of variability also at programme level. Results are presented in Table 49 only for those programmes for which we have 10 observations or more, and consequently, more reliable estimates:

- In the case of TIA, we find a return on investment of 1:6, with the top 25th percentile showing results as high as 1:20.
- The ratio is considerably lower for EO, with a return of 1:0.8. Note that this does not mean that the return is lower than the investment, it means that in addition to the £1m in contracts with ESA under the EO programme, organisations may be able to secure an additional £0.8m in follow on sales.
- The ratio is considerably higher for GSTP, with half of organisations making estimates of £10m-£50m expected income off the back of relatively small contracts (£100-£200k)

Table 50 ESA derived activities – income per value of contract (at programme level)

	Total income per value of contract			No. of respondents (all)
	All	75th percentile	Top 25th percentile	
TIA	6.0	0.4	20.1	30
EO	0.8	0.7	5.4	16
GSTP	24.0	12.5	181.0	12

Technopolis (2021). Based on ESA Contractor Survey

When asked about the proportion of their income achieved through exports, companies report a **growing expectation in terms of internationalisation,** with 50.7% of future income expected to come from international demand (i.e., outside the UK), in comparison with 28.2% in the period 2020-21.

Table 51 ESA derived activities - exports

	In period 2018 – 2019 (2 full calendar years)	In period 2020 - 2021 (2 full calendar years)	Expected from 2022 onwards
Proportion of this income achieved through exports (mean %)	10.4%	28.2%	50.7%

Technopolis (2021). Based on ESA Contractor Survey. Number of respondents=40-60

ESA contracts also lead to employment being created or safeguarded. The employment effects could materialise immediately, as companies are able to protect a percentage of their workforce to deliver ESA contracts or even increase it. Additionally, employment effects could also materialise from the additional activity enabled by the new capabilities, as well as products and services supported by ESA contracts.

Based on the responses to the ESA Contractor Survey, and after accounting for additionality, we estimate that each **£1m in value of contracts generates a total of 5.1 FTEs:**

- **1.6 FTEs as a direct & immediate result of contracts**
- **Plus 3.6 FTEs due to additional income from follow-on sales**

The figure for FTEs emerging from **direct & immediate** result of contracts somewhat overlap with the results from the economic modelling, which include the effects on ESA contractors, in addition to the effects in the supply chain. To avoid double counting we focus only on employment generated from additional income from follow-on sales.

This represents a total of 2,072 FTEs based on contract values of £580.2m for the period 2020-June 2021. **Furthermore, if we take into account the total projected spend for the CMIN19 investment period (£1.69bn) we estimate total projected *net* additional FTEs of 6,039.** For reference, total employment in the UK space industry was 45,000 in 2020, based on headcount, suggesting that employment support by ESA contracts will represent an important driver to support and sustain employment in the sector.[96]

[96] Know.Space (2021) UK Space Industry: size and health report, 2020

Table 52 Employment

Full-time equivalent employees (FTE) created and/or retained by contractor as a result of…	Period	Values Group 2
ESA contract income	In period 2018-2019 (2 full years)	184.5
Income generated by the new capabilities /products / services resulting from ESA contracts	In period 2018-2019 (2 full years)	75.0
ESA contract income plus additional income	(Additional) In period 2020-2021 (2 full years)	37.3
	(Additional) From 2022 onwards	246.2
Total employment per value of contract	ESA contracts (immediate effects only)	2.2
	ESA contracts and additional income generated	4.2
	Total	7.4
	Total (net)	5.1 (3.6 for follow-on sales)
Gross-up (net) estimate	Based on contract values of £580.2m for the period 2020-June 2021	2,072
	Based on ESA spend 2020-2025 (£1.69bn)	6,039

Technopolis (2021). Based on ESA Contractor survey. Number of respondents = 62.

In terms of geographical distribution, these jobs are expected to be concentrated in four regions, in the period 2020-2021 (based on data reported via survey) with London, the South-East, the South-West, and the North West accounting for 78% of the total. This is slightly higher than the overall concentration for the space industry, based on the latest data from the Size and Health report, which estimates a concentration of 60% in those regions (based on headcounts) (see Figure 59 in chapter 12).

10.4 ESA-derived spillovers benefits

Finally, a third route to economic impact comes from ESA-derived spillovers benefits. This includes the wider socio-economic effects from ESA-derived activities, including:

- **Innovation benefits**: Benefits to users (consumers, organisations, society) of space-derived goods and services.
- **User benefits**: Benefits to users (consumers, organisations, society) of space-derived goods and services.
- **Coordination benefits**: Benefits from coordination, standardisation and achievement of a critical mass of innovation adopters

These types of impacts are expected to materialise over a long period of time, after the ESA contracts have concluded, and as such at this point in the study we have not identified any examples or evidence of spillovers emerging from CMIN19 investments taken place yet. As such, there is a degree of uncertainty around these estimates, and they should be taken with caution. These estimates are high relatively to estimates of direct and indirect effects, as well as those emerging from ESA-derived activities. The importance of these spillovers effects to the overall calculation suggests the need for a more detailed focus on these in future iterations of the evaluation.

A recent literature review (2021) shows that studies that attempt to measure spillovers tend to do so using a bottom-up perspective, tracking specific developments and then quantifying benefits, in terms of, for instance, lives saved (through better disaster response, enhanced safety from navigation), benefits arising from better search and rescue, increased passenger safety, emergency response times, better air quality information etc. [97] The review does not identify studies that offer an overarching figure for spillover effects, although these are, in some cases, embedded within calculations of overall return on investment.

The CMIN 19 Business Case used a prior review (London Economic, 2018) to identify a median figure for the spillover rate of return for each of the three main application areas, and used these estimates taken from the literature to interpolate for the other ESA programme areas.

This prior review identified a relatively broader and bigger spillover ratio for EO (2-3 times the direct returns) as compared with telecommunications and navigation (1-2 times the direct returns). Spillover analyses are particularly scarce in areas relating to space science, launchers, and technology. The Business Case therefore used a series of proxy estimates for spillover ratios in the range of 1.0-2.7 (see Table 53).

The definition of 'direct' effects is used differently in different studies, and we take this to mean all effects that are not 'spillovers'. Taking into account this a median of 2.5, we estimate that an effect of 3.36 (from direct, indirect and ESA derived activities), could lead to 8.4 in spillover benefits. Taking into account the total projected spend for the CMIN19 investment period (£1.69bn), this means a total impact of £14.2bn in GVA.

Table 53 Variables used to assess value for money in the CMIN19 Business Case

Programme	Ratio of direct to spillover benefits
Science/Mandatory	1:2.5
Human & Robotic Exploration	1:2.5
Space Safety & Security	1:2.5
Earth Observation	1:2.7
Telecommunications & Applications	1:1
Navigation	1:1.5
Technology	1:2.5
Launch	1:2.5

Table 6 of the CMIN19 Business Case, page 42

[97] know.space (forthcoming), Returns and Benefits from Public Space Investments 2021.

11 Net-zero

11.1 Space activities and net zero

There are three space-related perspectives on net-zero and climate change more broadly

- **Direct effects: the greenhouse gas (GHG) emissions of the space industry**. While space is a small industry in relative terms, it does have **a proportionately higher carbon footprint** than many economic sectors, driven in large part by the country's success – supported by UK membership of ESA membership - in retaining several space primes and a large part of the associated manufacturing supply chain. The space industry is also contributing to climate change through its need to launch satellites into space, albeit this is very much less significant than carbon footprint of manufacturing. Moreover, the space launch programmes are based outside the UK, and as such are of less direct relevance.
- **Indirect effects:** while the industry's GHS emissions are proportionately higher than many other industry sectors, space has the potential to contribute positively to efforts to manage climate change, and thereby balance out the negative effects
  - Space enabled EO has played a critical role in improving our **understanding of climate change** (and informing government policies and mitigation measures) and continues to provide new insights that enhance climate change models and improve monitoring activities and mitigation measures.[98]
  - **Space-based data and services** support the wider economy to operate in a more environmentally friendly manner, whether that is more efficient transport systems or precision agriculture. While the major contributors in future years are likely to be are operational space infrastructure and services run by agencies other than ESA (e.g. GPS, Copernicus), these applications all benefit from ongoing research within ESA (and other) programmes, with incremental improvements in services providing equivalent incremental improvements in environmental performance. UK Space, the national trade association, has taken a similar approach to the issue of climate change, championing the role of space as a critical tool to support sustainability throughout the economy.[99]

11.2 ESA and net zero

ESA has focused most heavily on the development of space missions and infrastructure to inform our understanding of climate change. It has had limited involvement with the Net Zero agenda historically. However, ESA has been investing – at a very much lower level of effort as compared with its EO spend – during the past two or three ministerials to improve the space industry's carbon footprint, through:

- Studies to understand the contributions of the different parts of the industry to various types of environmental impact, supporting discussions about off-setting strategies[100]
- Funding research into more sustainable fuels or re-usable space hardware

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[98] https://www3.weforum.org/docs/WEF_Space_and_Net_Zero_2021.pdf

[99] https://www.ukspace.org/wp-content/uploads/2020/03/19058_Stratospheric-Growth_02u.pdf

[100] https://sa.catapult.org.uk/south-west/uncategorized/blog-spaceport-cornwall-to-minimise-carbon-footprint/

- Funding one or two smaller projects concerned specifically with the environmental performance of ESA contractors[101]
- Funding feasibility studies relating to radical new technologies, such as space-based solar power (SBSP), whereby satellites would deploy ultra large solar panels in space and then transmitting that power to earth by laser or microwave for collection via a large antenna.[102] This is a very long-way in the future, given the financial and technical challenges involved, but there are substantial investment programmes underway in the US and China. The UK government is monitoring the situation[103]

Table 54 summarises our review of the ways in which space activities, and ESA activities in particular, may impact GHG emissions, and how they might be assessed in any future study.

Table 54 Summary of factors where space/ ESA play a role in generating and/or mitigating GHG emissions

Factor / space activity	Brief description / role and relevance of ESA activities	ESA policy to address reduced GHG	Potential approaches to assessment of CO2e
Direct GHG sources due to space activities			
GHG emissions of the UK space sector and its supply chain	Direct GHG emissions due to space sector activities in the UK Only those GHG emissions that are related to UK space sector activities funded by ESA would be relevant to this study (and the CMIN22 business case)	Part of ESA Clean Space initiative covers advanced manufacturing techniques	Estimate attributable GHGs using CMIN19 spend flowed through the Cambridge Econometrics E3ME model. Note – this will provide a baseline, but it will not capture any improvements that may follow UK-ESA spend on 'greening' the space sector. Examples of improvement effects could be captured via case studies of individual CMIN19 activities under Clean Sky / GSTP – if relevant activities have been or are being funded
GHG emissions of: **launches of UK payloads on ESA missions/launches** **GHG emission of (future) fledgling UK space launch industry**	ESA has conducted a few studies looking at the environmental effects of launches. These show that launches have a negative effect on GHG emissions ESA CSTS programme is providing expertise to support the development of UK national launch capabilities	The ESA Clean Space Initiative – is looking (in part) at a greener launch method, especially greener propulsion (e.g. the manufacture of liquid hydrogen has big carbon footprint) ESA Net Zero call for proposals[104]	Complex study to identify: • Scale of emission from launches • Timescales of expected effects • Identifying which launches relate to UK assets
Indirect effects			

[101] There is some activity under the ESA Clean Space initiative, albeit this is concerned mostly with space debris

[102] https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/ESA_reignites_space-based_solar_power_research

[103] The UK-based multidisciplinary consultancy company, Frazer-Nash, has caried out a feasibility study for BEIS, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1020631/space-based-solar-power-derisking-pathway-to-net-zero.pdf

[104] See the ESA call on NZ under the 'ESA Discovery' element which is part of the Basic/ Mandatory programmes.https://ideas.esa.int/servlet/hype/IMT?documentTableId=45087661358490766&userAction=Browse&templateName=&documentId=24ea54cc9f205a0874ff45212b4d57dd

Factor / space activity	Brief description / role and relevance of ESA activities	ESA policy to address reduced GHG	Potential approaches to assessment of CO2e
Indirect 1 **Understanding and monitoring climate change**	Earth Observation (EO) programme: using EO assets to better understand the climate and climate change and enable others to design and take action to mitigate climate change EO plays a role in making measurements of around 50% of ECV* e.g., sea ice, land cover, atmospheric CO2, etc	Purpose of EO is improving scientific understanding of the climate and climate change and using space assets to determine / measure the state of the climate	These activities are important for understanding and assessing climate change, they do not in themselves change levels of GHG emissions. But case studies can demonstrate the role of EO in understanding climate change
Indirect 2 **Using space assets to reduce GHG emissions**	Applications using space assets to reduce GHG emissions e.g. some satellite applications /services may support the reduction of GHG emissions in end-user markets e.g. improved logistics, precision agriculture	ESA support for business applications UK Satellite Applications Catapult	The applications that might target reduced GHG emissions are highly varied and therefore would best be studied via impact case studies to trace effects. A more comprehensive assessment would require many detailed case studies of a wide range of impact routes to enable models to be built and aggregate effects to be estimated

*Essential Climate Variables (internationally agreed)

11.3 The UKSA and net zero

The UK Space Agency's activities have mirrored the ESA strategy, with an historical emphasis on the role of space in improving our understanding of climate change, and a more recent and limited interest in the sustainability and environmental performance of space activities themselves.

- **Space for understanding climate change** within CMIN19 has been addressed through our case studies. The Aeolus mission is a recent historical example, where a UK-built satellite – launched in 2018 – has implemented a new approach to measuring wind speeds globally, improving numerical weather prediction and supporting climate science.[105] The CryoSat programme is another example of an ESA Earth Explorer mission, originally proposed by Sir Duncan Wingham (NERC CEO), that used UK radar expertise to advance the state of the art in the measurement of the thickness of polar ice, which has greatly improved modellers' abilities to predict sea level rises associated with climate change.
- **Reducing the GHG emissions of the UK space industry** is not an explicit objective of the UKSA funding of ESA programmes, as described through CMIN19, and it is not a separate item in the UKSA / ESA theory of change. It is not something that is tracked currently by the UKSA and is not something that has been studied systematically in the UK or internationally. ESA has funded a few studies in this arena,[106] which are of some limited general interest.

[105] https://www.gov.uk/government/news/british-built-laser-spacecraft-due-to-be-launched-into-orbit

[106] For example: Environmental impacts of launchers and space missions, Deloitte, 2017 https://indico.esa.int/event/181/contributions/1443/attachments/1336/1561/2017_CSID_Chanoine_LCA_launcher_space_missions_FV.PDF

Meanwhile, the UK's National Space Strategy is committed to expanding the UK space economy overall and beginning to play a larger role in the space launch market, both of which will tend to push matters in the opposite direction, increasing the GHG emissions of the UK space economy over time. However, any UK or ESA activities introduced to directly address the emission of the space industry may ultimately be out-paced by wider UK initiatives to de-carbonise the UK energy system and the balance of effort and investment needs further consideration before actions are decided.

The UK is already active in the core areas of climate science and clean space, however, it is conceivable that its future investments in space technologies and satellite applications could involve specific calls targeting novel applications that would support the wider UK economy in its efforts to reach net zero, or more generally creating a UK criterion – additional to those used by ESA – whereby UK-based applicants would be invited to explain the positive (or negative) contributions their proposed activities would deliver form the perspective of net-zero, for space and the wider economy.

11.4 Modelling the carbon footprint of the UK space industry

To provide a baseline for future UKSA studies and evaluations, Cambridge Econometrics used its E3ME macro-econometric model[107] to estimate the carbon emissions associated with the UK-based industrial activity conducted under CMIN19 contracts. We have used the total CMIN19 budget as the input for the model.

From an environmental perspective, the impact of the increase in contract activity supported by the increase in the overall budget from CMIN16 to CMIN19 represents an additional increase in the carbon footprint of the industry (CO2 emissions).

At the portfolio level, around an additional 49 ktCO2 are expected to be generated. The share of emissions generated under the Science and EO programmes are in line with their share of GVA impact. Both account for 20-25% of additional GVA and emissions generated. Meanwhile, the HRE programme accounts for around 10% of GVA impact but 15% of emissions. In contrast, the TIA programme accounts for around 26% of GVA impact but just 21% of emissions. These differences across programmes reflect differences in the nature of the programmes and the required inputs (some programmes / activities are funding a greater proportion of office-based, knowledge-intensive services, while other programmes are investing more heavily in infrastructure and systems, and may be more reliant on (heavy) manufactured inputs) and the nature of the industries that provide these inputs.

ESA report, Executive Summary (of the same study): https://nebula.esa.int/sites/default/files/neb_study/1116/C4000104787ExS.pdf

[107] https://www.e3me.com/

12 Levelling up

12.1 Government white paper on levelling up

The Government White Paper on levelling up (February 2022) set out a complete 'system change' of how government works that will be implemented to level up the UK.[108]

While the UK government has been actively promoted regional economic development over much of the past twenty years, the levelling up agenda, marks an intensification of the commitment to a more even geographical distribution of influence and activity.

At the heart of this new way of making and implementing policy will be 12 national missions - all quantifiable and to be achieved by 2030 – one of which is the Research & Development (R&D) mission, which commits to increasing by at least 40% by 2030 the share of public R&D investment outside the Greater South East, and assuming that this redistribution would be reinforced by a similar remapping of the distribution of private investment too through match funding. As such, the UK Space Agency's budget will form part of this R&D mission, and its strategic priorities and flow of contracts, will be part of this bigger picture going forwards.

12.2 Levelling up and CMIN19

As a new policy, levelling up was not part of the UKSA proposals for CMIN19 and there are no specific objectives whereby investments in ESA programmes might be framed in light of their implications for the UK home countries or English regions. This will no doubt be a feature of the CMIN22 business case, theory of change and intervention logic.

Notwithstanding the absence of a levelling up agenda in CMIN19, the UK space economy has a spatial dimension, and the flow of UK funding of ESA programmes is being received by businesses and research groups around the country.

As an aside, the UK space industry has a particular geographical distribution that reflects historical patterns of industrial activity and the emergence of regional clusters in the associated defence and aerospace industries and major investments in national centres of excellence (e.g. RAL Space, UCL's Mullard Space Science Laboratory). As such, the industry and public research institutes have a longstanding basis in the South of the UK.

12.3 The geographical distribution of the UK space industry

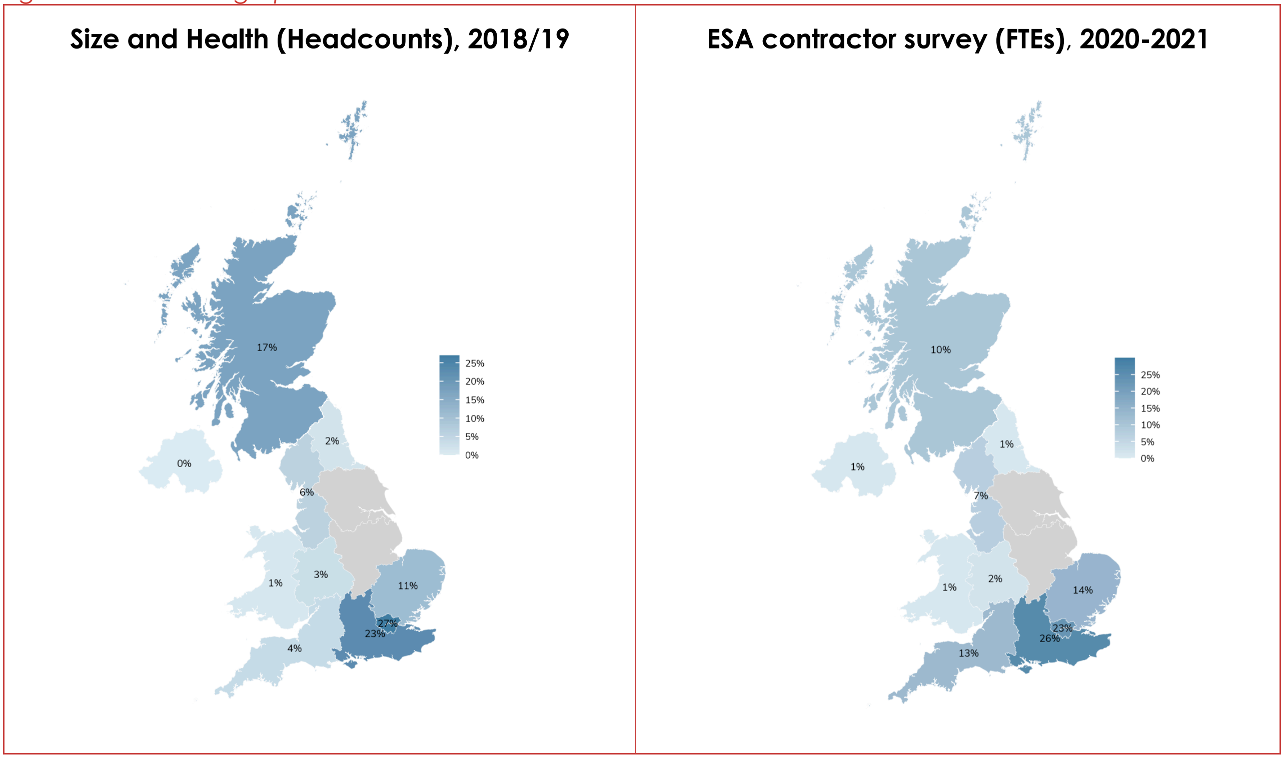
In terms of a baseline geographical distribution, ESA-derived space activity and jobs are concentrated in four English regions. In the CMIN19period 2020-2021 (based on data reported via our survey of UK-based ESA contractors), London, the South-East, the South-West, and the North-West accounted for 78% of the total.

This is higher than the concentration for the space industry overall, based on the latest data from the Size and Health report, which estimates a concentration of 60% in these four English regions (based on headcounts). The two surveys do not provide an immediate explanation for this significant difference in geographical concentration between all UK space activities and ESA-funded space activities. The likely reason for the greater focus is the highly specialist and technical nature of ESA contracts, and the high barriers to entry, with ESA contracts being heavily skewed – number and value – towards the larger, globally dominant primes (e.g. Airbus) and international centres of excellence (e.g. RAL Space). As such, the great majority of income

[108] https://www.gov.uk/government/publications/levelling-up-the-united-kingdom

and associated employment is located in Stevenage and Portsmouth and Harwell. While there is a long list of UK-based ESA contractors, the very great majority are partners and sub-contractors to the Primes and their ESA-related income while critical to future capability and reputation does not constitute a significant share of their total activity.

Figure 59 FTEs - Geographical distribution



Technopolis (2021). Based on ESA Contractor survey. UK Space Industry: size and health report, 2020

12.4 Future evolution

The established geographical distribution will not change dramatically in the near future, as there are high barriers to entry for winning ESA contracts and the existing major players are fully committed to the UK. Notwithstanding BREXIT and the implications for the UK industry's access to various EU flagship space programmes that are being implemented through ESA, our surveys suggest that the major players and new inward investors view the UK as an important spacefaring nation.

The degrees of freedom are further limited by the fact these major players are often the anchor for larger space cluster, and as such it seems likely that a dynamic and competitive UK space economy will continue to be over-represented in London, the South, South East and South West. This does not preclude opportunities for the UKSA to use ESA programmes to drive a levelling up agenda. Indeed, the increased commitment within CMIN19 to new space and the UK's investment of c. £12m in the ESA commercial space transportation (CSTS) programme has already helped deliver a number of major levelling up benefits.

- The Goonhilly Earth Station in Cornwall has been supported by ESA and the UK Space Agency in its efforts to create the world's first commercial deep-space communications station, capable of tracking future missions to the Moon and Mars. While this initiative predates CMIN19, and has also relied on UK regional growth fund funding, the programme has continued to be supported through ESA's HRE programme in CMIN19.

- The CSTS programme is funding D-Orbit's plans to develop a new end-to-end space transportation service offering additional in-orbit flexibility. D-Orbit will establish its satellite assembly, integration and testing facility at the Spaceport Cornwall Centre for Space Technologies, while working with a wide range of launch service providers operating from the UK, including Virgin Orbit and Skyrora, but also plans to collaborate with other operators launching from other spaceports in Europe.[109] [110]
- Scotland is also developing a new spaceport in Sutherland and the UKSA and the ESA CSTS programme have been providing support for several Scottish companies looking to develop small launch technologies. Forres-based rocket manufacturer Orbex was one of four British companies the government supported in 2021, to successfully secure a total of over £10 million in European Space Agency funding to develop their world-leading small satellite launch technologies and bring them to market.

The UK Space Agency has also granted small additional awards to a series of regional hubs or space clusters outside the greater south east, with around £0.6m of national space funding being earmarked to support jobs and growth in for example, Cornwall, Northern Ireland, the Highlands and Islands amongst many others.[111] While this is tiny in comparison with ESA funding, the funds will support the recruitment of space cluster champions who will strengthen local leadership groups business development opportunities.

In terms of monitoring progress with levelling up going forwards, the UK Space Agency has worked with the Knowledge Transfer Network (KTN) to develop an interactive portal (the UK Space Sector Landscape Map) that maps the location of the companies, universities, funding bodies and networks that form the UK Space sector.[112] The tool maps the location of more than 1,000 organisations[113] allowing people to explore the geographical distribution of different sub-sectors, applications users and centres of excellence. This database provides a useful means by which to understand the evolution in the geography of UK space overall, and it might conceivably be further developed to map ESA contracts and contractors, and thereby provide an immediate and useful point of reference for tracking changes in geography for ESA-related activities compared with all Space-related activities.

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[109] https://www.esa.int/Enabling_Support/Space_Transportation/Boost/ESA_s_Boost!_fosters_new_launch_and_in-orbit_services

[110] https://elecnor-deimos.com/uk-space-port-study/

[111] https://www.gov.uk/government/news/boost-for-space-clusters-across-the-uk

[112] https://ktn-uk.org/programme/space-satellite-applications-landscape-map/

[113] Many are also presented in the more conventional flat-file database maintained by the UK space agency in its industry catalogue, which can be found at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/991621/4674_UKSA_UK_Space_Sector_Catalogue_update_TC_2.pdf

13 Summary and conclusions

13.1 Overview

The first implementation of the M&E framework collected evidence against an extensive set of quantitative indicators designed to encompass the breadth of expected impacts of UK's investments made via ESA in order to: create a baseline for UK's investments made in the CMIN19 period; and assess the effects generated to date (*programme effectiveness*). Taking a theory-based evaluation approach it explored and tested the pathways to impacts outlined in the Theories of Change (ToC) for the ESA programmes to assess the extent to which effects identified to date can be attributed to UK's investments and the likelihood that the expected effects will arise.

Conclusions reflect on both the effectiveness of the M&E methodology as well as the first impact evaluation findings.

13.2 Impact evaluation

Context

CMIN19 investments will be made from January 2020 to December 2024 and therefore this first impact evaluation of CMIN19 was undertaken at an early point in the investment lifecycle. At this point in time, not all investments (i.e. ESA contracts) have yet been made and contracts that are in place have not yet finished. Furthermore, the timescales to develop and generate space infrastructure are long, 10-15 years or longer, and therefore the subsequent impacts arising from the their use are further into the future.

In terms of investments; approximately 20-25% of expected CMIN19 ESA contracts (by value) have been let as of end of June 2021, with a quarter of these starting in 2021.[114] Therefore, much of the project work funded via ESA contracts has either not yet started (i.e. contracts not yet placed) or not yet finished (i.e. contracts have not yet finished). Therefore this first evaluation can only consider the outputs, and any early outcomes, generated to date by a sub-set of the intended CMIN19 investment.

The first evaluation has been able to identify positive effects in terms of outputs being generated. It has also explored and validated the Theory of Change for UK investments in ESA for each of the eight ESA programmes. This provides evidence that the expected pathways to impact are valid and makes a qualitative assessment of the extent of attribution and additionality of the benefits identified to the investment made via ESA.

Inputs (i.e. ESA CMIN19 investments)

- The total planned UK commitments to ESA for 2020 to 2024 is €2,114m, with 90% of the ESA budget for the five-year CMIN19 period from 2020-2024 is assigned to the four large programmes: Science, TIA, EO and HRE115
- 675 ESA contracts with a total value of €392m have been let to date to 281 UK organisations
- 88% of the ESA contracts (i.e. between Jan 2020 and Jun 2021) are with industry

[114] As already reported, it is not possible to accurately determine the proportion of investments made to date in terms of the funding agreed at CMIN19 due to the overlapping CMIN commitment periods

[115] This includes the 'carry-over' funding from the CMIN16 investment period

- Six organisations account for 50% of the value of contracts let to date, reflecting the concentrated structure of the UK space industry
- Industrial co-funding is required for some funding mechanisms within the programmes that support technology development (TIA, GSTP, NAVISP and CSTS). Co-funding is agreed on a contract-by-contract basis and not systematically recorded by ESA or UKSA. Using co-funding guidelines and advice from UKSA programme leads, co-funding for the contracts let to date was estimated to be of the order of €145m, representing additional investment of 37% of the ESA funding.

Prosperity: outputs

- As would be expected, contracts are supporting a progression in the TRL of technologies being developed and around a half of respondents expect the outputs of their contracts to contribute to operational space infrastructure within the next 0-10 years
- ESA contracts support large numbers of collaborations with 90% of those responding to the survey reported at least one form of collaboration
  - 86% of ESA contractors (that responded to the evaluation survey) reported collaborations within their ESA contracts
  - 80% reported collaborations with other businesses; 69% with UK businesses, 54% with business in other ESA member states and 23% with businesses in non-ESA countries
  - 48% reported collaborations with academia; 44% with UK academics, 25% with academics in other ESA member states and 15% with academics in non-ESA countries
- Around half of respondents (53%) reported gaining new strategic partnerships as a result of their ESA contracts, with 71 new partnerships already gained within Europe and 47 outside Europe and a further 107 or so partnerships expected in each of these two regions post-2021
- 58% ESA contractors reported significant positive reputational and competitiveness benefits in international space markets
- Respondents reported that three spin-outs have been established as a result of CMIN19 contracts. As group they currently employ 24 people and one spin-outs has achieving an investment of £10m. A further eight spin-outs are expected in the future (from 2022 onwards)

Prosperity: outcomes for ESA contractors

The first type of outcomes are on-going commercial benefits experienced by ESA contractors themselves. A considerable proportion of survey respondents reported having achieved or expecting to achieve a range of commercial benefits

- The most frequently reported effect is new or improved employee skills and knowledge, 89% of contractors reported this
- 19% have already commercialised new products or services and 54% expect to from 2022 onwards
- 27% have achieved follow-on sales from their new capabilities, products and services and 54% expect to achieve this type benefit in the future (2022 onwards)
- 20% have achieved employment benefits as result of follow-on sales and 32% expect employment benefits in the future
- 7% have accessed new markets to date and 18% expecting to in future

- Contractors were able to provide estimates of the expected value of their follow-on sales and the value of these are reported in the Economic Assessment section below

Prosperity: effects on the wider space sector

- While it is too soon to determine the effects of ESA contracts on the wider space sector, the evaluation developed baseline data for these wider effects in terms of patents in space domains and investment in space businesses.
- While patents in the space domain have been declining in recently years, the number of investment deals, and number and value of venture capital deals in particular, in the upstream space sector have been increasing.

Prosperity: usage and innovation benefits (spillovers)

- For most CMIN19 investments it is too soon for downstream usage and innovation effects to have occurred. But this does not mean that there is not a high expectation of impacts in the future and ESA contractors provided information on the type of usage benefits they expect their contracts to lead to
- 64% of contractors reported significant expected applications and downstream benefits, with environmental protection the most frequently reported, followed by productivity benefits, security of assets on Earth.
- The downstream applications developed in the UK under the ESA TIA Business Applications and Space Solutions (BASS) programme provide examples of the innovative products and services that make use of data from ESA space infrastructure and the type of downstream benefits that can be created. The majority of applications can be considered to be spillovers to non-space sectors.
  - Applications are under BASS cover many application domains from smart cities, transport and finance to health, culture and the environment
  - The majority of the applications supported (65%) were based on EO data, followed by satcom capabilities (22%) and satnav (position, timing, navigation data) (7%). Two projects were based on technologies developed for human spaceflight
  - Applications are expected to provide economic benefits for both the companies themselves and the wider economy once in use by their customers. Environmental and social benefits are also expected.

Knowledge: outputs

- The main knowledge generation effects of ESA contracts are considered outcomes (rather than outputs) as they do not arise until ESA missions are operational i.e. after all member states and ESA investments deployed to develop a mission have been integrated and launched. Nevertheless, ESA contractors reported a total of 109 papers in the current CMIM19 period, with the majority of papers published in EO

Knowledge: outcomes

- Scientific knowledge generated from research using the data generated by ESA missions can be assessed in terms of a range of bibliometric indicators (no. of papers, citations, etc). This knowledge has yet to be generated from the missions being developed under CMIN19 and therefore bibliometric data was used to compile a baseline for CMIN19 investments.

- The data indicates that the majority of scientific knowledge outputs are generated by the missions in the Science programme and that the UK performs well compared to other leading ESA member states in terms of citations (a measure of quality and scientific impact).

Outcomes: global influence

- As the fourth largest investor in ESA (among 22 full MS) contributing 10% to the total ESA budget, the UK has considerable influence within ESA. It is among the small number of countries that are home to space primes able to manufacture and/or operate the large-scale complex spacecraft for science, EO and HRE missions and home to innovative and entrepreneurial smaller and younger space companies. Having said that only around 50-60% of ESA contractors think that that the UK is well-represented within ESA senior leadership UK's political leadership, that UK's space sector's capabilities and needs are reflected in ESA strategy and planning or that UK's strategic goals for space are reflected in ESA strategy and planning. This may be an issue of visibility of UKSA activities within ESA.
- The UK is represented on relevant European and international space bodies and standards bodies – such as UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) and the European Cooperation of Space Standardisation (ECSS)
- The UK played a central role in the recent development of ESA long-term scientific strategy – with a UK academic as the Co-chair of the ESA Voyage 2050 senior committee and a large number of UK academics on the committee's thematic groups

Outcomes: security and protection

- The UK is a major contributor to what are two relatively small programmes – SSS and CSTS as both clearly align with UK's national priorities in space security (protecting space assets from space debris and protecting terrestrial assets from anomalous space weather) and a national launch capability.
- The programmes also support the UK's ambitions to be a global leader in these fields and maximising the commercial returns to the UK companies. SSS and UK's national ambitions have already attracted innovative SMEs to the UK, with ESA contracts playing an important role in securing venture capital investment.
- ESA contractors are generally positive about UK investments in space ensuring UK's access to space and enhancing the UKs ability to influence the global regulatory environment for space and the resilience of the UK space sector and its supply-chain.

Contribution of the eight ESA programmes to the outcomes and impact

The eight ESA programmes contribute to the outcome/impact domains to varying degrees both by design (e.g. the Science is intended to create new scientific knowledge and SSS is intended to increase security of space and terrestrial assets) and by more generic means (e.g. placing contracts with space companies). The table overleaf presents a synthesis of the role and extent of contribution of each programme to the outcome/impact domains.

The UK National Space Strategy was published during the evaluation (in September 2021) and so after the Theory of Change was developed. The table below provides a mapping of the outcome/ impact domains used in the evaluation to the five goals of the new National Space Strategy published during the evaluation. The goals are also included in the synthesis overleaf.

CMIN19 Business Case (Sept 2019)	National Space Strategy 2021 (5 goals)
	Over-arching: Goal 5: Use space to deliver for UK citizens and the world
Increased global influence: driven by Global Britain – stimulate partnerships with other ESA member states and countries engaged in space activities that align to UK strengths and ambitions	**Goal 2:** Promote the values of Global Britain **Goal 4:** Protect and defend our national interests in and through space
Increased prosperity and (scientific) knowledge: support industry and research communities to stimulate science, research and development and innovation. Drive exports and foreign investment through engagement with the wider UK economy and space sector (ensure markets are working effectively & driving economic growth)	**Goal 1:** Grow and level up our space economy **Goal 3:** Lead pioneering scientific discovery and inspire the nation
Increased security and protection: Support national efforts around protection of critical national infrastructure, emergency services, crises and civil contingencies and to build national resilience (protection from negative externalities)	**Goal 4**: Protect and defend our national interests in and through space **Goal 5**: Use space to deliver for UK citizens and the world

Table 55 Summary of ESA programmes and impact effects

		Increased prosperity and (scientific) knowledge			Increased security and protection (Goal 4 / Goal 5))		
	Increased global influence (Goal 2)	**Successful & growing UK space sector (Goal 1)**	**Economic benefits for wider economy (Goal 1)**	**Increased scientific knowledge (Goal 3)**	**Access to space / security of space assets**	**Protection of terrestrial CNI**	**Effective design of public policy & services**
Science	• UK's leading role in global scientific collaborations	• RDI & skills development in UK space sector • Follow-on sales • Investment in UK space sector	• Potential for knowledge spillovers	• Designing world-class mission infrastructure • Using missions for high-quality research	• Membership of ESA mandatory science programme provides access to space		
TIA	• UK's world-leading commercial space sector	• RDI & skills development in UK space sector (*with significant commercial potential)* • Follow-on sales • Investment in UK space sector	• RDI & new products/ services in applications of space assets	• Designing leading satcom systems & applications		• UK access to secure communications	Contributions to • Transport policy • Disaster/crisis policy • Environment policy
EO	• UK role in global EO capabilities & global climate change policy	• RDI & skills development in UK space sector *(with increasing commercial potential)* • Follow-on sales • Investment in UK space sector	• RDI & new products/ services in applications of EO assets	• Designing world-class mission infrastructure • Using missions for high-quality research	• Membership of EO programme provides access to space EO assets	• Monitoring & assessing disasters using EO assets	Contributions to • Climate change/ environment policy • Disaster/crisis policy
HRE	• UK role in global exploration effort	• RDI & skills development in UK space sector • Follow-on sales • Investment in UK space sector	• Potential for knowledge spillovers	• Designing world-class mission infrastructure • Using missions for high-quality research	• A Membership of EO programme provides access to space for exploration		
SSS	• UK leading role in space weather	• RDI & skills development in UK space sector *(with increasing commercial potential)* • Follow-on sales • Investment in UK space sector	• Avoidance of CNI outages	• Designing world-class mission infrastructure • Using missions for high-quality research	• Debris removal/ collision avoidance missions	• UK lead in space weather	• CNI policy
GSTP	• UK's technological capabilities	• RDI & skills development in UK space sector • Follow-on sales • Investment in UK space sector	• Potential for knowledge spillovers				
NAVISP	• UK's technological capabilities	• RDI & skills development in UK space sector • Follow-on sales • Investment in UK space sector	• Potential for knowledge spillovers • RDI in applications of PNT	• Designing leading GNSS/PNT systems & applications	• Developing UK capability in GNSS / PNT	• UK access to GNSS/ PNT capabilities	• Contributions to GNSS/ PNT policy • Transport policy
CSTS	• UK's increasing role in access to space	• RDI & skills development in space sector	• Potential for knowledge spillovers		• Supporting development of UK launch capability		• Contributions to space launch policy

Technopolis (2022) **Dark green:** high expected impact **light green:** some expected impact **Grey:** no/limited impact

13.3 Attribution and additionality

- The **outputs** reported are in line with what is expected of the various ESA programmes and a direct result of the activities of ESA contracts as, as would be expected, the contracts are placed with organisations with existing capabilities relevant to ESA's requirements.
- Where **outcomes** for ESA contractors are concerned, further additional inputs are required and external factors will influence the generation of outcomes. Nevertheless, ESA contractors reported a high level of (self-reported) attribution and additionality of the outcomes reported as achieved to date (and expected outcomes reported to the ESA investments. This was corroborated by the interviews with ESA contractors and the examinations of the programme Theories of Change. From an industry perspective, there are limited other forms of public support for RDI in the space domain, giving them limited alternative options to work on space technologies and applications.
- Where the wider usage and innovation impacts are concerned i.e. the applications based on space data and capabilities, the detailed examinations of the programme Theories of Change validated the pathways from UK ESA investment and activities to outcomes - suggesting that future benefits will be generated. These outcomes will not be wholly attributable to UK ESA investments as other private (and possibly further public) investment and actions are required to develop and commercialise new products or services using space data. To bring about wider economic or social benefits, the products' end-users (businesses, consumers, public service providers, policy-makers) must expend further resources to adopt and utilise them.
- The analysis of the Theories of Change also indicated that for outcomes arising from programmes with a high level scientific content (Science, HRE and elements of EO) the knowledge, skills and technological advances and the infrastructure itself wouldn't exist without ESA investments.

13.4 ESA added value

- The evaluation interviews, surveys and literature reviews confirmed there is considerable value-added working via ESA and widespread agreement regarding the principal types of added value that derive from the UK's national membership of ESA. This is in comparison with the alternative of a larger, UK national space programme with more targeted international collaboration delivered through selected bilateral or multilateral missions with other national space agencies.
- **Scale and indivisibility:** From the UK perspective, the minimum scale of public investments required to be a space-faring nation is considerable, such that for an economy the size of the UK, going alone is not feasible. It is not just the substantial costs to design, develop and operate an individual space mission but also the reliance upon decades of capability development and wider capital investment in the coordination structures, facilities and infrastructure. These are large, cumulative investments that would be hugely costly to replicate at a national level, and such a strategy could take 10-20 years to implement fully and with questionable value for money in comparison with other national infrastructure priorities. While bilateral arrangements might offer an alternative to a wholly national approach, the majority of our current relationships with NASA, JAXA, CNAS are a result of our ESA membership and while a small number of UK instruments might be attractive for individual US, Japanese or Chinese missions the extent and breadth of access to mission would likely decrease.

- **ESA in-house coordination and technology capability:** the strategic coordination and technical capability and capacity within ESA which far exceeds the capacity one might expect to establish in the UK. ESA has established a series of coordination, management and operational structures to design, project mange, launch and operate missions – that far exceeds anything any other European country has in place. It is value adding and takes substantial pressure of national space agencies, including UKSA. It would be challenging to replicate these international mechanisms within a national agency Interviewees were unequivocal in their praise for the technical capabilities available at ESA (at ESTEC in particular).
- **UK space economy:** UK membership of ESA has underpinned growth in the UK space economy, not only supporting the development of capabilities and skills development in complex technologies and systems but also providing reputational benefits, a 'badge of approval', to UK businesses. While contract income from ESA amounts to a small share of the total UK space economy, a many of the key players are EU-headquartered businesses that maintain subsidiaries in the UK in part to maximise their access to ESA contracts. This is true especially for the upstream space sector, which is largely responsible for building and operating ESA funded spacecraft and operational infrastructure. These foreign-owned businesses account for a majority of R&D investment and innovation in the space sector (itself a high investor in R&D) and while they have long-standing ties to the UK – accessing key local labour markets, supply chains and centres of excellence – any reduction in UK investment in ESA would be likely to lead to a switch in new investment from the UK to the EU and a gradual downsizing of these 'anchor' businesses, and a likely erosion of UK-based networks and supply chains. The expansion in the number and output of UK-based businesses developing or making use of space applications may offset some of these losses, however, these areas of 'new space' remain challenging and highly contested.

13.5 Economic assessment

GVA impact

We explored the economic effect of ESA expenditure to assess the return of UK investment. This analysis takes into account four routes to impact including effects on ESA contractors and their suppliers (direct and indirect effects), ESA-derived 'ripple effects' in terms of follow-on sales leveraging the capabilities developed by ESA contractors, and wider spillovers. Most of these effects are expected to materialise in the future and therefore our estimates include projections.

In terms of GVA, we estimate that the total return on investment from CMIN19 will be 1:11.8, based on projected spend for CMIN19 investment period, ie. each £1m invested will generate a return of £11.8m, over time. If we take into account ESA overheads (~20%) this ratio is 1:9.8.

We also estimate that the projected spend for the CMIN19 investment period (£1.69bn) we estimate a total projected net additional income of £5.75bn (in cash terms), for the period 2020-2036 (i.e., £0.50bn per annum). Additionally, £14.2bn are expected to materialise in the long-term via spillover effects.

Type of benefit	Ratio (Investment to GVA	Grossed up estimates (based on projected spend for CMIN19 investment period) (2020 prices)	Duration	Notes & Caveats
(1) Direct effects of ESA funded activities (CMIN 19 contracts) And (2) Indirect effects of ESA funded activities (CMIN 19 contracts)	**1:0.86 (*)**	**£1.45bn**	Up to 2030 (5 years after last spending year)	Compared to a baseline/ counterfactual of doing nothing. Based on the E3ME macro-economic modelling
(3) ESA-derived activities	**1:2.5**	**£4.3bn**	2020-2036 (11.5 years after last contract)	Accounting for contractors' self-assessment of counterfactual scenario. Does not account for additional investments needed by industry or other funders. Extrapolations based on ESA contractor survey
(4) ESA-derived spillovers (**)	**1:8.4**	**£14.2bn**	Long-term	Based on estimates found in the literature and as shown in the CMIN 19 Business Case
Total	**1:11.8**	**£20.0bn**		

Employment impact

In terms of employment, we estimate that the return of investment is 1:9.8, meaning that each £1m spend delivers 9.8 person years employment (emerging from direct and indirect effects, and benefits from ESA-derived activities). If we take into account overheads (~20%) this ratio is 1:8.2.

We also estimate that the projected spend for the CMIN19 investment period (£1.69bn) we estimate a total of 16,524 person years employment.

For reference, total employment in the UK space industry was 45,000 in 2020, based on headcount, suggesting that employment support by ESA contracts will represent an important driver to support and sustain employment in the sector.

Type of benefit	Ratio	Grossed up estimates (based on projected spend for CMIN19 investment period) (2020 prices)	Duration	Notes & Caveats
(1) Direct effects of ESA funded activities And (2) Indirect effects of ESA funded activities	**1: 6.2**	**10,485**	Up to 2030 (5 years after last spending year)	Compared to a baseline/ counterfactual of doing nothing. Based on a macro-economic modelling
(3) ESA-derived activities	**1: 3.6**	**6,039**	2020-2036 (11.5 years after last contracts)	Accounting for contractors self-assessment of counterfactual scenario. Does not account for additional investments needed by industry or other funders. Extrapolations based on ESA contractor survey
Total	**1: 9.8**	**16,524**		

13.6 Contributing to net zero

Historically the focus of ESA and UKSA where climate change is concerned has been the development of space missions and infrastructure to inform our scientific understanding of climate change and monitoring key climate change variables (i.e. contributing data for Essential Climate Variables) through the EO programme. This continues in CMIN19 and the UK is building on its expertise in this field and contributing to key missions such as CO2M and TRUTHS. These climate change-focused activities do not directly move us towards net-zero by actively reducing CO_2 (or other greenhouse gases) in the atmosphere but do play a critical role in monitoring progress at a global level. In terms of generating positive effects (and potential effects) on net-zero within the UK space sector there are a number of options;

- As an energy intensive sector, the space industry currently makes a negative contribution to net-zero. UKSA can continue to support ESA's clean-space activities targeting reusability of space hardware and more sustainable fuels and the small initiatives exploring options to reduce the carbon footprint of the space sector. However, any returns from these activities may be out-paced by wider UK initiatives to de-carbonise the UK energy system and the balance of effort and investment needs further consideration before actions are decided.
- UKSA could target a proportion of investment in space applications (supported via ESA's TIA/BASS programme) on products and services that can make a positive contribution to net-zero or, at a minimum, creating a UK criterion for applications projects to explain the positive (or negative) contributions their proposed activities would deliver from a net-zero perspective.

13.7 Contributing to levelling up

As a new policy, levelling up was not part of the UKSA proposals for CMIN19 and there are no specific objectives whereby investments in ESA programmes might be considered in terms of their implications for shifting the balance of economic activity within the UK. The current UK space industry is concentrated in the south (65% of headcount in the SE, SW, London, East of England) with a growing activity in Scotland (17% of headcount) and this concentration is largely reflected, although not entirely, in the distribution and benefits of ESA contracts. The geographical distribution is the result of the history of industrial development of the aerospace sector and its supply-chain, who remain the recipients of the majority of ESA investment.

The established geographical distribution will not change dramatically in the near future, as there are high barriers to entry for winning ESA contracts and the existing major players are committed to the UK. The degrees of freedom are further limited by the fact these major players are often the anchor companies for regional space clusters.

This does not preclude opportunities for the UKSA to use ESA programmes to contribute to the levelling up agenda building on a range of activities already underway:

- The smaller ESA programmes such as CSTS and SSS are supporting (and can further support) the emerging private sector space launch and clean-space activities clustered around the UK's developing spaceports in Cornwall, Scotland and Wales.
- The UK can also continue to support the development of the Goonhilly Earth Station in Cornwall, via the ESA HRE programme, as world's first commercial deep-space communications.
- The UK can continue to support and/or increase support for, existing and new entrants to the small satellite and small-sat constellation segment via the TIA, EO and GSTP programmes as well as space applications businesses (via TIA) who are not bound by the locations of the traditional space sector