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April 2022

Impact evaluation of UK investment in ESA

PART A: First impact evaluation of CMIN19 investments

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Version: *Final*

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Impact evaluation of UK investment in ESA

PART A: First impact evaluation of CMIN19 investments

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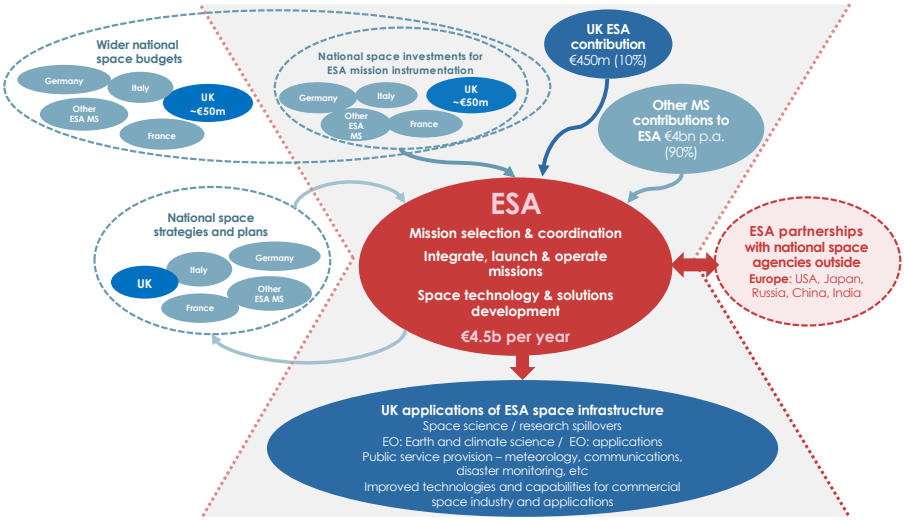
INTRODUCTION

The European Space Agency (ESA) is an important route for the delivery of UK government objectives for space; a significant proportion of the UK's public investment in space is made via ESA **- around 75% of UK Space Agency's (UKSA) annual budget is allocated to ESA each year**. Within the current five-year investment period, agreed at the ESA Ministerial Council in November 2019 (CMIN19), the UK's annual contribution of €420-450m represents around 10% of ESA's ~€5bn annual budget. UK is now one of ESA's top four contributors along with France, Germany and Italy.



UKSA is committed to ensuring that UK investments made via ESA are properly evaluated and the development and implementation of a monitoring and evaluation (M&E) framework was a condition underpinning the approval of the business case for UK's ESA funding commitments made at CMIN19 and is a commitment of the UKSA 2020/21 Corporate Plan.

M&E DESIGN AND TIMESCALES

The M&E framework covers the eight core ESA programmes. It has been designed to cover the five-year CMIN19 investment period but could equally be applied to future investment periods.

The framework is a theory-based approach centred on a *theory of change* (ToC) for ESA investments, combining quantitative and qualitative data and analyses to (i) provide evidence of the outputs, outcomes and impacts generated by ESA investments and (ii) test and validate the expected pathways to impacts to assess attribution and additionality.

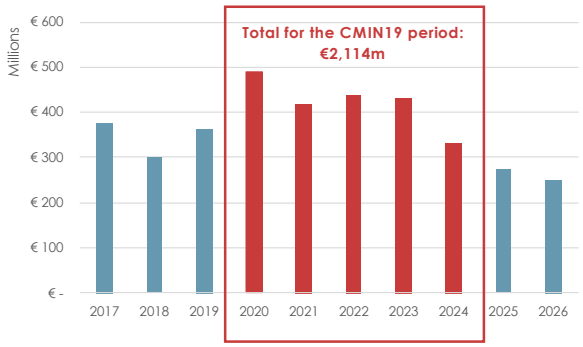
Four large ESA programmes	Four small ESA programmes
Space Science (mandatory programme)	General Support Technology Programme (GSTP)
Telecoms & Integrated Applications (TIA)	Space Safety and Security (SSS)
Earth Observation (EO)	Navigation Innovation and Support Programme (NAVISP)
Human & Robotic Exploration (HRE)	Commercial Space Transportation Services (CSTS)

Investment in space R&D and innovation and the development of space infrastructure is a long-term endeavour. ESA missions and infrastructure can take 10-15 years to develop and span several of ESA's five-year investment periods, and will then be operational in space for a similar length of time after launch. Therefore, the majority of investments being made in the five-year CMIN19 period will not start generating outcomes and impacts until some time after the period has ended.

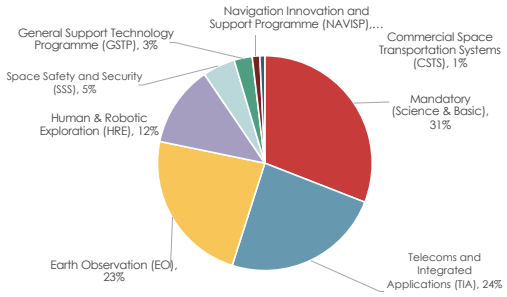
INPUTS (CMIN19 INVESTMENTS)

- The UK has committed €2,114m to ESA for the five-year period from Jan 2020 to Dec 2024. This includes commitments made at the ESA Ministerial Council in late 2019 (CMIN19) and on-going commitments made in 2016
- 90% of the budget is assigned to the four large ESA programmes: Science, EO, TIA & HRE
- ESA contracts with a total value of €392m have been 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). While this suggests that contracts for the UK may be running behind schedule, a number of large contracts are expected for UK organisations in the Science, EO and HRE programmes that will change the total value considerably.
- 88% of contracts are with industry and six companies account for 50% of the value of these contracts. This pattern of investments reflects the concentrated structure of the UK space industry.
- Industrial co-funding is required under some ESA programmes and, for contracts let to date, it is estimated to be of the order of €145m

Annual UK commitments to ESA



CMIN19 commitment by ESA programme



ESA ADDED VALUE

- **There is considerable added-value to working via ESA and widespread agreement among stakeholders regarding the principal types of added value that derive from the UK's national membership of ESA.** This has been confirmed by evaluation interviews, surveys and literature reviews confirmed

Scale and indivisibility	ESA in-house coordination and technology capability	UK space economy
• Minimum scale of public investments required to be a space-faring nation is enormous, such that for an economy the size of the UK, going alone is not feasible • Bilateral arrangements might offer an alternative, but the majority of our current relationships with NASA, JAXA, CNAS are a result of our ESA membership. While a small number of UK instruments might be attractive for individual US, Japanese or Chinese missions the extent and breadth of access to missions would likely decrease.	• The strategic coordination and technical capability within ESA 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 hugely valued by the UK community. It would be challenging to replicate these international mechanisms within a national agency.	• Many of the key 'upstream' space players are EU-headquartered businesses that maintain subsidiaries in the UK in part to maximise their access to ESA contracts. • 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 support wider UK supply chains and labour markets. • Any reduction in UK investment in ESA would likely lead to a switch in new investment by these companies from the UK to other ESA member states.

- **There is also evidence of high levels of attribution of outputs and outcomes for ESA contractors.** ESA contractors report that a high proportion the outputs and outcomes generated to date would not have happened without ESA investment
- Also, from an industry perspective, there are limited other forms of public support for R&D and innovation activities in the space domain, giving them limited alternative options to work on leading-edge space technologies and applications. The ESA investment supports many of the key UK space companies at some point and also supports new entrants via programmes such as GSTP, SSS and CSTS - providing funding and opportunities to conduct R&D and innovation activities to explore and develop technologies and build and enhance high-value skills.
- Our detailed examinations of the theories of change (ToC) at programme level validated the expected pathways from UK ESA investment and activities to outcomes and impact - suggesting that future benefits will be generated. These benefits will not be wholly attributable to UK ESA investments as other private (and possibly further public) investment and actions are required to develop, commercialise and operate space infrastructure and develop and commercialise space applications.

KEY ACHIEVEMENTS TO DATE

NEW KNOWLEDGE

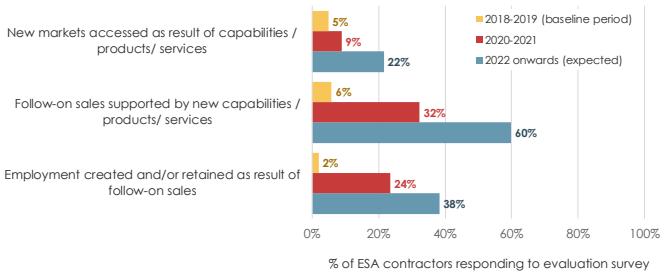
- **Scientific impact is expected but yet to materialise**. The Science, EO and HRE programmes support space missions that aim to generate new knowledge about the Earth, Solar System and Universe. The majority of scientific impact (new knowledge) from missions being developed during the CMIN19 period will not arise until missions are launched and making observations.
- The baseline data collected in this study shows that the majority of the UK's ESA-related space publications arise from the Science programme (84%) and that the UK publications are growing in quantity (number of papers) and increasing in quality (citations). Furthermore, the UK also has a strong performance in international co-publication rates and the rate of publications per £ invested compares favourably to other key space-faring countries.
- **ESA's science-based programmes play an important role in terms of outreach.** It provides interesting and exciting content for outreach activities to engage the public and inspire young people, especially in terms of choosing subjects in science, technology, engineering and maths (STEM) for study and for careers. The evaluation developed a baseline for higher education enrolments for three groups of relevant courses (space-specific, space-related and wider physical sciences and engineering) which will allow tracking longer-term outcome of activities directed at school children. As the activities target children from primary school to sixth, the effects of these activities will materialise over timescales from 2-12 years.

INNOVATION

- **There is a broad range of innovation activities supported by ESA contracts –** from developing innovative spacecraft, components and systems for specific ESA missions to exploring innovative technologies with the potential to support future ESA missions in the longer term and developing innovation applications of space infrastructure.
- **Although many of the contracts are still in progress, a wide range of direct outputs have already been generated** in terms of progression of technology readiness levels, new products and services, and skills. Evidence on patents and spin-outs is rather limited, but in line with the expected time lags of R&D and innovation activities.
- **ESA contracts have supported (and will continue to support) collaborations and new strategic partnerships.** Current ESA contracts directly support large numbers of collaborations; 88% of contractors reported at least one form of collaboration. Furthermore, a third of contractors (34%) reported developing new significant international strategic partnerships as a result of their ESA contracts (in Europe and beyond).

- **The initial innovation outputs have translated into early economic gains for the UK Space Industry.** 32% of ESA contractors reported (via a survey) follow-on sales already achieved from products, services and the capabilities developed within their contracts, with the sales leading to the creation and/or retention of employment. 60% expect follow-on sales in the future. These follow-on sales are due, in part, to reputational effect of working with ESA, with UK ESA contracts perceiving that having the ESA 'badge of approval' allows demonstrating high levels of technical and professional capabilities and quality which are particularly valuable in international markets.

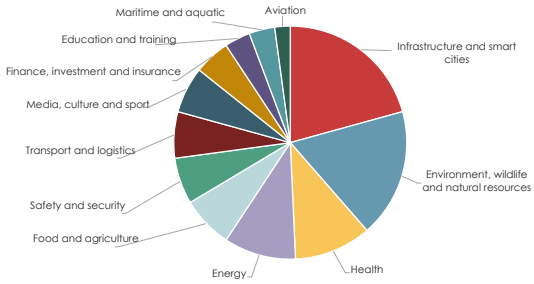
Economic effects for ESA contractors



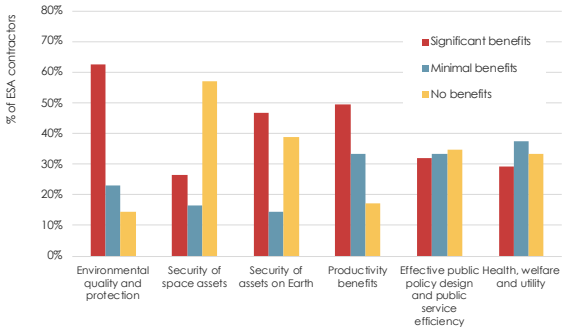
Wider innovation and usage benefits (spillovers)

- There is a high expectation from stakeholders as to future socio-economic benefits of missions being developed under CMIN19. These include environmental protection and security of space assets in particular, but also in the security of assets on Earth, productivity and improved public policy design and delivery and benefits in health, welfare and utility.

Downstream applications being developed under TIA



Downstream applications and benefits expected



Examples of wider innovation and usage benefits

EO missions with UK contributions will provide improved assessments of Essential Climate Variables including CO2 (e.g. TRUTHS, CO2M) missions) and better data for weather modelling and ecology mapping, water, agriculture and forestry management, predicting and managing natural disasters (e.g. HydroGNSS, CHIME. LSTM, ROSE)	TIA is supporting the reach and applications of 5G, providing additional capacity from space and increased coverage to support increasing demand for communications and data capacity for applications from IoT to autonomous vehicles. The TIA IRIS partnership will support increasingly digitally driven and more effective management of airspace	Contracts under the TIA Business Applications and Space Solutions programme are supporting the development of innovative applications in a wide range of domains using existing operational space infrastructure. The majority (65%) are using data from EO space assets, with others using satellite communications capabilities (22%) and satellite navigation (7%). *An assessment of these expected benefits is presented below in the 'Economic assessment' section.*

GLOBAL INFLUENCE

- As the fourth largest investor in ESA (out of 22 member states), contributing 10% to the total ESA budget in the CMIN19 period, the UK has considerable influence within ESA. The UKSA plays a full and active role at a political level and in all of ESA's formal governance structures. In addition, the UK is disproportionately over-represented within ESA's scientific advisory structures and had a central role in the recent development of ESA long-term scientific strategy Voyage 2050. Globally, ESA is one of the largest civil space agencies (in the top three), giving the UK an additional pathway to international influence in the space realm over and above its national influence.
- Nevertheless, ESA contractors would like to see even more UK leadership and influence: only 50-60% of ESA contractors think that that the UK is well-represented within ESA senior leadership and that the UK's space sector's capabilities and needs are reflected in ESA strategy.

SECURITY & PROTECTION

- **CMIN19 investments are also developing new capabilities to support a range of future applications in security and protection.** The ESA EO missions in development with significant UK contributions, such as CO2M, HydroGNSS and TRUTHS, will add to the space EO capabilities, with CO2M and TRUTHS in particular increasing the accuracy and robustness of the internationally agreed essential climate variable (ECVs). Timescales to impacts vary (depending on the phase of development of missions): HydroGNSS and CO2M will launch during the CMIN19 period and TRUTHS will not launch until 2029.
- The UK is also a major contributor to the SSS programme, both clearly aligned with UK's national priorities in space security (protecting space assets from space debris and protecting terrestrial assets from significant space weather events). Demonstration debris removal and clean space missions will launch during the CMIN19 period and the space weather mission (Vigil) will not launch until at least 2030.

CONTRIBUTING TO NET-ZERO

Historically the focus of ESA and USKA 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.

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.

ECONOMIC ASSESSMENT

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 (*) (2020 prices)	Duration
Direct and Indirect effects and of ESA funded activities (CMIN 19 contracts)	**1:0.86 (**)**	**£1.45bn**	Up to 2030 (5 years after last spending year)
ESA-derived activities	**1:2.5**	**£4.3bn**	2020-2036 (11.5 years after last contract)
ESA-derived spillovers (***)	**1:8.4**	**£14.2bn**	Long-term
Total	**1:11.8**	**£20.0bn**	

(*) Based on projected spend for CMIN19 investment period (**) Including a direct GVA effect of 1:49. (***) Spillovers are expected to materialise in the long-term and at this point in time, had to be estimated based on evidence from prior studies, and consequently relies in strong assumptions

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 ((2020 prices)	Duration
Direct and indirect effects of ESA funded activities	**1: 6.2**	**10,485**	Up to 2030 (5 years after last spending year)
ESA-derived activities	**1: 3.6**	**6,039**	2020-2036 (11.5 years after last contracts)
Total	**1: 9.8**	**16,524**	

(*) Based on projected spend for CMIN19 investment period

SUMMARY

The table overleaf resents a synthesis of the evaluation, presenting a summary of the extent and manner in which, each of the eight ESA programmes contribute to the impact domains identified in the CMIN19 business case and used in the ToC. The table below identifies how the impact domains map on to the five goals of the new National Space Strategy that was published during the evaluation (in September 2021). The goals are also identified 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

Summary of ESA programmes and impact effects

	Increased global influence (Goal 2)	Increased prosperity and (scientific) knowledge			Increased security and protection (Goal 4 / Goal 5))		
		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 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 expect impact **Grey:** no/limited impact

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 and 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 and the UKSA Evaluation Strategy.[1]

The study covers eight space 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
UKSA Evaluation strategy, August 2015
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 (*Impact Evaluation: PART A*) 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 provides an overview of the methodology and the theory of change (ToC)
- Chapter 3 presents the *inputs* i.e. the current and planned investments made/ to be made during the ESA CMIN19 investment period
- Chapters 4 to 7 presents the impact evaluation evidence for the *outputs* and *outcomes* identified in the theory of change. It is structured into the four high-level impact domains
  - Knowledge
  - Prosperity
  - Security and protection
  - Global influence
- Chapter 8 presents the added value for the UK of investing via ESA
- Chapter 9 presents the economic assessment
- Chapter 10 presents a consideration of the contribution of UK ESA investments to net-zero
- Chapter 11 presents consideration of the contribution of UK' ESA investments to levelling up
- Chapter 12 presents the summary and conclusions

This report is accompanied by three separate documents:

- *Impact Evaluation Report: PART B* – a presentation of the analysis of the theories of change for each of the eight ESA programmes
- *Impact Report: Technical Annex* – a longer report presenting the evaluation data and findings in more detail
- *Appendices*

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]

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

- **Long-lead times of space R&D and innovation (RDI) investments**: the UK and ESA are investing in the development of space infrastructure that have 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, explores the (ToC).
- **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.
- The qualitative data gathering methods within TBE allows the **complexity of the ESA investments to be fully explored**. ESA investments 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 to 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 is intended to support a diverse range of scientific, economic and social activities and impacts - from understanding the Universe and the Earth's climate to providing communications capabilities in remote places, providing weather forecasts and monitoring disasters

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.

[4] HMT Magenta Book, March 2020

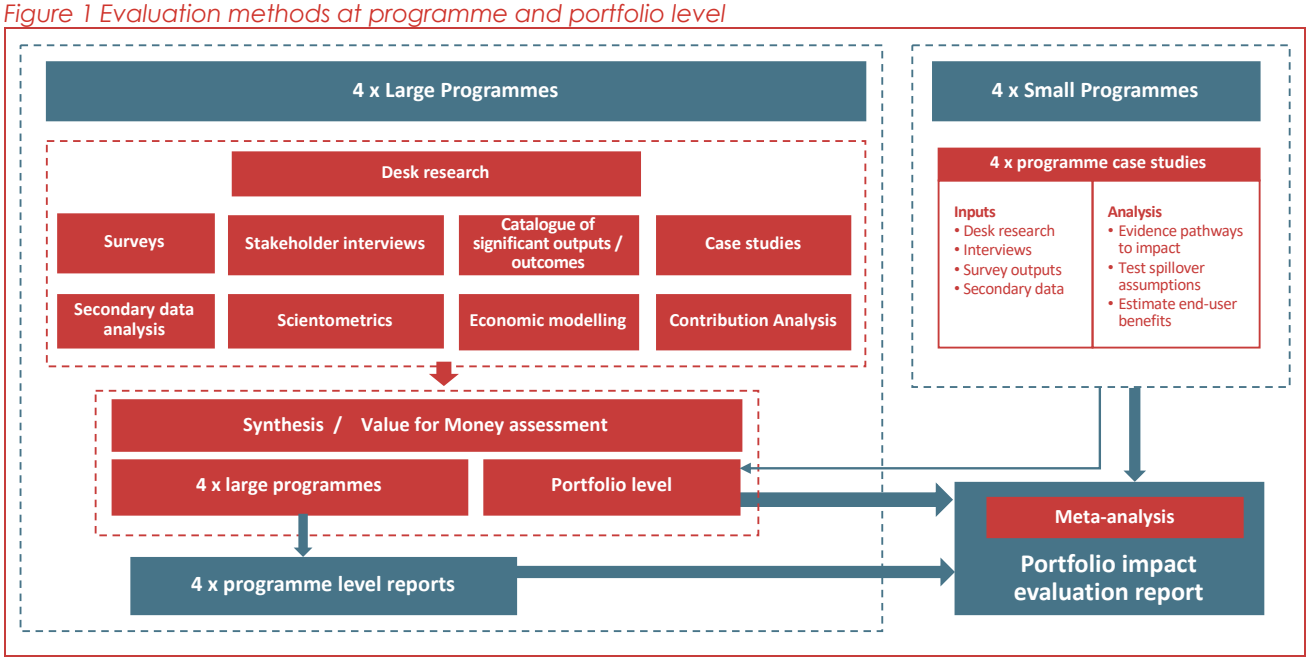
[5] ESA has 22 Full Member States (who sit on the ESA Council): Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. There three 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.

2.2 Methods

The methodology is described in full in the evaluation framework[6] and here we provide an overview of 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 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, and are additional to, 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

Figure 1 Evaluation methods at programme and portfolio level



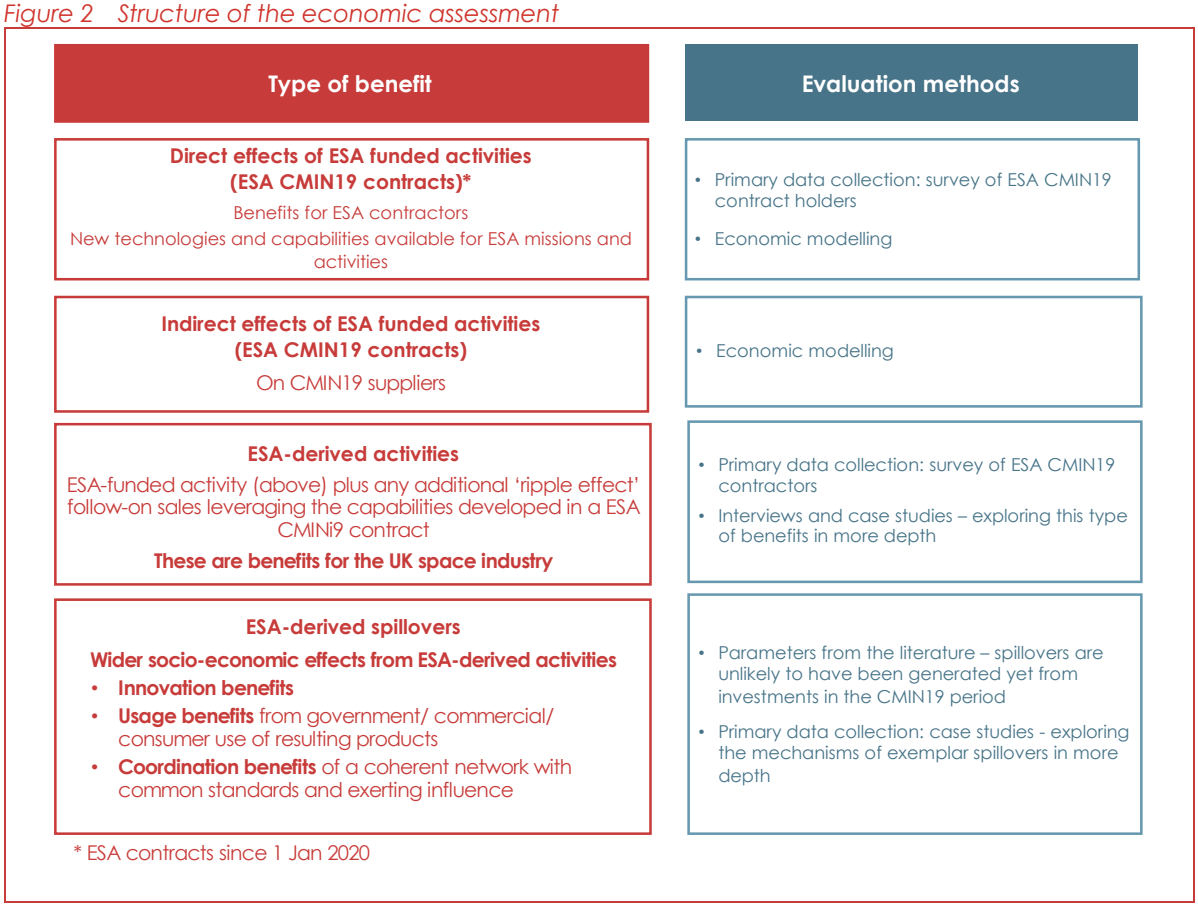
Technopolis (2021)

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

Table 2 Methods to assess the impact categories

Impact domain	Desk research	Primary research	Analytical approaches	Counterfactual
Knowledge	Literature review Bibliometric databases HESA data	Interviews ESA contractor survey Case studies	Descriptive statistics Bibliometric analysis Altmetric analysis	Qualitative (CA)
Prosperity	Literature review Business information / patent databases	ESA contractor survey Interviews Case studies	Descriptive statistics Economic modelling	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)

Figure 2 Structure of the economic assessment



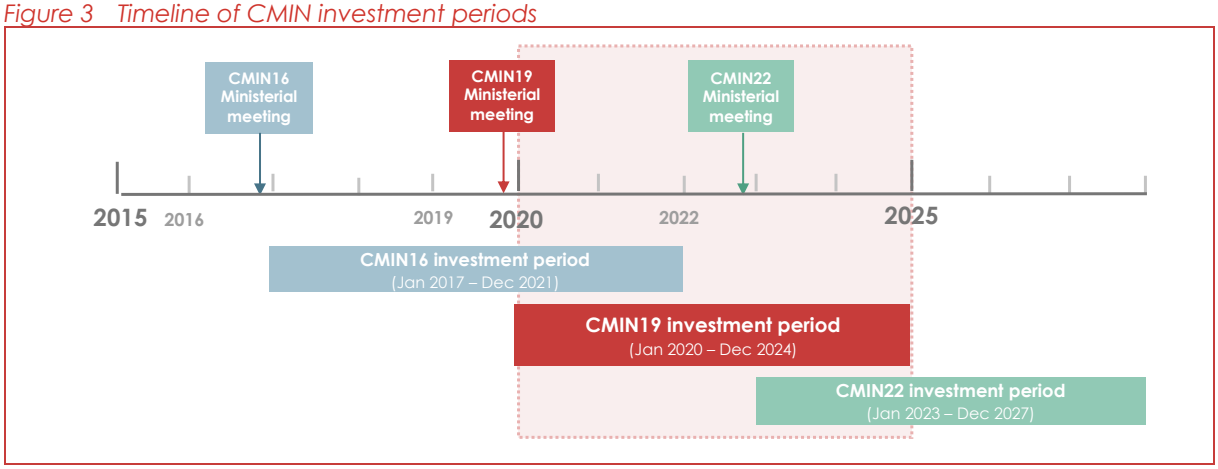
Technopolis (2021)

2.3 Time periods and investment covered by the first evaluation of CMIN19

The focus of the evaluation is the UK investments agreed at CMIN19 for the five-year period from January 2020 to December 2024.[7] However there are number of practical challenges to evaluating these investments:

- The evaluation is taking place at an early point in the CMIN19 investment lifecycle. At this point in time, not all investments (i.e. not all ESA contracts) have yet been made and most of the contracts that are in place have not yet finished. As shown in Table 3, 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, it is only 20-25% into the CMIN19 investment period. This means that it is too soon for impacts and most outcomes to have been generated. Therefore, the first evaluation has focused on:
  - Providing a clear picture of inputs i.e. the investments made (ESA contracts) to date
  - Capturing evidence of the direct outputs of ESA contracts
  - Capturing evidence of any early outcomes generated
  - Developing a baseline for this and future evaluation[8]
- Development of space infrastructure require investments over long periods of time (typically 10-15 years but can be longer) and are expected to span several CMIN investment period - both those before and after the CMIN19 period. This means that CMIN investment periods overlap (Figure 3) and, in ESA's annual budget 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 we took 1 January 2020 as the starting point for the current and included investments and activities starting from that date. 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.

Figure 3 Timeline of CMIN investment periods



Technopolis 2022

[7] The business case also shows that there are some longer investments agreed, with 5% of the agreed total CMIN19 funding allocated for 2025 to 2028.

[8] This report is primarily focused on the achievements to date. The baseline data is presented in the *Impact Evaluation: Technical Report Annex*. A small number of specific baseline indicators are provided where it has been instructive to do so

Table 3 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	**21months** *(as of Oct 2021)*	**€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 directedly compared – this is explained further in the chapter on 'CMIN19 Inputs' (Chapter 3)

2.4 Theory of change (ToC) 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 for UK investments in ESA (Figure 4). The ToC for each programme level was provided in an appendix to the evaluation framework[11] with each presented as a tailored version of the over-arching logic model and a detailed explanatory narrative. 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 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

[9] Data from the *ESA Financial Obligations* datasheet - this provides the expenditure for each ESA member state 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 (€1,598m) is the total value of the CMIN19 for 2020-2024 proposed in the UKSA CMIN19 business case. The upper bound (€2,114m) 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)

[11] Design, development and implementation of a monitoring and evaluation programme for the UK Space Agency's investments in the European Space Agency, Appendix A Programme Theories of Change

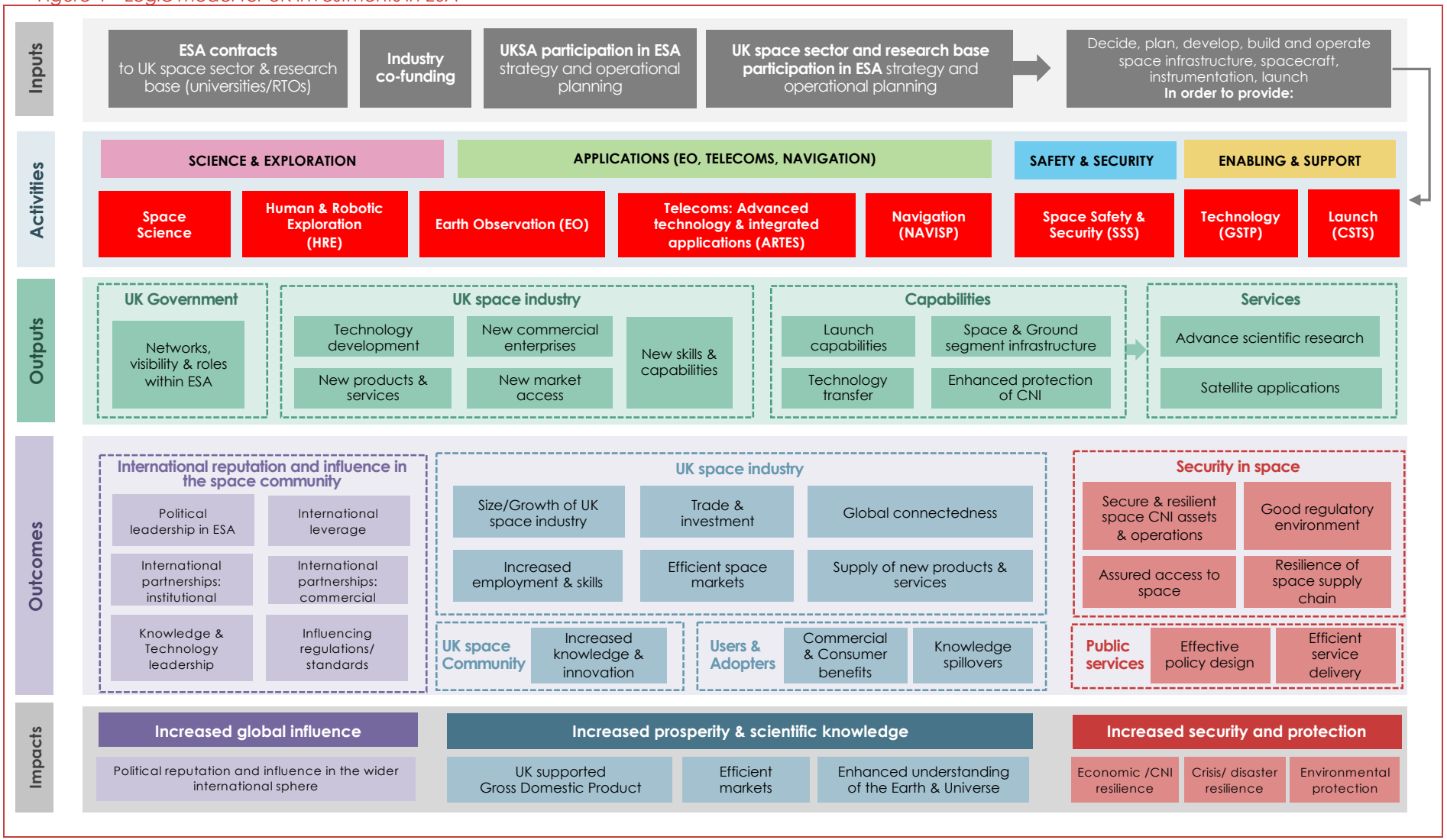
will make a contribution to the outcome and impacts but they will not be fully attributable to ESA investments.

We note that a new UK National Space Strategy was published during the evaluation (in September 2021) and therefore after the ToC 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.

Table 4 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

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. *

3 CMIN19 inputs

Summary

- The **UK has committed €2,114m to ESA for the five-year period from Jan 2020 to Dec 2024**. This includes commitments made at the ESA Ministerial Council in late 2019 (CMIN19) and on-going commitments made in 2016
- **90% of the budget is assigned to the four large ESA programmes**: Science, EO, TIA & HRE
- **ESA contracts with total value of €392m have been 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)
- **88% of contracts are with industry.** Six companies account for 50% (by value) of the contracts. This pattern of investments reflects the concentrated structure of the UK space industry
- **Industrial co-funding is required under some ESA programmes and, for contracts let to date, it is estimated to be of the order of €145m**

3.1 Introduction

This section presents data on the UK's financial investments for the CMIN19 period in two ways (both are based on datasets provided by ESA):

- **The expected investments the UK will make via ESA**
  This is based on ESA's actual and planned annual expenditure[12] and does not distinguish between investments committed at CMIN19 or the previous CMIN16. Therefore, the expenditure in any one year may contain data for contracts that started before the CMIN19 period (i.e. before 2020) and may include expenditure based on UK commitments to ESA made prior to CMIN19.
- **The number and value of ESA contracts let to UK organisations**
  This is based on ESA's geo-return dataset[13] that provides information on the value of contracts in the year they were signed i.e. the total contract value is assigned to the year the contracts were signed. For the evaluation we included all contracts[14] let to UK organisations that started in period from 1 January 2020 to 30 June 2021.

The differences in the design of the two datasets means that data on the value of expected expenditure and on the value of contracts signed cannot be directly compared.[15]

1.1 UK's annual commitments to ESA

Table 5 presents the UK investments made and expected to be made via ESA from 2017 to 2026. **The data relevant to the evaluation is the expenditure for the period from January 2020 to December 2024**. As noted above, it includes the funding agreed at CMIN19 plus the funding agreed at CMIN16 that 'carries-over' into 2020-2024. We present the data from 2017-2026 to

[12] Data source: ESA datasheet ESA Report on Contributors' Financial Obligations"

[13] ESA data source: "ESA geo-return datasheet, Q2 2021". This was the most recent version available at the time of the evaluation

[14] "contracts" here includes both contracts let to a lead organisation in the UK and sub-contracts let to UK organisations

[15] The datasets are described in more detail in the *Impact Evaluation: Technical Report Annex*

demonstrate the continuity of ESA funding before and after CMIN19.[16] 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.[17]

Table 5 UK commitment to ESA 2017-2026 (M€)

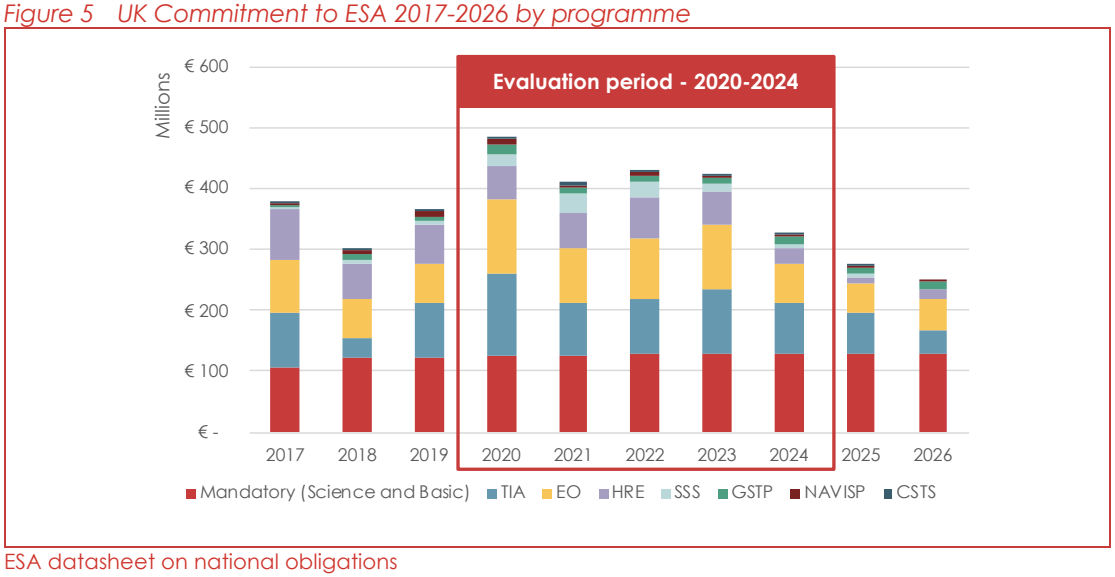
				Evaluation period						
Year	2017	2018	2019	**2020**	**2021**	**2022**	**2023**	**2024**	2025	2026
UK commitment to ESA	€375.0	€300.0	€361.7	**€490.7**	**€418.8**	**€438.5**	**€433.0**	**€332.7**	€273.2	€251.7

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,[18] 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.

Figure 5 UK Commitment to ESA 2017-2026 by programme



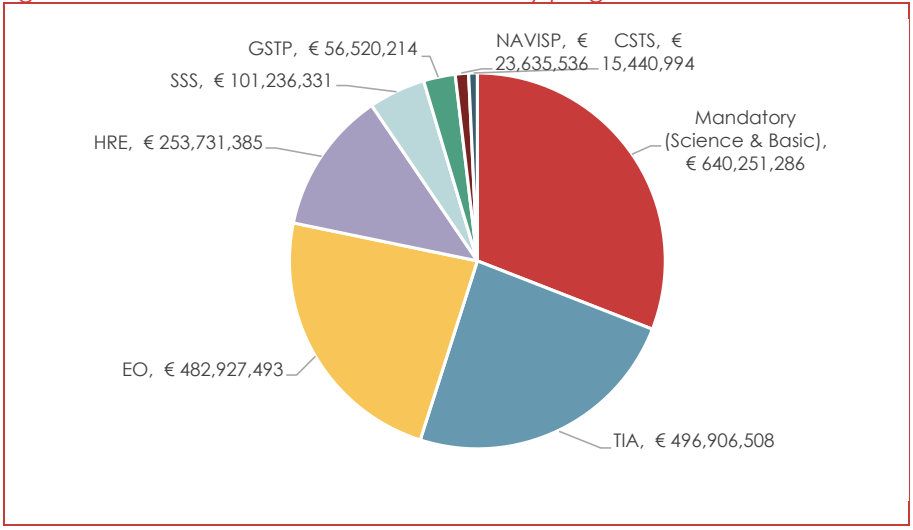
ESA datasheet on national obligations

[16] The data for 2026 and 2027 are taken from the ESA obligations data set. 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)

[17] 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

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

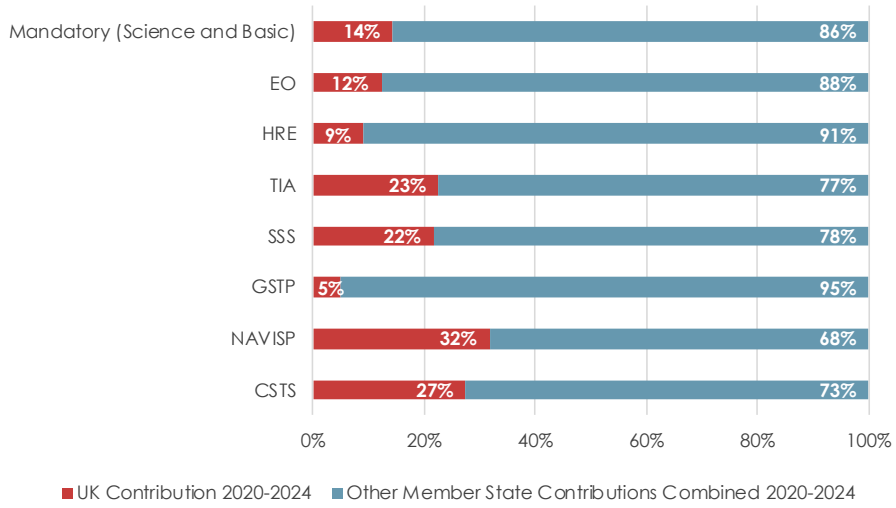
Figure 6 UK Commitment to ESA 2020-2024 by programme



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

3.2 Value of UK ESA contracts let to date (to end of June 2021)

Table 6 and Table 7 present 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 contracts 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 estimated carry-over expenditure from CMIN16 commitment is excluded).[19] At 21 months into a five-year investment period (35% of the way though), this suggests that UK contracts are running behind schedule. However, the contracts vary greatly in size and a number of large contracts are expected for UK organisations in Science, EO and HRE that will change the total value considerably. For example, since the data was provided for the evaluation, Airbus (France and UK) have been contracted (value ~€200m) to build the Science programme's ARIEL spacecraft and SSTL has been contracted (€24m) to build the HydroGNSS EO spacecraft and develop the communications services for HRE's Lunar Pathfinder (€12m).

Table 6 Value of ESA contracts let to UK organisations

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

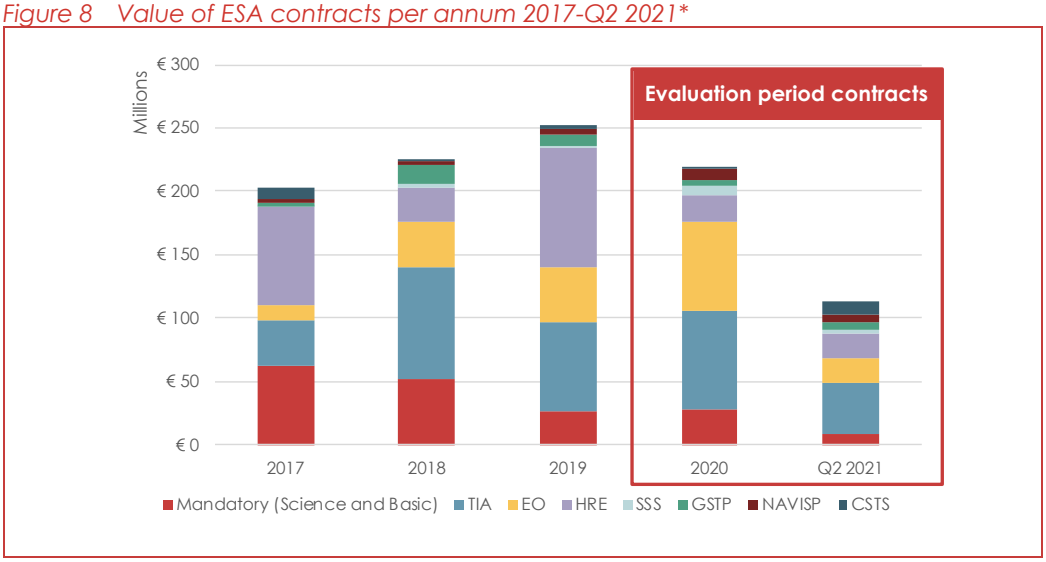
ESA geo-return datasheet

Table 7 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

[19] As noted in footnote 10, we estimate the carry-over to be 25% of the €2,114m figure

3.3 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 industry 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.

Table 8 provides an estimate of industry co-funding for relevant contracts let during the CMN19 period (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.

The total estimated industrial co-funding is €145m which is an additional 37% investment of the €392m contract value.

Table 8 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

3.4 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 (Table 9). Six organisations account for 50% of the value of contracts let since Jan 2020 to Q2 2021and the top 10 account for 59% (Figure 9), reflecting the structure of the UK space industry where 13 organisations accounting for 82% of total space-related income.[20] 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 in ESA member states have the capacity and capabilities to do this and these contracts tend to large in value and are preceded by several

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

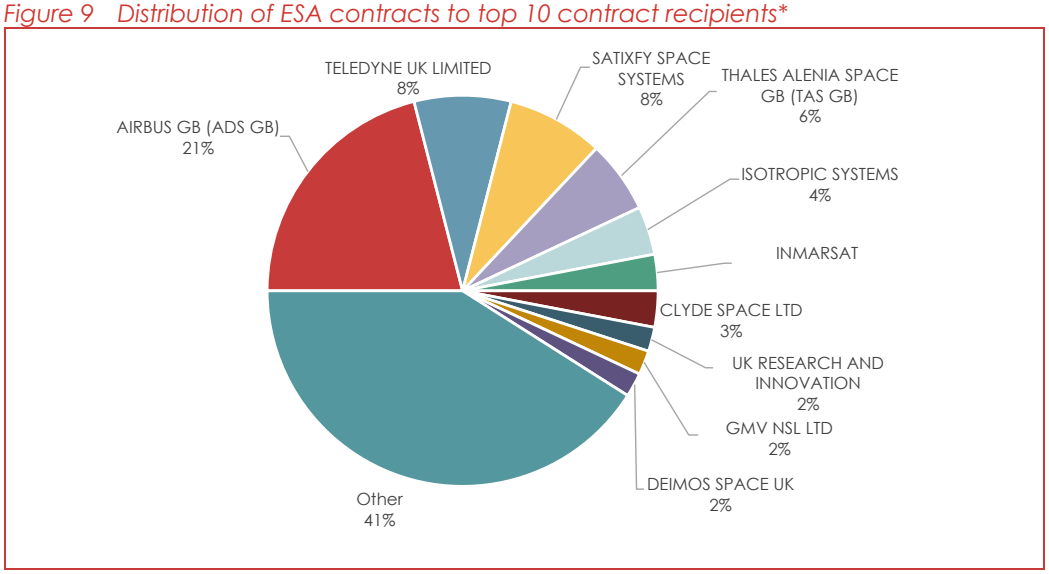
smaller contracts to develop spacecraft designs. Airbus UK (and its subsidiaries such as SSTL) is particularly active in Science, EO, HRE and SSS with multiple contracts related to the development and build of spacecraft for missions including LISA, TRUTHs, Earthcare, Mars Sample return, Lunar Gateway, Vigil.[21] 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 9 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

*Figure 9 Distribution of ESA contracts to top 10 contract recipients**



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

3.5 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:

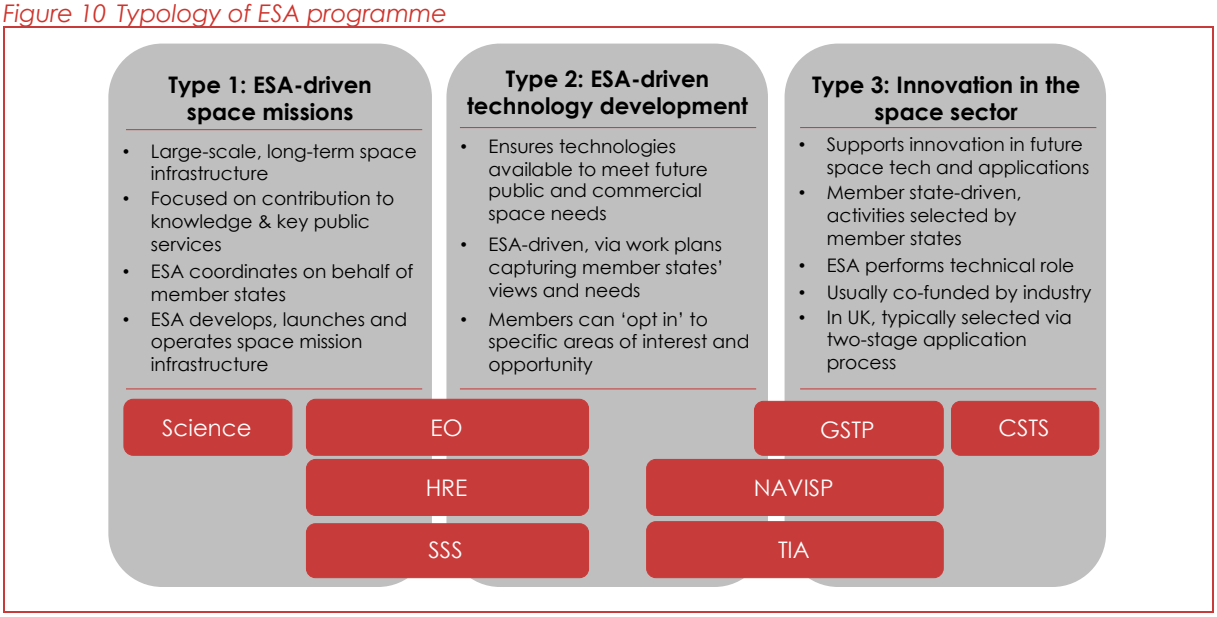
- **ESA-driven space missions** – building and operating large-scale space infrastructure. Each mission is a highly complex and long-term endeavour that requires equally complex management and oversight and includes ESA activities to:

[21] 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

  - Coordinate member 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' inputs to mission objectives, design and instrumentation
  - Integrate, launch and operate missions in space.
- **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 to identify needs, propose ideas and agree workplans to develop the technologies needed for the future
  - Procure and fund technology development
  - Monitor contracts, provide technical support to contractors and validate outputs
- **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

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 four key impact domains identified in the ToC:

- Increased knowledge
- Increase prosperity
- Increased security and protection
- Increased global influence

We do this to keep data for outputs and outcomes for each domain together, while noting that **the domains 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 to all contracts as the role of a mid-programme evaluation is to assess progress to date.

The majority of the quantitative data presented for outputs and outcomes achieved to date has been derived from a survey of *ESA contractors*. The survey was targeted at every UK organisation holding at least one ESA contract in each ESA programme in the evaluation period. This meant that organisations involved in more than one programme were asked to complete more than one survey (i.e. they were asked to compete one survey per programme). As a result, the target population for the survey was 358.[23]

Securing responses to the survey proved challenging, requiring numerous requests from both the evaluation team and UKSA staff and it was necessary to extend the survey data collection period from three weeks to three months to gain sufficient responses. Nevertheless, a good response rate of 34% was achieved, sufficient to draw conclusions about the ESA investments. Significant efforts were made to gain responses from the contractors from industry as they represent the majority of ESA contractors (by number and value) and, in particular, from the contractors that accounted for a high proportion of the total value of contracts let to date. AS a result, the survey respondents represented 61% of ESA contracts by value. Table 10 presents the number of survey targets and responses and response rates by programme.

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

[23] Further details of the survey are presented in the *Impact Evaluation: Technical Report Annex*

Table 10 Survey target population 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[24]	49	88	22	25%
TOTAL	**255**	**358**	**123**	**34%**

Technopolis 2022. *where 'target' refers to all survey requests and is larger than the no. of organisations because some organisations are active in more than one programme

Survey respondents were invited to provide projections for expected values 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 9.

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.

At this early point in the CMIN19 investment period, secondary data (e.g. bibliographic, patent, investment data, etc) is used primarily to compile baseline indicator only - for two reasons: because it is too soon for outcomes of CMIN19 to have been generated; and because there are time lags in secondary sets meaning that data is either not available or not complete for the most recent years.

Note on the baseline data presented

We present the baseline data for the indicators used wherever it has been possible to do so. 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 and 2019 alongside the output data collected for the two-year period 2020 and 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 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, 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 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.

[24] "Other" includes the organisations referred to as Public Sector Research Establishments (PSRE)and Research and Technology Organisations (RTO) i.e. RAL Space, NPL, Met Office, Satellite Applications Catapult, Plymouth Marine Laboratory, National Oceanographic Centre, UK Centre for Ecology and Hydrology, Trinity House

4 Impact domain: Knowledge

Summary

- **Scientific impact is expected but yet to materialise.** The Science, EO and HRE programmes support space missions that aim to generate new knowledge about the Earth, Solar System and Universe. The majority of scientific impact (new knowledge) from missions being developed during the CMIN19 period will not arise until missions are launched and making observations. Nevertheless, some papers have been published as a result of ESA contracts.
- **The baseline data shows that the majority of the UK's ESA-related space publications arise from the Science programme** (84%) and that the UK publications are growing in quantity (number of papers) and increasing in quality (citations). Furthermore, the publication rate per £ invested compares favourably to other key space-faring countries.
- **ESA's science-based programmes play an important role in terms of outreach**. They provided interesting and exciting content for outreach activities to engage the public and inspire young people, especially in terms of choosing subjects in science, technology, engineering and maths (STEM) for study and for careers. The evaluation developed a baseline for higher education enrolments for three groups of relevant courses (space-specific, space-related and wider physical sciences and engineering) which will allow tracking longer-term outcome of activities directed at school children. As the activities target children from primary school to sixth, the effects of these activities will materialise over timescales from 2-12 years.

4.1 Introduction

The Science, EO and HRE programmes support space missions that aim to generate new knowledge about the Earth, Solar System and Universe. However, the majority of scientific impact (new knowledge) from missions being developed during the CMIN19 period will not arise until missions are launched and making observations.

As most missions under development in CMIN19 have not yet been launched, they are not yet generating data to support the intended scientific research. Two missions in the Science programme were launched early in CMIN19 as their development, largely funded under earlier CMINs, was completed in 2020 and 2021 (Solar Orbiter and James Webb Space Telescope (with NASA)) and Solar Orbiter is just starting to generate data. Other missions, such as JUICE, Euclid, HydroGNSS, CO2M will launch later in CMIN19 and others will launch in subsequent investment periods (e.g. ARIEL, TRUTHS, Vigil, ESPRIT Re-fuelling) with some (LISA, ATHENA) as much as 20 years away from launch and delivering scientific impacts.

Indicators

The indicators for the **knowledge** domain address the increase in scientific knowledge as a result of ESA contracts.[25] The data for the indicators are based on primary data collected via the survey of ESA contractors (output data) plus baseline data from bibliographic databases (outcome data).

We present the output data plus some key features of the baseline from the bibliographic data. Due to the time lags inherent to generating and publishing peer-reviewed research publications ('papers') plus time lags in indexing papers in the bibliographic databases, the bibliometric indicators do not as yet reveal any data regarding the papers arising from CMIN19

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

investments. The full set of baseline bibliometric indicators are provided in the *Impact Evaluation: Technical Report Annex.*

4.2 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 i.e. papers that relate to the development of missions, such as the development of mission concepts and instrumentation design, rather than the scientific research conducted one missions have been launched.

Table 11 No. of papers arising directly from ESA contracts

Programme	No. of papers authored / co-authored by ESA contractors					
	2018-2019 (baseline)			2020-2021		
	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[26] reported a total of 67 papers in the baseline period and 109 papers in the current CMIM19 period (Table 11).[27]

- The majority of papers published in both time periods were in EO
- Three organisations account for a large share of the papers in both periods (54% in the baseline period, 38% in the 2020-2021 period) with these being from the public / semi-public research sector[28] - Plymouth Marine Laboratory (PML); National Oceanographic Centre (NOC) and National Physical Laboratory (NPL). These three organisations are predominantly active in the EO domain
- Industry is publishing papers in peer-reviewed journals, with papers reported by both technology-driven companies developing hardware and software for space activities (upstream) and by companies developing applications using space data (downstream)
- Respondents reported that, on average, it takes 1.6 years from the start of an ESA contract to publishing a paper (range 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 (range 0–40 years).

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

[27] See note on page 18 regarding the baseline data

[28] i.e. organisations referred to as Public Sector Research Establishments (PSREs) or Research and Technology Organisations (RTOs)

- Some respondents reported zero years to the start of the benefit (papers published in this case). This is rather surprising given that this requires R&D activities to be completed, papers drafted, peer-reviewed and published (it can then take 6-18 months from submission of a paper to publication). Taken with the fact that many papers published are by three research labs that have had contracts in prior CMIN periods, it may be that some of the papers reported to date are based on R&D activities from these earlier periods.

4.3 Outcomes: ESA-related research (baseline)

As noted in the introduction, at this early point in the lifecycle of CMIN19, no papers have been published as yet a result of data generated by missions funded under CMIN19. Therefore, the bibliometric analysis was undertaken to provide a baseline for future monitoring of the quantity and quality of new knowledge outputs of UK investments in ESA.[29] The full baseline is presented in the *Impact Evaluation: Technical Report Annex*. Here we present some of the key bibliometric outcome indicators.

The bibliometric analysis focused on 'ESA-related papers' – papers identified via a reference to ESA, named ESA programmes or specific ESA missions plus papers reported via ResearchFish. Papers were assigned to individual programmes based on reference to the programme name, mission name or a research domain that clearly aligned to a specific programme.

Papers can be published throughout the lifetime of the development, launch and use of a mission and data from ESA space missions will be used for many years, sometimes decades. Papers are still being published from missions dating back to the late1990s (e.g. SOHO and XMM-Newton). For CMIN19, Solar Orbiter, launched in February 2020 and ESA instruments are on board NASA's James Webb Space telescope launched in late 2021 and these are expected to start generating papers in the near future. The EUCLID and JUICE missions are planned to launch during the CMIN19 period (in 2022) and missions such as PLATO and ARIEL are expected to launch in later CMIN periods (2026 and 2028 respectively), while others such as TRUTHS, LISA and ATHENA will not launch until 2029 or the early 2030s.

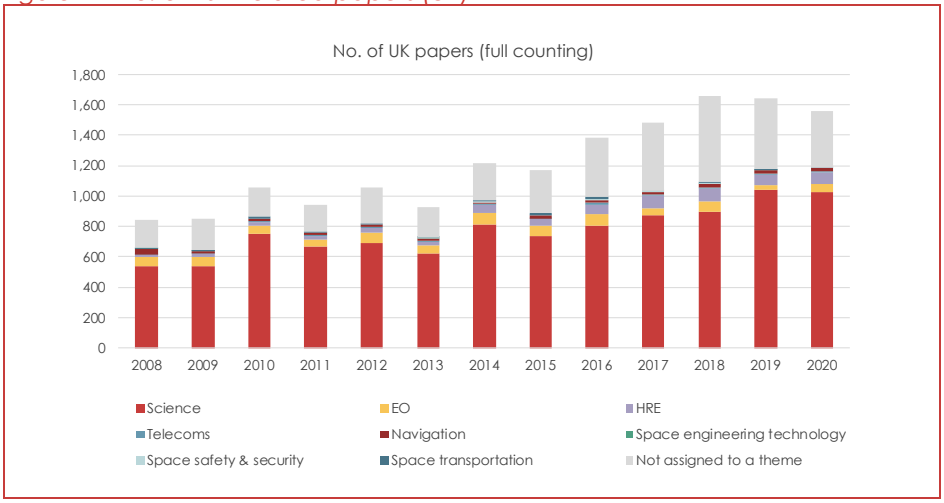
4.3.1 Quantity of ESA-related research (baseline)

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).

Three-quarters of all the papers that could be assigned to themes that align with specific ESA programmes and of these 84% were related to the Science programme (Figure 11). This reflects the fact that the Science programme is entirely focused on generating new knowledge about the Universe and Solar System. 50-70 papers a year are published in EO (related to ESA EO infrastructure) representing 4-10% of all annual papers (that were assigned to a programme). This reflects the fact that EO has a strong focus on scientific understanding. Papers in HRE have been increasing from around 20 a year from 2008-2013, rising to around 55 a year in 2017-2017 and around 75 a year in 2018-2020 reflecting the UK's increasing investment in HRE.

[29] The baseline is not analysed or interpreted in terms of an evaluation of outcomes of past investments in ESA as this the current evaluation is focused on the effects of CMIN19 investments

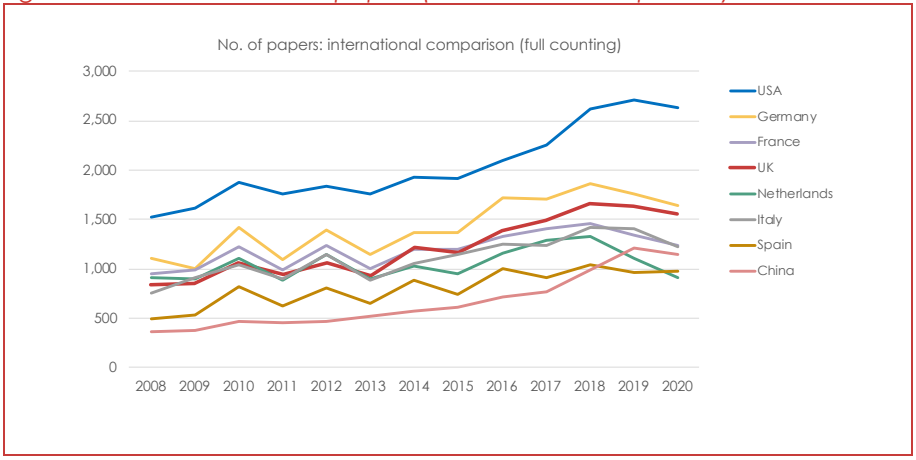
Figure 11 No. of ESA-related papers (UK)



Science-Metrix (2021) / Scopus

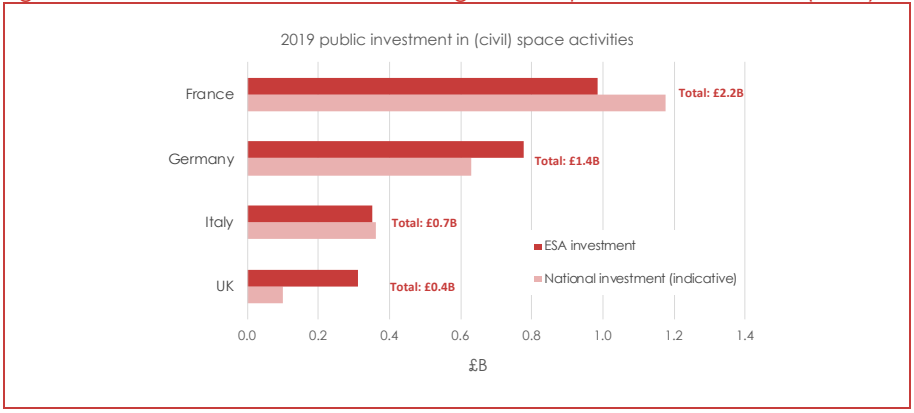
In terms of its international peers, in recent years the UK ranks third in terms of number of ESA-related papers behind the USA and Germany (Figure 12). However, the UK publishes more papers per £ invested than Germany, France, Italy (who along with the UK are the top four investors in ESA), USA and China (Table 12).

Figure 12 No. of ESA-related papers (international comparison)



Science-Metrix (2021) / Scopus

Figure 13 Indicative national / ESA budgets for top 4 ESA contributors (2019)



Technopolis (2021)

Table 12 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]

4.3.2 *Scientific impact of ESA-related papers (baseline)*

Research quality is determined by the extent to which ESA-related papers are cited by others – as a measure of their value to other researchers and subsequent research (this is also referred to in bibliometric analysis as 'scientific impact'). 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): citations of all papers published by a given entity (e.g. research group, institution or country) normalised in terms of research discipline, type of publication and year of publication (to enable comparisons across time and disciplines). 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): the extent to which citations of papers from a given entity are among the highest in their respective field. We considered highly cited papers at three levels: the top 10%, 5% and 1% of cited papers.[31] The indicator is frequently used to examine research excellence, measuring how many high-impact papers are produced by a given entity, relative to their expected contribution to world-leading research.

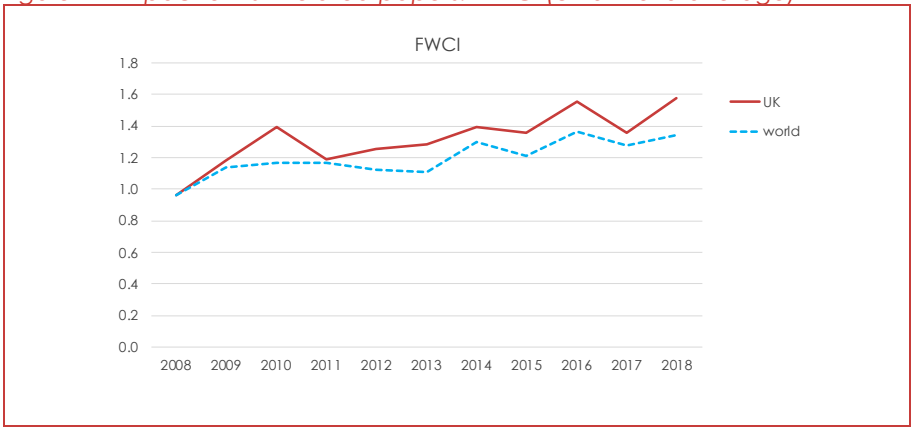
Over the 10-year period from 2008 to 2018 the UK has improved its research impact citation (Figure 14, Figure 15), increasing its FWCI from a value the same as the world average for all to a value almost 20% higher than the world average in 2018. The UK's HCP10 and HCP5 performance has also increased compared to the world average for all ESA-related papers. It should be noted that the FWCI values for all ESA-related papers worldwide ('world' in Figure 14) 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.

[30] ESA: https://www.esa.int/ESA_Multimedia/Images/2019/01/ESA_Budget_2019

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 comparable. A definitive budget for China's civil space investment is not available and it is estimated from articles in the public domain

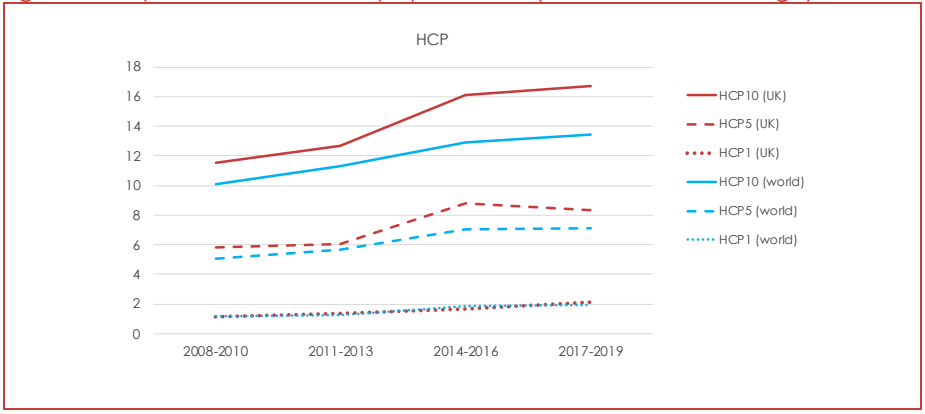
[31] E.g. for HCP10, an entity with an HCP above 10% contributes more than its expected to the highly-cited papers and an entity with an HCP below 10% contributes fewer than its expected number of highly cited publications (and similarly above and below 5% for HCP5 and above and below 1% for HCP1)

Figure 14 Impact of ESA-related papers: FWCI (UK & world average)



Science-Metrix (2021) / Scopus

Figure 15 Impact of ESA-related papers: HCP (UK and world average)

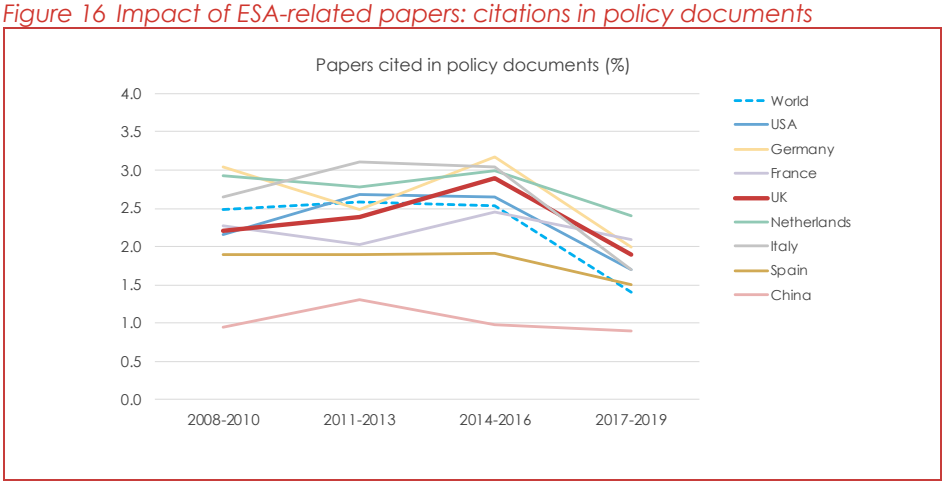


Science- Metrix (Scopus)

4.3.3 *Wider impact of ESA-related papers – citations in policy documents (baseline)*

The impact of the ESA-related papers is further assessed in terms of the extent to which they are cited in policy documents (Figure 16) as a measure of their contribution and value to public policy. The former provides an indication of one form of spillovers. Citations of UK papers in policy documents increased from 2008 to 2016 but has decreased in recent years, with a similar trend in most other key space-faring countries.

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



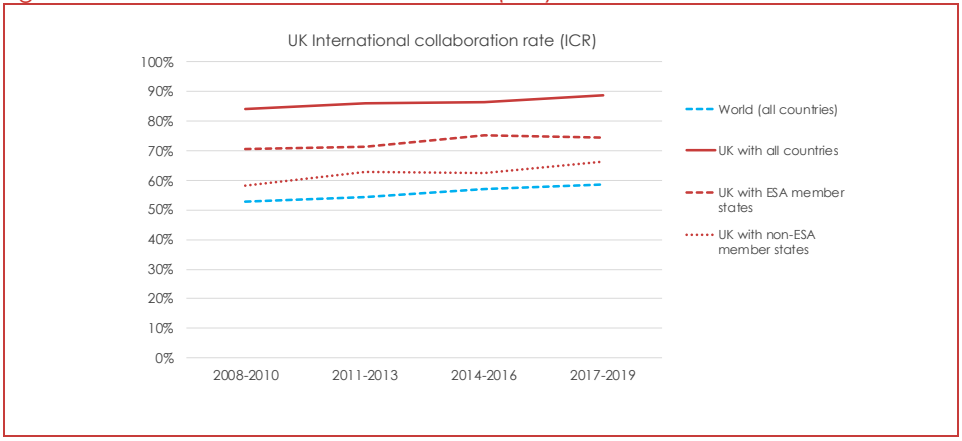
Science-Metrix (2021) / Scopus / Overton

4.3.4 *International research collaboration (baseline)*

Co-authorship of research papers provides a good measure of collaboration in the research activities. Therefore, the analysis of co-authors affiliated with organisations in different countries can be used to assess levels of international collaboration. We do this using the international collaboration rate (ICR), whereby the ICR of a country is a measure of how many articles are co-published with international partners as a proportion of the given country's total output.

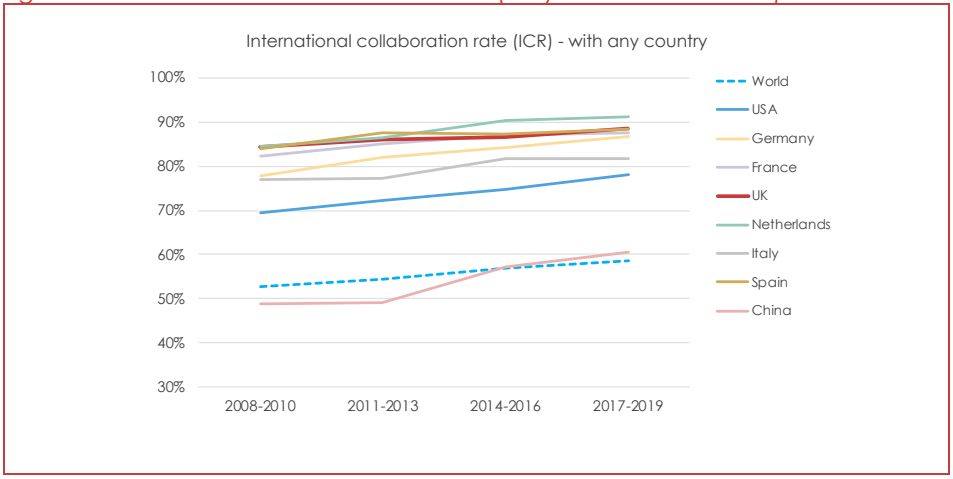
At a global level, the UK has had a high international collaboration rate for its ESA-related papers (Figure 17), with the majority of its papers (89% in the period 2017-2019) being published with researchers outside the UK (Figure 17). The UK's collaboration rate is slowly increasing following the trend in the world average and in other space-faring countries (Figure 18). The more detailed analysis (reported in the Impact Evaluation: Technical Report Annex) indicates that the UK's rate of collaboration with ESA member states is higher than for non-ESA countries which might be expected for ESA-related papers.

Figure 17 International Collaboration Rate (ICR) for the UK



Science-Metrix (2021) / Scopus

Figure 18 International Collaboration Rate (ICR): international comparison



Science-Metrix (2021) / Scopus

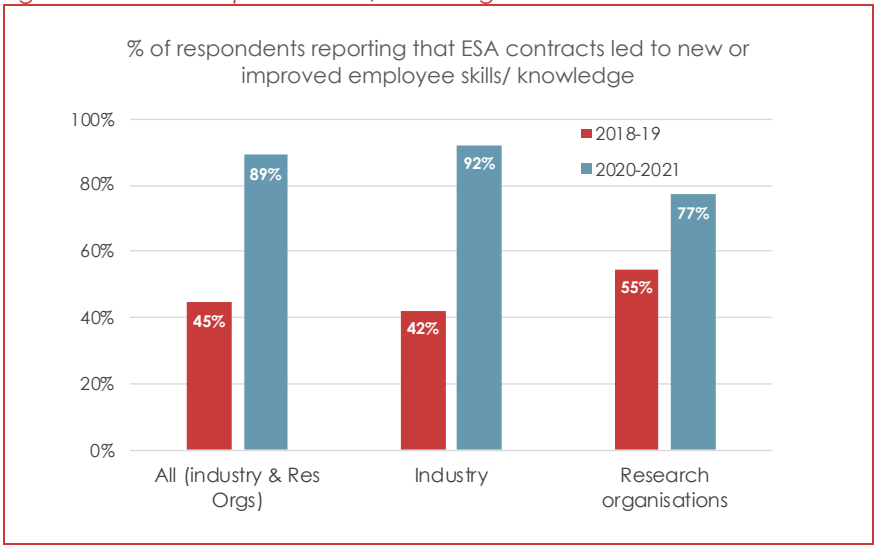
4.4 Skills

4.4.1 *Skills arising directly from ESA contracts*

The space industry requires a wide range of skills, some highly specific to the manufacturing, operation and use of space infrastructure, and others more generally applicable to complex

technological complex systems. A little under half of survey respondents (45%) reported an uplift in skills in the baseline period and 89% in the period 2020-2021 (Figure 19). We note, as for all comparisons of the 2020-2021 period with the baseline, 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.

Figure 19 New or improved skills/knowledge



ESA contractor survey

4.4.2 *Inspiration effect*

Space activities are also expected to contribute to longer-term skills development in space specific skills and in STEM more generally.[32] UKSA, like space agencies worldwide, undertakes dissemination and communication activities 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.

The *inspiration effect* is assessed in terms of (i) outputs: how many people were engaged with via outreach activities – using data collected by the UKSA Education and Outreach team and (ii) outcomes: how many people are studying space and STEM related subjects – using HESA data[33] on enrolment of students on relevant higher education (HE) courses.

4.4.2.1 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 office of ESA's European Space Education Resources Office (ESERO) are part-funded by ESA. UKSA also

[32] STEM = science, technology and engineering and mathematics

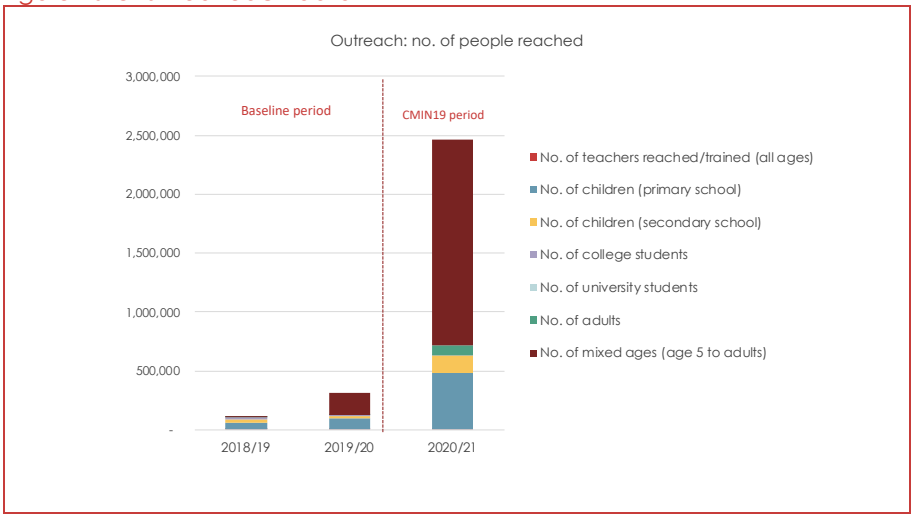
[33] HESA = Higher Education Statistics Agency

provides co-funding to UK-ESERO (Appendix G). ESERO also develops content and schemes to support national outreach activities[34]

- 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 20) represents the activities undertaken by both ESERO-UK and the UKSA Education and Skills Team (and their sub-contractors).

Figure 20 UKSA outreach data[35]



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

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.

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 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 and this may create more opportunities for outreach as was the case during his previous mission. 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.[36]

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

[35] The data is provided as a table in the *Impact Evaluation: Technical Annex*

[36] 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

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

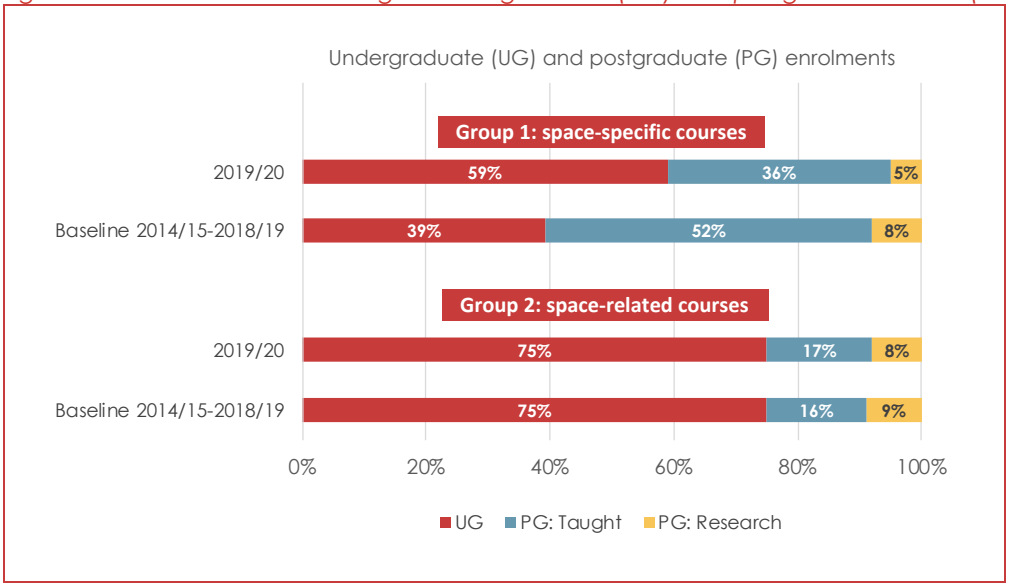
A baseline has been established for numbers of students enrolling on three groups of HE courses (based on the HESA typology):[37]

- **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
- **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

The data presents 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 (Figure 21, Figure 22)
- There appears to have been 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. This can be monitored in future years and this uplift can then be considered in terms of later trends.
- More students are enrolled on space-related courses (Group 2) compared to space-specific courses, with numbers of the order of 2,500 and 0.25% of all students, and a greater proportion of these are enrolled on undergraduate courses.

*Figure 21 No. of students enrolling at undergraduate (UG) and postgraduate levels (PG)**



Technopolis (2021)/ HESA data PG: Taught = Master's degrees, RG: research = PhDs

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

[37] The specific subjects included in each group are provided in Appendix G

Figure 22 No. of students enrolling on subjects relevant to space

Technopolis (2021)/ HESA data

4.5 Attribution and additionality

Using a theory-based evaluation (TBE) approach, attribution and additionality are assessed qualitatively. That is, *the extent to which the outputs and outcomes achieved (evidenced by the quantitative data) can be reasonably determined to be a result of the investments and activities supported (attributable) and would not have happened by other means (additional),* is assessed via examining and testing whether the *pathways to impact* (identified in the ToC) are plausible and reasonable via interviews, desk research and case studies.[38] Because, in TBE, the attribution and additionality is assessed qualitatively it is not possible to assign values or proportions of benefits identified as attributable or additional to the investments. Where we provide estimates or proportions they are provide to give a sense of scale rather as precise proportions.

[38] The ToC analyses and case studies are reported in Impact Evaluation: Report B

- **New knowledge: outputs:** The papers reported as a direct result of activities undertaken under ESA contracts can, in principle, be considered to be highly attributable to ESA contracts and have high additionality.
- **New knowledge: outcomes:**
  - There is a high and reasonable expectation that scientific papers will be generated in the future from missions being developed under CMIN19. This is the intended purpose of the Science programme and also an important objective for missions in EO and HRE. These papers will be entirely dependent on ESA infrastructure (spacecraft, mission operations) but are also dependent on funding from UKSA (and other national space agencies) to develop mission instrumentation and from UKRI (STFC) to fund the research itself. 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.
  - Scientific research using space data is, in principle, possible (once openly available) without being a member of an ESA mission's scientific consortium but 'external' researchers are at a significant disadvantage compared to consortium members (who are from ESA member states). Furthermore, without ESA, UK researchers would be involved in fewer mission consortia, so greatly reducing the UK's knowledge outcomes.[39] Therefore, we conclude that there is very high level of additionality of the knowledge outcomes to investments made via ESA. As describe above it is not possible to put a precise number on it, however, given that the UK contributes 10% to the ESA budget and 15% to the Science programme, we can say that without ESA the UK could only expect to participate in scientific space missions at a level of the order of 10-15% of its current activity. Therefore, there is a high level of additionality as the majority of UK knowledge outcomes would not have happened without investment via ESA.
- **Skills: outputs:** The survey data, 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 R&D and innovation 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 in the space domain.
- **Skills: outcomes:** The skills outcomes achieved in terms of HE enrolments are 2-12 years in the future, given that CMIN19 outreach activities targe children of all ages from primary to sixth form. 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 cannot be determined 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.

[39] We consider the related question regarding ESA added value in chapter 8

5 Impact domain: Prosperity

Summary

- **A broad range of innovation activities supported by ESA contracts:** from developing innovative spacecraft, components and systems for specific ESA missions to exploring innovative technologies with the potential to support future ESA missions in the longer term and developing innovation applications of space infrastructure
- **Although many of the contracts are still in progress, a number of direct outputs have already been generated** in terms of technology development, new products, services and skills.
- **ESA contracts have supported (and will continue to support) collaborations and new strategic partnerships**. Current ESA contracts directly support large numbers of collaborations, with the majority of contractors reporting at least one form of collaboration. Furthermore, a third of contractors also reported developing new significant international strategic partnerships as a result of their ESA contracts (in Europe and beyond).
- **Some of the initial innovation outputs have already translated into early economic gains for the UK space industry.** 32% of ESA contractors reported follow-on sales already achieved from products, services and the capabilities developed within their contracts, with the sales leading to the creation and/or retention of employment. 60% expect follow-on sales in the future. These follow-on sales are due, in part, to reputational effect of working with ESA, with contractors reporting that the ESA 'badge of approval' allows demonstrating high levels of technical and professional quality which are particularly valuable in international markets.
- **There is a high expectation from stakeholders that innovation and usage benefits (spillovers) will arise in the future as a result of missions and technologies being developed under CMIN19** and that these can be expected to lead to future socio-economic benefits. These include environmental protection and security of space assets in particular, but also in the security of assets on Earth, productivity and improved public policy design and delivery and benefits in health, welfare and utility.

5.1 Introduction

Increased prosperity from UK investments in ESA are expected to arise as a result of innovation activities in the development and use of ESA mission and technologies.

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.[40]

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

5.2 Outputs

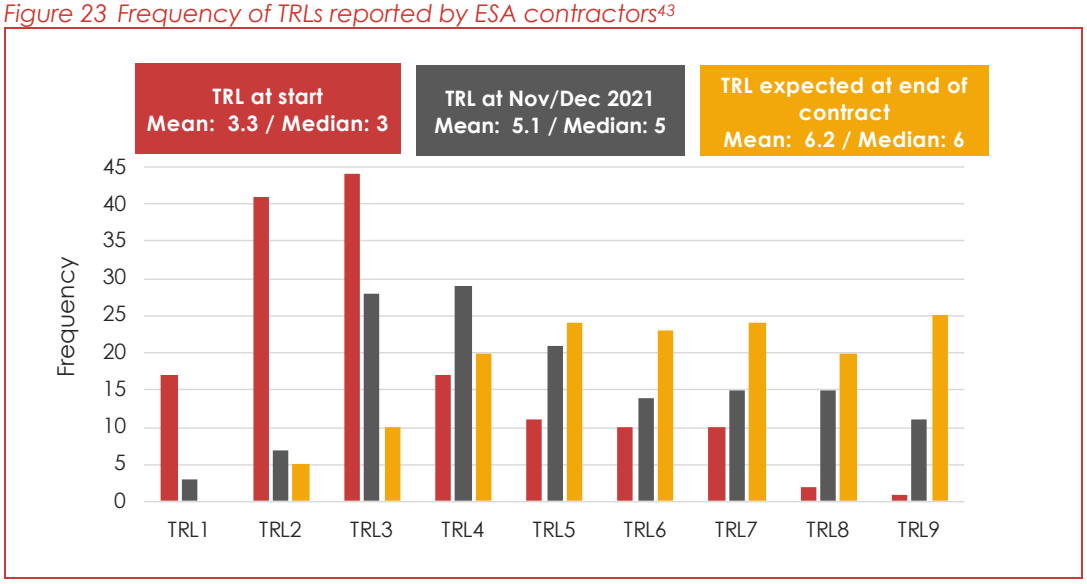
5.2.1 TRL progression and contribution to new space infrastructure

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,[41] with the ultimate aim being the provision of new space infrastructure.

Technological development is considered in terms of progression along a scale of Technology Readiness Levels (TRL).[42] The scale of progression is provided as the mean and median for all the individual technologies under development in current ESA contracts – as reported by respondents to the survey of ESA contractors. It is provided for two time periods (Table 13): from the start of the contract to Q4 of 2021 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 23) as different programmes and different contracts target different stages of the technology and mission development lifecycle.

The mean TRL progression to Q4 2021 is 1.8 (TRL progression A in Table 13) 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 13) with a median of 2.

Figure 23 Frequency of TRLs reported by ESA contractors[43]



ESA contractor survey

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

[42] This scale was designed by NASA specifically for space missions and is used by space agencies worldwide including ESA. It is a 9-point scale spanning 'basic concept observed and reported' (TRL1 to 'actual system flight proven through successful mission operations' (TRL9).
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

[43] TRL progression is calculated for each individual technology reported and then a mean and median calculated for these individual 'progressions'. This means the mean / median progression in Table 13 are not necessarily the same as taking the differences in the mean /median shown at the three time points shown in Figure 23

Table 13 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 for all of the TRL progressions for each individual technology being developed and reported by respondents)

Contractors were also asked if their contracts have already led to operational space infrastructure or are expected to. Very few respondents reported that their contracts have already led to operational infrastructure, just 10%, but 47% expect to in the future (Table 14). As shown in Table 15 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 15).

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.

Table 14 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 15 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

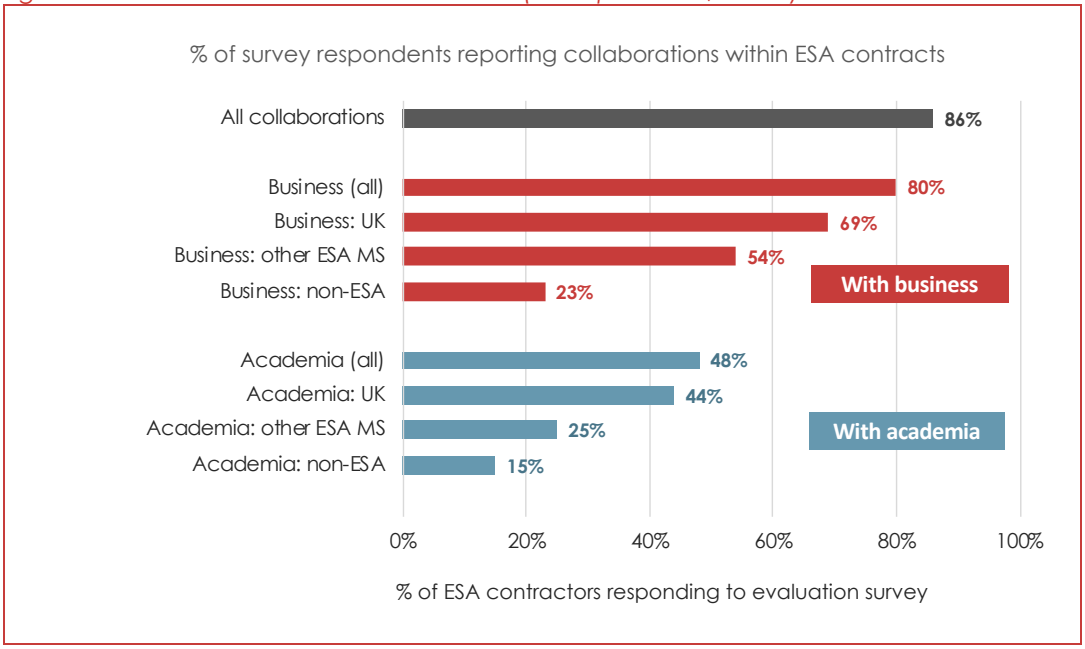
5.2.2 *Collaboration within ESA contracts*

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.

Collaboration rates are high, with 86% of those responding reporting at least one form of collaboration within their current (2020-2021) ESA contracts (Figure 24). 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. 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 academics; 44% reporting collaborations with UK academics, 25% with academics in other ESA member states and 15% with academics in non-ESA countries.

Figure 24 Collaboration within ESA contracts (all respondents, n=110)



ESA contractor survey.

5.2.3 *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 5.3.2.

Table 16 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

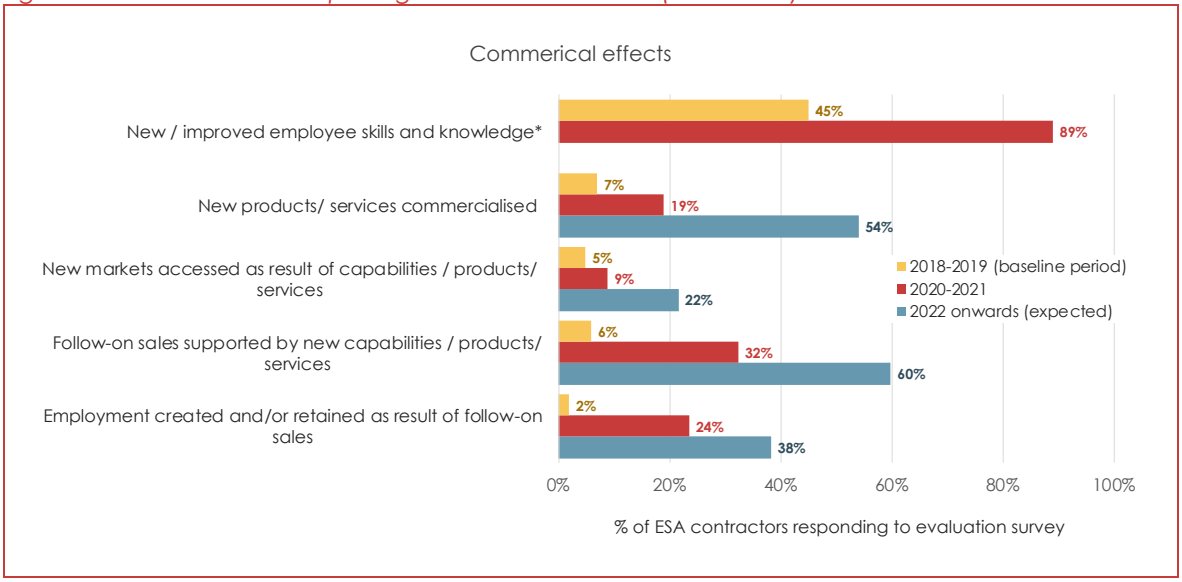
Very few patents have been reported by ESA contractors in either the baseline or the CMIN19 period (to date) (Table 16) and those have been reported are all from the TIA programme. Given that patents can take 2-3 years to be granted once the R&D work has been completed, the low numbers are not unexpected. Some respondents commented that they had applied for patents but they 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 noted that commercial confidentiality, rather than patents, was their preferred method route to protecting IP.

ESA contractors were asked to report any licence income and the value reported for both the baseline and CMIN19 period was zero.

5.2.4 *Commercial benefits*

A key outcome of mission development and technology development contracts is contributing to ensuring 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 survey respondents expect them to lead to new products and services for commercial/institutional space and downstream markets and entry into new markets (new sectors, new geographical regions) with expected subsequent effects on sales and employment.

Figure 25 ESA contractors reporting commercial effects (N=102-110)*



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

Survey respondents report positive commercial effects arising as a result of ESA contracts:

- The greatest effect to date is in terms of new or improved employee skills and knowledge and 89% of contractors report having already achieved these effects here
- Other positive commercial effects have also been achieved:
  - **19% have already commercialised new products or services and 54% expect to do so from 2022 onwards**. A total of 43 products and services have been commercialised to date and 130 are forecast for 2022 onwards. The majority (55%) are reported by contractors in the TIA programme.[44]
  - 32% have achieved **follow-on sales** from their new capabilities, products and services and 60% expect to achieve this type of benefit from 2022 onwards)[45]
  - 24% have achieved **employment benefits** as result of follow-on sales achieved and 38% expect employment benefits in from 2022 onwards
  - 9% have **accessed new markets** (new geographies, new sectors) to date and 22% expect to from 2022 onwards. A total of 39 new markets have been accessed to date and 196 are forecast for 2022 onwards. The majority (40%) are reported by contractors in the TIA programme, followed by GSTP (26%).

[44] The data is presented in the *Impact Evaluation: Technical Report Annex* A

[45] The economic assessment in chapter 9 makes further use of the follow-on sales and employment data

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 presented above are inter-related, it is more informative to present them together.

5.2.5 Spin-outs

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

A small number of respondents providing data regarding spin-outs; only a quarter to a third of respondents answered the questions on spin-outs and most reporting that no spin-outs had been created. To date, three spin-outs have already been established as a result of contracts in the CMIN19 period (Table 17), one each from TIA and GSTP one from the Open Space Innovation Platform (a programme under the ESA mandatory budget). Eight further spin-outs are expected from 2022 onwards. In the baseline (2018-19) one spin-out accounted for all the investment and in 2020-21 one accounted for 91% of the investment. This skewed distribution of investment is common for spin-outs, where a very small number of companies receive large investments 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.

Table 17 Spin-outs (All respondents, n=24-41)

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))

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 to focus on space technologies and applications and expected to arise as a result of several programmes – Science, HRE and EO in addition to TIA and GSTP.

5.2.6 Reputational benefits and new strategic partnerships

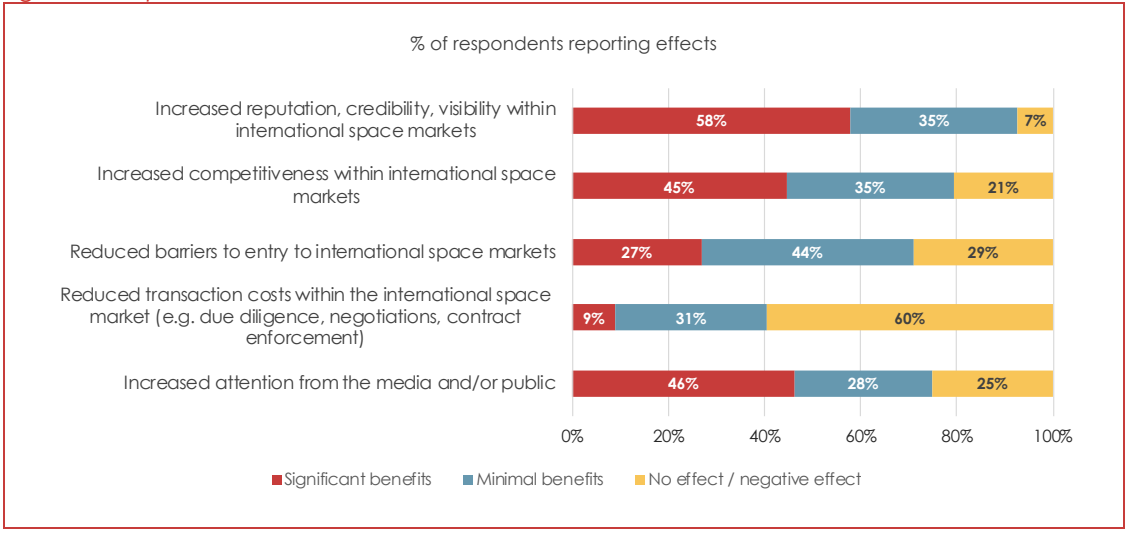
ESA contracts also have direct effects for contractors that are not directly technological or financial. Contracts may lead to new connections and networks and reputational benefits that may result in *significant strategic* new partnerships and new international connections and partnerships can be key to accessing wider space markets and export-led growth.

Around half of contractors report reputational effects (Figure 26): 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.

These reputational effects may lead to new international partnerships with customers and suppliers in space markets and with space agencies beyond the UK and ESA. 53% of contractors report gaining, or expect to gain, new significant strategic international

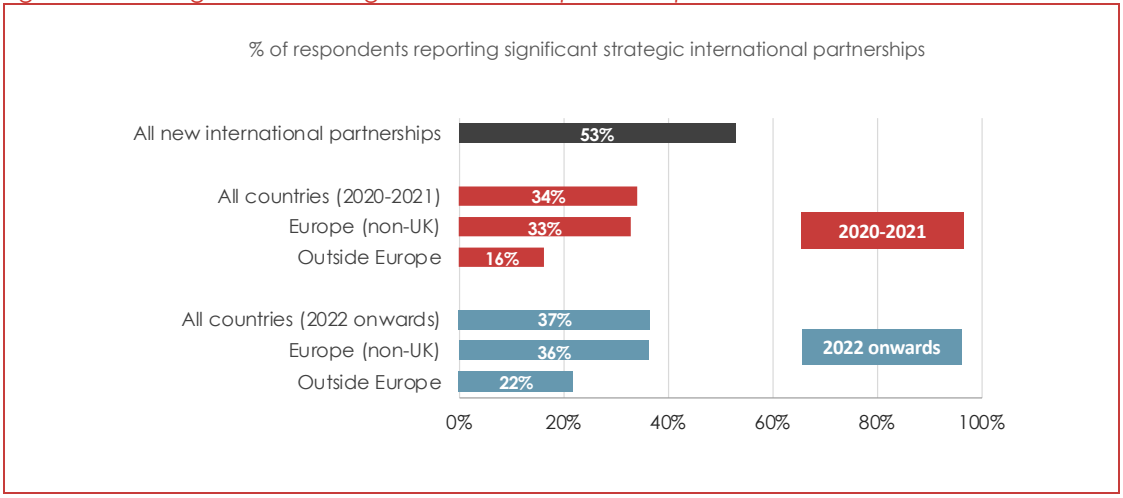
partnerships as a result of their ESA contracts in CMIN19 (Figure 27). 34% have achieved new partnerships to date and 37% expect from 2022 onwards. The majority of these partnerships are with partners in other ESA member states. Additional details provided by respondents indicate that the majority of the new international strategic partnerships are commercial partnerships with customers within the supply-chain, so suggesting a high potential for future exports.

Figure 26 Reputational benefits



ESA contractor survey

Figure 27 New significant strategic international partnerships



ESA contractor survey

5.3 Outcomes (baseline)

The outcomes of ESA contracts cover the wider and longer-term benefits for ESA contractors themselves and benefits 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. 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; 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.

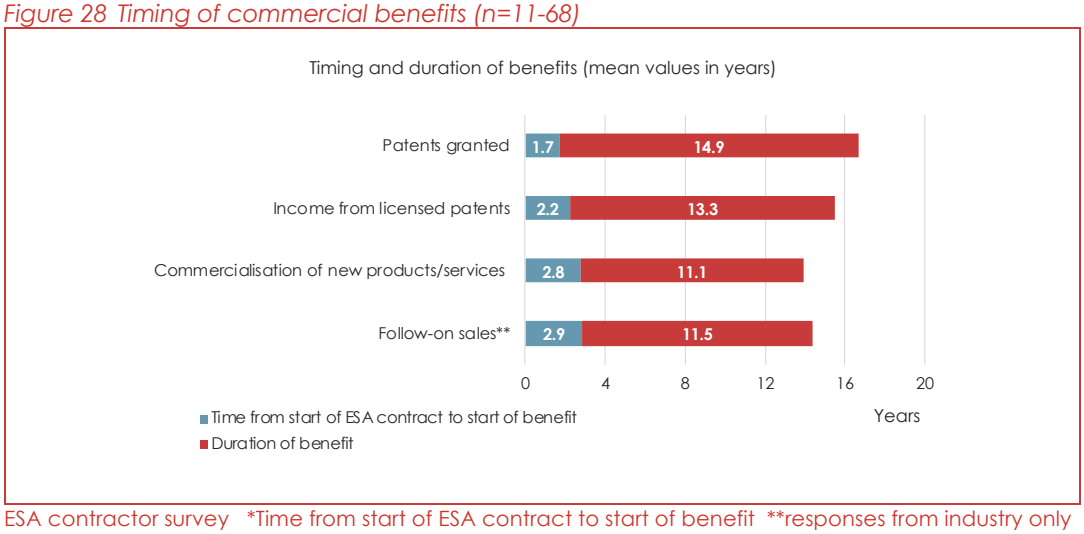
The data is presented at the level the portfolio of UK investments in ESA i.e. for all eight ESA programmes together. Data from secondary sources cannot be disaggregated at programme level as many space companies participate in more than programme and therefore any effects for individual companies will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

5.3.1 Timing of commercial benefits

By definition outcomes follow outputs and contractors were invited to provide information on the timescales to, and duration of, outcomes:

- Commercialisation of products and services and follow-on sales (reported in section 5.2.4) occur, on average, just under 3 years from the start of a contract and last for around 11 years. The range of values is large: 0-12 years for benefits to start and 2-50 years for duration.[46] The range is likely to be due, in part, to contractors being in different part of the supply-chain (components, sub-systems, systems, spacecraft assembly, etc) and therefore sell their products or services to customers 'further up' the supply-chain at different points in time. **This means that for current CMIN19 contracts the commercial outcomes will commence, in the main, in 2023-2024 and therefore some benefits will arise during the CMIN19 period but will also continue into the CMIN22 investment period and beyond.** Furthermore, many CMIN19 contracts have not yet been let and will commence between 2022 and 2024 and so 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 a contract, with license income expect to follow around six months later and benefits lasting 13-15 years. Again, the range of values reported is quite large (for the same reasons as above); 0-5 years for patents / 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 28 Timing of commercial benefits (n=11-68)



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

[46] The data is presented in the *Impact Evaluation: Technical Report Annex A*

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

The benefits of ESA contracts (new skills, technologies, products, etc) may play a key role in the wider patenting behaviour of both ESA contractors and the wider UK space sector. The outcome indicator captures data on UK patenting activity[47] in the space domain for the ESA contractors and for the UK more widely for the period 2008 to 2019. 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[48] a year in the period 2008-2019 (Figure 29) 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, the current ESA contractors account for half (49%) of all space-related patents granted to UK organisations across the time period. 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 16), 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 just 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 30).

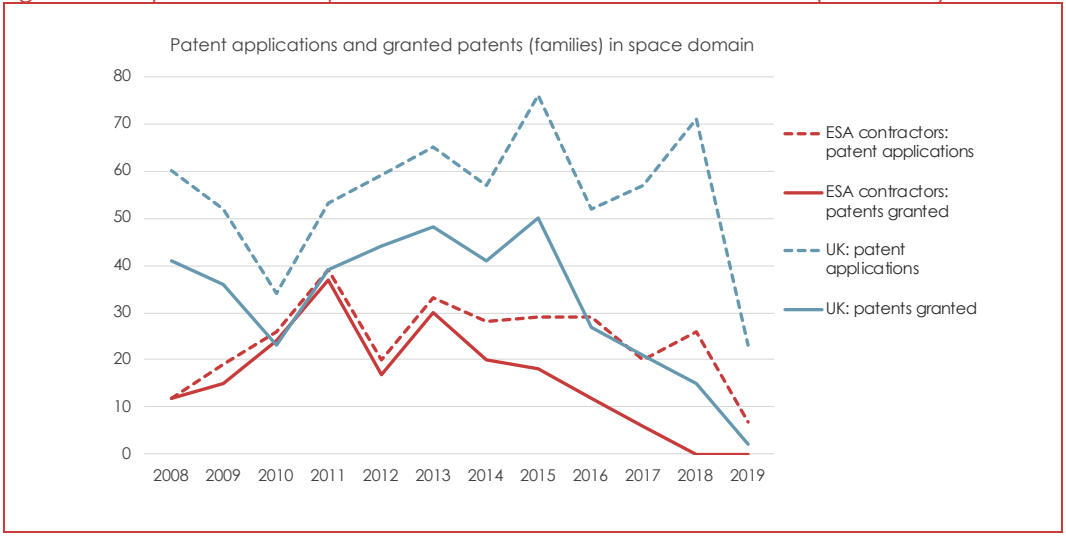
It is important to note that companies can take other routes to protect their intellectual property, not just other formal routes (copyright, trademarks, etc) but also via *trade secrets* i.e. keeping their knowledge within the company (as reported by one survey respondent).

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

Data on patents is reported as "patent families: rather than as individual patents. 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.

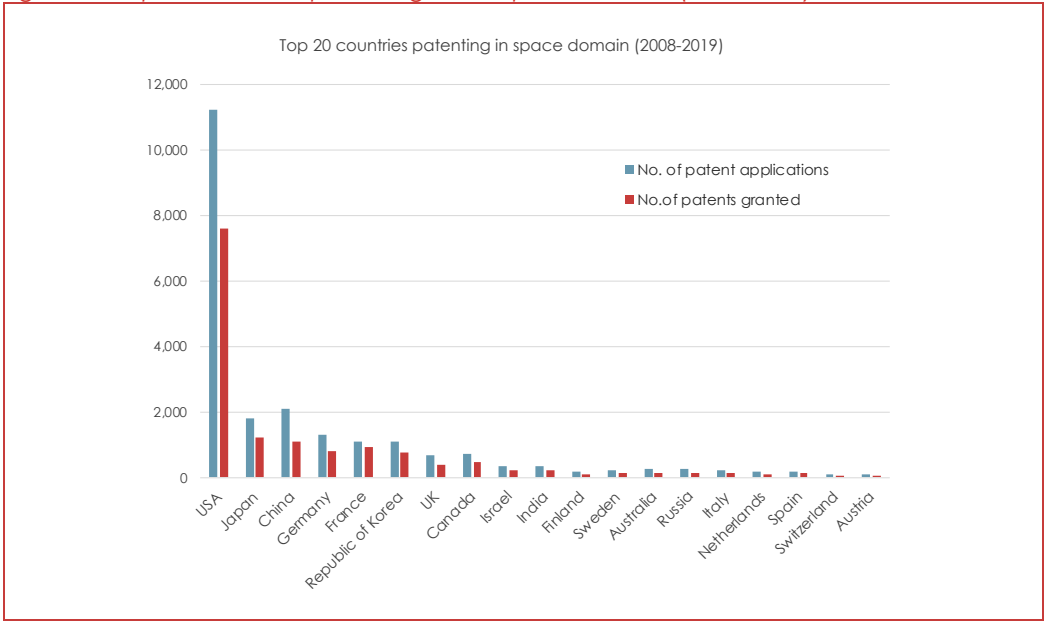
[48] "Space-related patents" were identified by a combination of keyword searches and selection of relevant Cooperative Patent Classification (CPC) categorisations defined by the European Patent Office (EPO) and the US Patent and Trademark Office (USPTO)

Figure 29 UK patents in the space domain: ESA contractors and all UK (2008-2019)[49]



Science-Metrix (2021) / PATSTAT

Figure 30 Top 20 countries patenting in the space domain (2008-2019)



Science-Metrix (2021) / PATSTAT

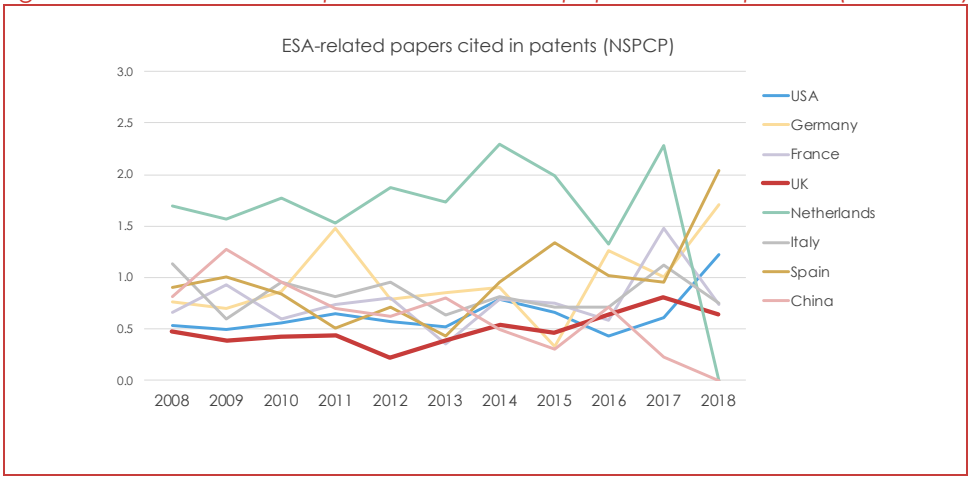
5.3.3 *ESA-related papers cited in patents in the space domain (baseline only)*

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. This data is based on papers published from 2008-2018 and based on prior ESA investments and therefore the data for this indicator provides a baseline only.

[49] The decline in recent years may be due to the considerable time lag between a patent application and its first appearance in the PATSTAT database. Due to this time lag the most reliable data for is that up and including to 2017. 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.

The UK performs below the world average (which is 1.0 for this indicator) in terms of its ESA-related papers cited in patents (Figure 31). 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. The Netherlands has a low number of patents (ranked 16th internationally) indicating that its papers are being utilised by other countries rather than in-country organisations.

Figure 31 International comparison: ESA-related papers cited in patents (2008-2019)



Science-Metrix (2021) / Scopus / PATSTAT

5.3.4 *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 business database Pitchbook. To ensure the baseline is representative of the wider pool of typical UK ESA contractors we included all companies with ESA contracts active in 2020 and up to Q2 2021 (not just those with contracts starting in that time 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 and divided into two sub-sets (Figure 32)[50]
  - Upstream space companies - those manufacturing and operating space infrastructure and providing ancillary services (Figure 34)
  - Downstream space companies - those providing products and services using space infrastructure and data (Figure 35)
- 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 (Figure 36)

There has been a general upward trend in the number of deals over the period 2014-2021 with an exception in 2019 when deal numbers declined. 2021 is currently a little below that of 2020

[50] 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.

but the Pitchbook database will not yet have captured all activity in 2021 (Figure 32). It is important to note that the total value of deals is typically skewed by one or two large deals (e.g. a large private equity investment or corporate merger) and therefore the annual data can vary considerably year to year. These deals involve large UK businesses that are active both in space and non-space sectors (e.g. BT, Atkins) as well as space businesses such as Inmarsat, OneWeb and MDA. The large spike in the deal value in 2018 in Figure 32 for example is largely due to a single £18m corporate merger (Rockwell Colins).[51] The venture capital investment is more focused on space start-ups and SMEs. Downstream applications businesses have more deals across the time period than upstream businesses, but the deals tend to be smaller in size than for the upstream companies (Figure 33).

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 5.2.6, 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 and 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 occur after contracts have delivered new capabilities and technologies. **Therefore, it is reasonable to consider data from 2020 onwards as 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.

All ESA contractors

Figure 32 Investment ESA contractors (all)

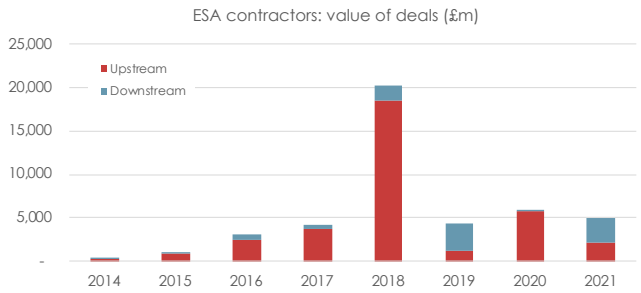
Technopolis (2021) / Pitchbook

[51] A list of the largest deals reported in Figure 32 is provided in the *Impact Evaluation: Technical Report Annex*

Figure 33 Investment ESA contractors (upstream & downstream)

Total number of deals (2014-2021)

Upstream	158
Downstream	196



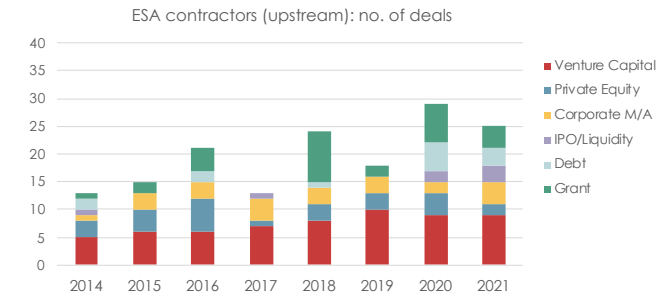
Total value of deals (£m) (2014-2021)

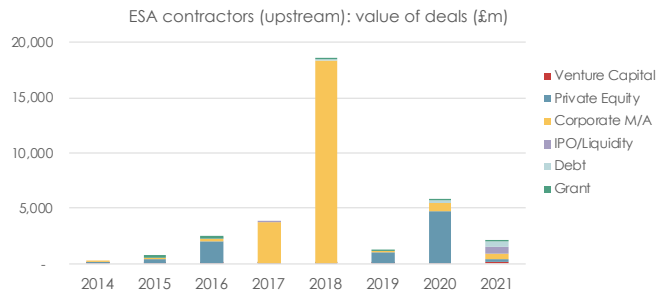
Upstream	34,742
Downstream	8,799

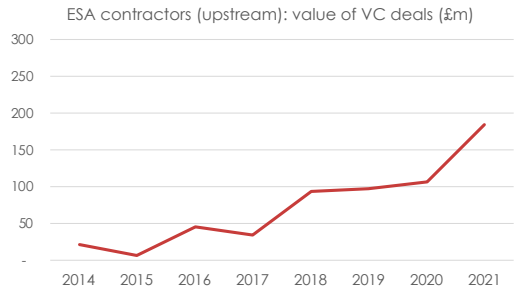
Technopolis (2021) / Pitchbook

ESA contractors: upstream

Figure 34 Investment ESA contractors (upstream)





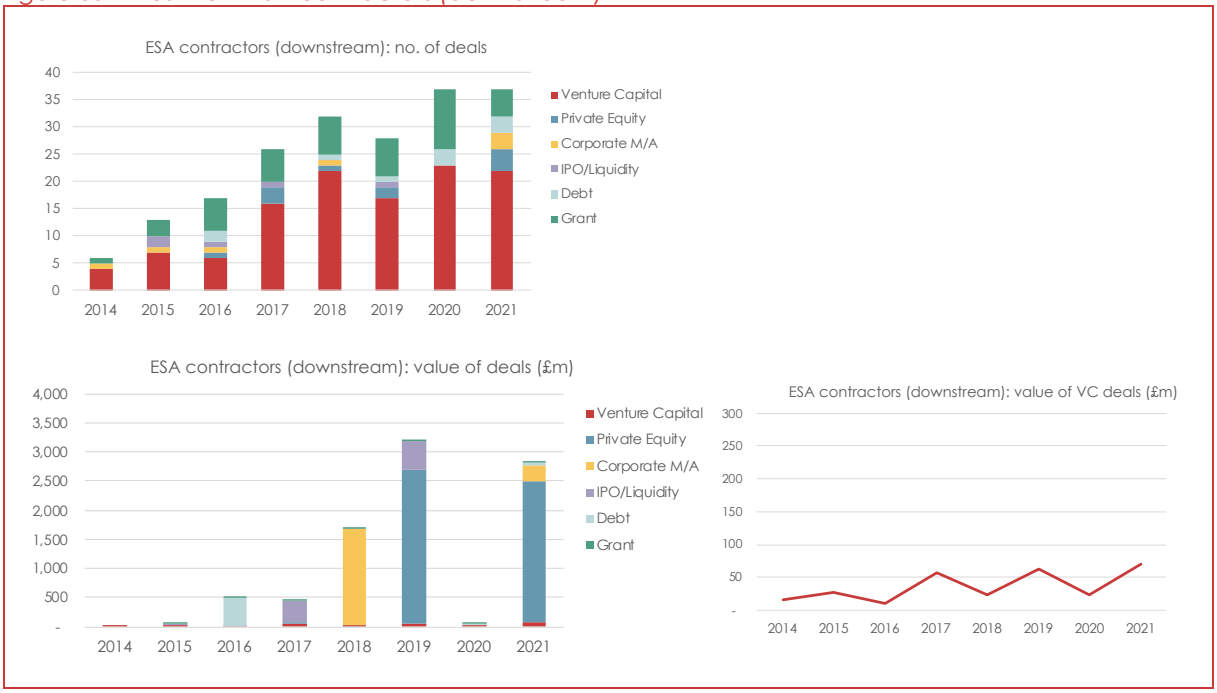


Technopolis (2021) / Pitchbook

The *Impact Report: Technical Annex* provides details of the companies receiving investment.

ESA contractors: downstream

Figure 35 Investment ESA contractors (downstream)



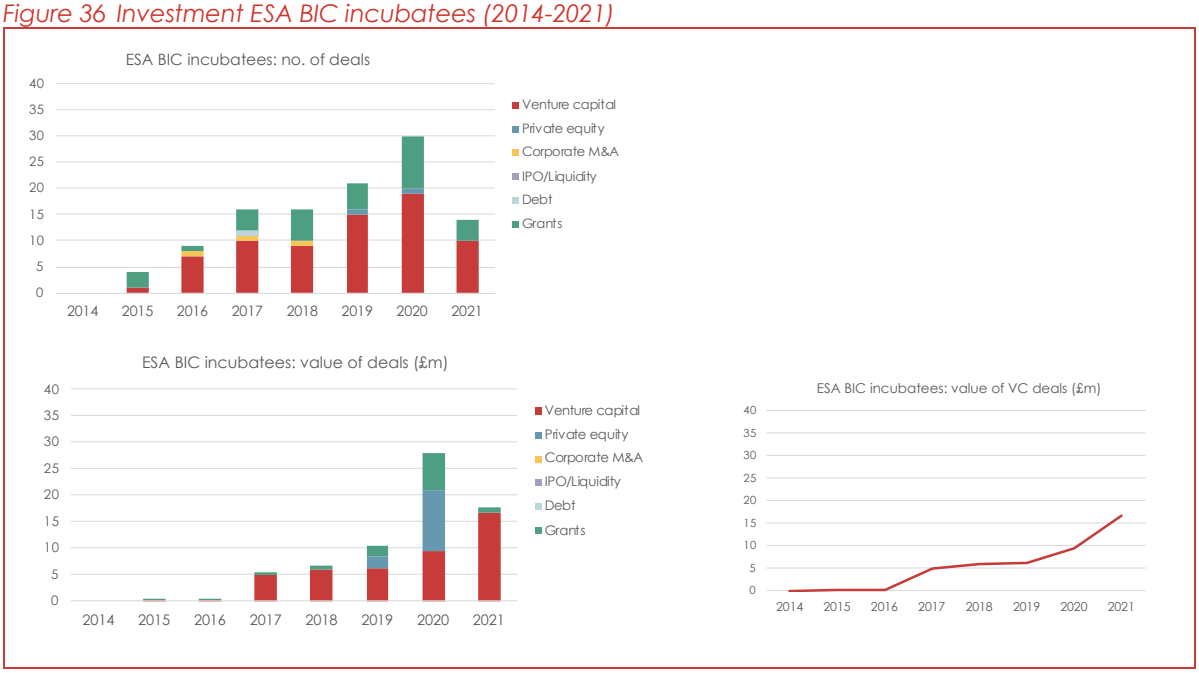
Technopolis (2021) / Pitchbook

The *Impact Report: Technical Annex* provides details of the companies receiving investment.

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 36 Investment ESA BIC incubatees (2014-2021)



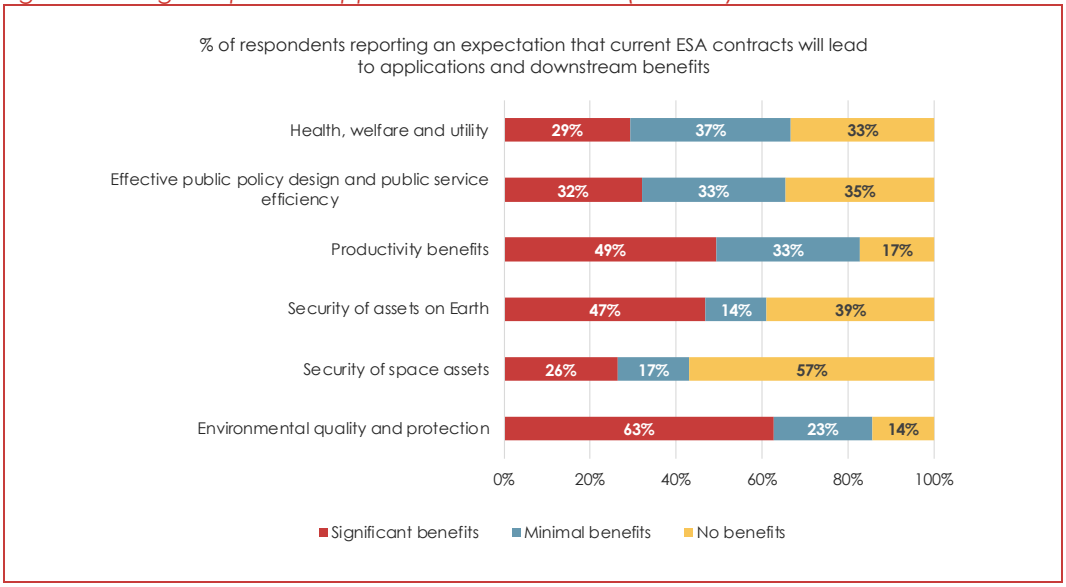
Technopolis (2021) / Pitchbook

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 wider 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.[52]

5.4 Usage and innovation benefits

Space infrastructure is intended to be used for a wide range of commercial and social purposes, both the uses intended from the outset (scientific research, meteorology, environmental monitoring, communications, navigation, etc) and innovative (downstream) applications using space data that are unknown when the infrastructure is designed. Further innovation effects are generated when technologies and capabilities developed for space are transferred and used 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.[53]

Figure 37 Usage: expected applications and benefits (n=75-83)



ESA contractor survey

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, EarthCARE), some in the late 2020s (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 TIA, but increasingly in EO) generally work on shorter timeframes but may make use of ESA technology development funding from several years earlier. Interviewees

[52] 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.

[53] The Literature Review provided earlier in this study provides a review of studies on the form and scale of downstream benefits of space infrastructure

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 outcomes and impacts are even further into the future.

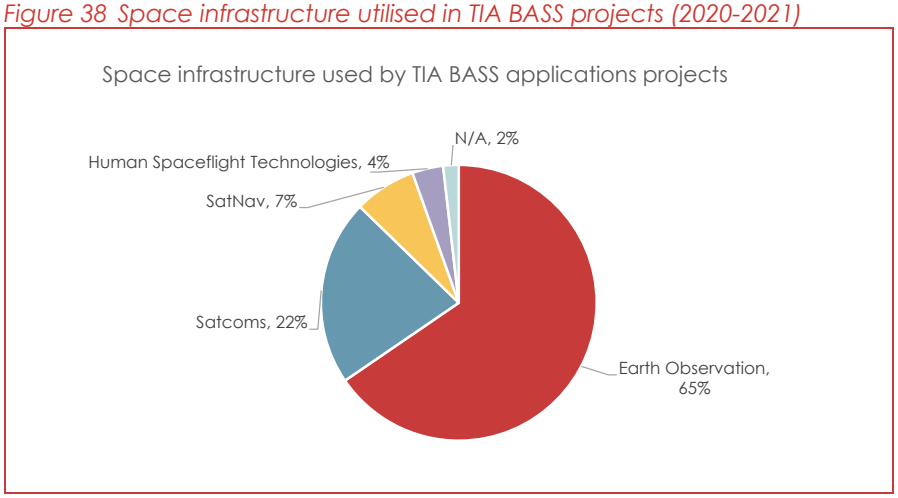
This does not mean that there is not a high expectation of impacts in the future and ESA contractors provided information on the type of usage benefits they expect their contracts to lead to (Figure 37). 64% of respondents reported significant expected applications and downstream benefits in at least one of the benefit categories, with environmental protection the most frequently reported, followed by productivity benefits, security of assets on Earth.

The Business Applications and Space Solutions (BASS) programme within TIA invests in feasibility studies and demonstration projects focused on developing of innovative applications 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. Just under a quarter (22%) were 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.

- The majority of the applications projects (65%) were based on the use of data from EO satellites, followed by satcom (22%) and satellite navigation (7%) capabilities. Just two projects were based on technologies developed for human spaceflight (Figure 38)
- The products and services under development addressed a wide range of application areas (Table 18). 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 in use (Figure 39). All projects were developing products or services targeting economic impact, but many were also targeting environmental and wider social (health, improved public services, welfare benefits) impacts.

Most of the benefits of BASS projects are in the future as the innovative products and services have not yet reached the market or have only reached one or two early adopters. Furthermore, as they are 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 usage and innovation benefits.

Figure 38 Space infrastructure utilised in TIA BASS projects (2020-2021)



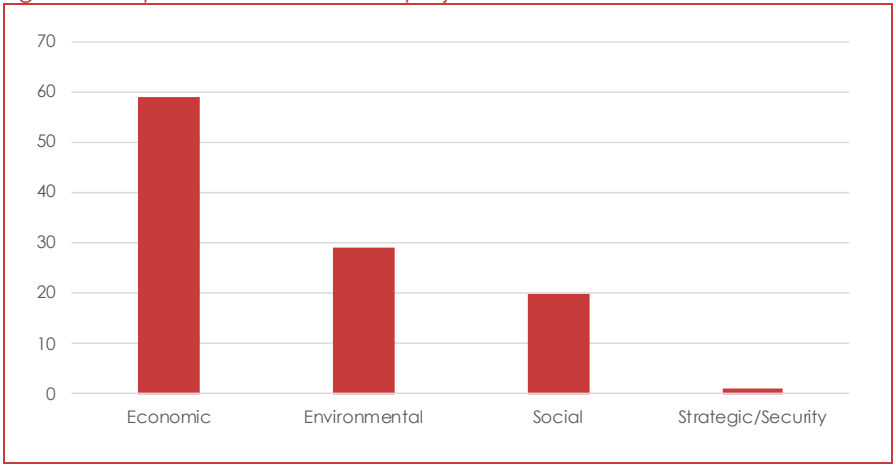
Technopolis (2022): Analysis of ESA website TIA applications case studies

*Table 18 Application areas covered by TIA/BASS 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) *the application areas are defined by ESA #each BASS project can address more than one application area

Figure 39 Impact domains of BASS projects



Technopolis 2022: ESA TIA data

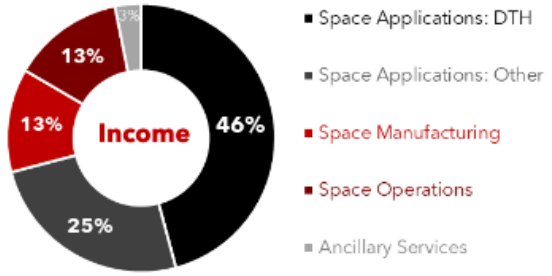
Taking a broader perspective on downstream applications, in 2018/2019 space applications generated revenue of £11.7bn in the UK (Figure 40), representing 71% of income for the UK space industry, indicating that applications generate more revenue than the upstream (i.e. manufacturing and operations) part of the space industry. Furthermore, the data presented is captured via a survey of the space industry itself and while the definitions for the sector used is fairly broad, it is unlikely to cover all companies making or using downstream applications. While two-thirds of all applications is comes from direct-to-home (DTH) broadcasting, the non-DTH applications make a greater contribution to applications-related GVA than DTH. 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.

*Figure 40 UK space industry income and GVA by segment 2018/19**

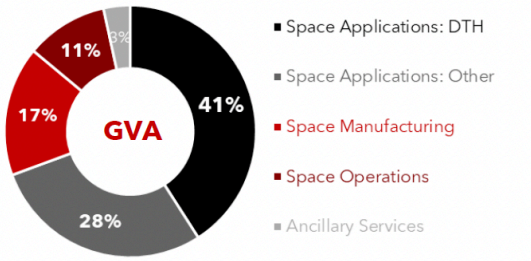
Segment	2018/19 £m
Space Applications	11,659
- DTH broadcasting	*7,533*
- Other applications	*4,126*
Space Operations	2,216
Space Manufacturing	2,052
Ancillary Services	514
Total	**16,440**

Source: know.space analysis



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) [54] **Space applications* are shown in the first three rows in each table. DTH represents 65% of all applications income (i.e. 46% of 46%+25% (for DTH + Space Applications: Other))

5.5 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[55] and are a direct result of the activities undertaken within contracts and so are attributable to ESA contracts to a significant extent. Where additionality is concerned, there differences for upstream and downstream focused activities:

- The mission-focused contracts are undertaking well-defined work developing spacecraft for ESA and therefore the outputs generated have high additionality. The outputs would not be generated without ESA contracts/funding and there are currently no alternative sources of funding for this work and its outputs.
- It might be considered that the longer-term and more speculative technology development work for future missions and commercial space activity might be funded by businesses themselves or via alternative public sources. However, interviewees were clear that this type of activity is either targeting capabilities for future ESA missions and therefore would not be undertaken without ESA support or is risky R&D and innovation activity that they would need to seek alternative sources of public support. In the latter case, UKSA

[54] https://www.gov.uk/government/publications/uk-space-industry-size-and-health-report-2018

[55] Reported in Impact Evaluation Report: PART B

support is available but, at the current time, at a much lower level than that available via ESA. Innovate UK does not support the development of upstream space technologies to any significant extent but does provide opportunities to access support for downstream applications (such as the support provided via the Satellite Applications Catapult). Therefore while there is high additionality for upstream space technologies, additionality for applications will be lower

Innovation: outcomes

While there is some evidence of early outcomes for ESA contractors in the form of early sales of new products and services and new markets accessed, the majority of innovation outcomes from CMIN19 investments are in the future. Contractors' self-reported views on additionality of these outcomes indicated a high level of attribution and additionality to ESA investments. 56% reported that the benefits reported would not have occurred without the ESA contracts and 26% that only a small proportion of the benefits would have occurred without them. This was corroborated by the interviews with contractors; from an industry perspective, there are limited other forms of public support for R&D and innovation activities in the space domain, giving them limited alternative options to work on space technologies. Interviewees noted the fairly small scale of national funding for space activities whether from UKSA or other sources such as Innovate UK compared to that available via ESA. As was the case for the outputs, non-mission focused 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 new skills and capabilities, the lack of access to ESA technical and project management capabilities and reduced reputational benefits.

The majority of the wider innovation and usage outcomes and impacts will arise in the future. The pathways to impact for these expected outcomes were explored in the qualitative research and exploration of the programme level ToCs. This work indicated that the pathways to future innovative uses of ESA space infrastructure developed via CMIN19 are plausible although the extent of attribution of these outcomes and impacts to ESA investments will be variable and additionality will be partial.[56]

- Innovative products and services whose development was funded in part by ESA or rely on commercial space capabilities whose development was supported by ESA (e.g. SatComs) will have some attribution to ESA but their development and commercialisation will be result of considerable levels of private and public investments and therefore their additionality to ESA investments will be partial.
- Downstream applications / 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 ESA provides. However, their development and commercialisation will be a result of a range of private and public investments. Furthermore, in many cases, they will integrate data from a range of sources, not just ESA infrastructure or alternative data sources may be available from other space or non-space infrastructure, so additionality will be partial.
- Wider economic or social impacts will arise (or are expected to arise) as a result of the use of the innovative products and services discussed above. The intended end-users, be they businesses, consumers, public service providers or policy-makers, will need to expend further

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

resources to adopt and utilise them and, as above, there may also be alternative sources of data or capabilities - therefore additionality will be partial.

The use cases are expected to be highly particular and highly varied - from monitoring and tracking physical assets to precision-agriculture and monitoring climate change and biosystems. The levels of attribution and additionality will be highly dependent on the specific example and will depend of many factors, for example, to the whether the ESA data 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.

6 Impact domain: Security and protection

Summary

CMIN19 investments are developing new capabilities to support a range of applications in security and protection, though the impacts will not be seen until missions are launched

- **The UK is a large contributor to the EO programme in terms of budget (at 12% of the total for the programme in the five-year CMIN19 period) and scientific and technological capabilities.** EO missions play an important role in monitoring and understanding climate change, providing data on half of the internationally agreed essential climate variable (ECV) and making a critical contribution to policies and actions to mitigate climate change. The ESA EO missions currently in development with significant UK contributions, such as CO2M, HydroGNSS and TRUTHS, will add to the space EO capabilities, with CO2M and TRUTHS in particular increasing the accuracy and robustness of ECVs. Timescales to impacts vary: HydroGNSS and CO2M will launch during the CMIN19 period and TRUTHS will not launch until 2029.
- **The UK is a major contributor to two relatively small programmes – SSS and CSTS. 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.** Demonstration debris removal and clean space missions will launch during the CMIN19 period and the space weather mission (Vigil) will not launch until at least 2030. These 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.

6.1 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 impact domain is addressed qualitatively, capturing ESA contractors' views on issues in security and protection and considering the ToCs for the SSS and CSTS programmes as these support key activities in security and protection.

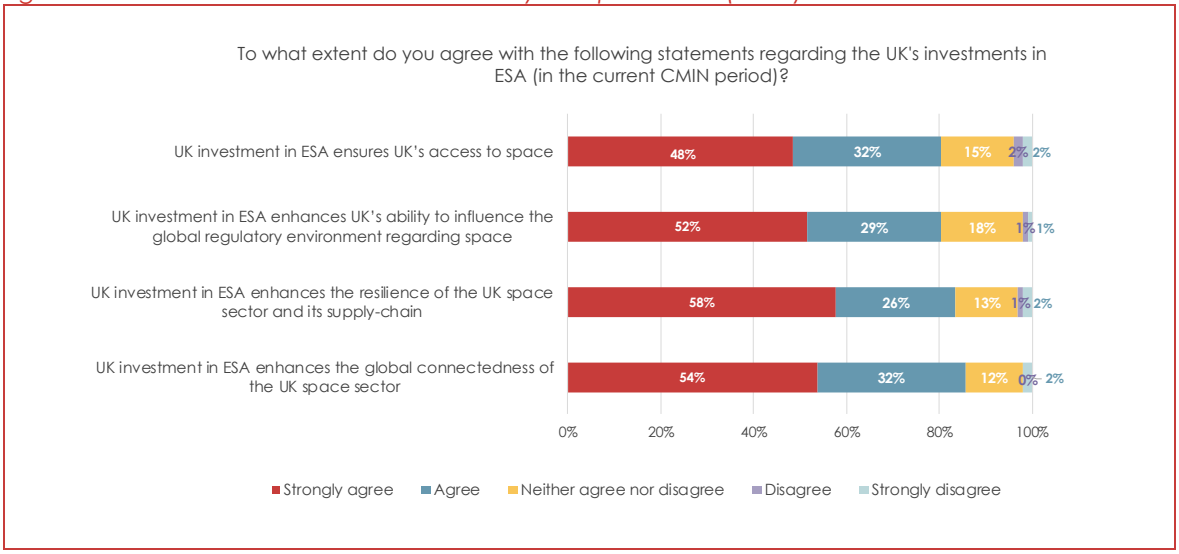
6.2 Outputs and outcomes

6.2.1 Access to space

Our interviews and survey (Figure 41) 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 6.4).

Figure 41 UK ESA contractors views on security and protection (N=97)



ESA contractor survey

6.2.2 *Influencing the global regulatory environment*

Our interviews and survey (Figure 41) 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 that 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.

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 (such as the European Cooperation for Space Standardization) 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 also flag

[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] https://www.pwc.fr/fr/assets/files/pdf/2020/12/en-france-pwc-main-trends-and-challenges-in-the-space-sector.pdf

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.

6.2.3 *Resilience of the UK space sector and its supply chain*

Our interviews and survey (Figure 41) 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. In addition, membership of ESA encourages and enables supply-chain linkages among member states cross borders, providing UK businesses with wider markets to serve. 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 a TIA funding call relating to the convergence between satellites and 5G, initiated on behalf of the UK government.[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.

6.2.4 *Global connectedness of the UK space sector*

Our interviews and survey (Figure 41) found that the great majority of stakeholders consider that UK membership of ESA has contributed to enhancing the global connectedness of the UK space sector.

Our desk research and interviews suggest that membership of ESA has had a positive impact on other space-faring 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.

6.2.5 *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. 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

[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)

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

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 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 and from space debris. These are specifically addressed below.

6.3 Space Safety and Security (SSS)[62]

6.3.1 The SSS programme

The Space Safety and Security (SSS) programme is an optional ESA programme with three pillars: space weather, planetary defence (protection from asteroid impacts), and debris & clean space (prevention of collisions with space debris).

The UK has participated in the SSS programme since its inception in 2009 and is the single largest contributor with its €96.8M investment in CMIN19 accounting for is 22% of the total budget. SSS addresses several key objectives of the UK's National Space Strategy, including helping to address the space weather risks outlined in the National Risk Register and improving debris mitigation and collision prevention. The UK is participating in the programme's core activities and in three of its four cornerstone missions (Vigil, ADRIOS/CleanSpace-1, and CREAM)[63] with these aligning with UK national investments in space safety: the National In-Orbit Servicing Control Centre at Catapult in Harwell was built from a £4m Government grant,[64] 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.[65] 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.[66]

6.3.2 SSS benefits

Space Weather

Because of the delay to the Vigil mission, (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 space weather, which track back to its involvement in building the instruments that feature on previous missions to the Sun (STEREO and SOHO) and recently launched Solar Orbiter mission. 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.[67] Contractors such as the Met Office, RAL Space and

[62] The SSS programme is presented in more depth in the *Impact Evaluation Report: PART B*

[63] The UK chose not to participate in the planetary defence mission (HERA), because of the much lower risk of a severe asteroid impact

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

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

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

[67] UKSA Business Case

others expect to see an increase in, 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 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.[68, 69]

Debris and clean space

ESA contracts are supporting UK-based companies 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 2030.70

Under CMIN19 contracts have been awarded to UK companies to, for example, provide the AOCS sub-system[71] for the ClearSpace-1 satellite, perform an in-orbit demonstration of a 'De-orbit Kit and develop software to estimate the debris impact of all future missions and better support lifecycle assessments of space assets. All of which should help to consolidate and extend UK leadership in the emerging collision avoidance / clean space market. 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.

6.4 Commercial Space Transportation Services (CSTS)[72]

6.4.1 The CSTS programme

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, with the UK's €15.1m CMIN19 investment into CSTS, representing 27% of the total budget for CSTS, second only to 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. The programme allows UK companies to access technical assistance and expertise within ESA and participating member states to support the development of its national launch capabilities.

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

[69] UK Space Safety Community Meeting: Part 1

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

[71] Attitude and Orbit Control

[72] The CSTS programme is presented in more depth in the *Impact Evaluation Report: PART B*

6.4.2 *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 by ESA) as having a potentially notable effect in improving the UK's reputation as a launching nation. 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

For UK companies, ESA contractors give a 'stamp of approval' effect helping to enhance their reputation in the launch segment of within international space markets. Contractors 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 under CMIN19.

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. 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.

6.5 Attribution and additionality

The UK's ability to ensure security of its 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 UK's 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 from ESA funding, which could be directed to them without ESA, but also from 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 its space priorities. Space missions, some EO missions, exploration activities and the space weather Vigil mission require the capabilities of ESA's spaceport or international equivalents. 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.

7 Impact domain: Global influence

Summary

- **As the fourth largest investor in ESA (out of 22 member states), contributing 10% to the total ESA budget in the CMIN19 period, the UK has considerable influence within ESA**. The UKSA plays a full and active role at a political level and in all of ESA's formal governance structures. In addition, the UK is disproportionately over-represented within ESA's scientific advisory structures and had a central role in the recent development of ESA long-term scientific strategy Voyage 2050. Globally, ESA is one of the largest civil space agencies (in the top three), giving the UK an additional pathway to international influence in the space realm over and above its national influence.
- **Nevertheless, ESA contractors would like to see even more leadership and influence**. Only around 50-60% of ESA contractors think that that the UK is well-represented within ESA senior leadership andS that the UK's space sector's capabilities and needs and UK's strategic policy goals for space are reflected in ESA strategy.

7.1 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.

7.2 Outputs and outcomes

7.2.1 Political Leadership in ESA

As the fourth largest investor in ESA (among 22 full member states) 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 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 within ESA and appropriately influence decisions.

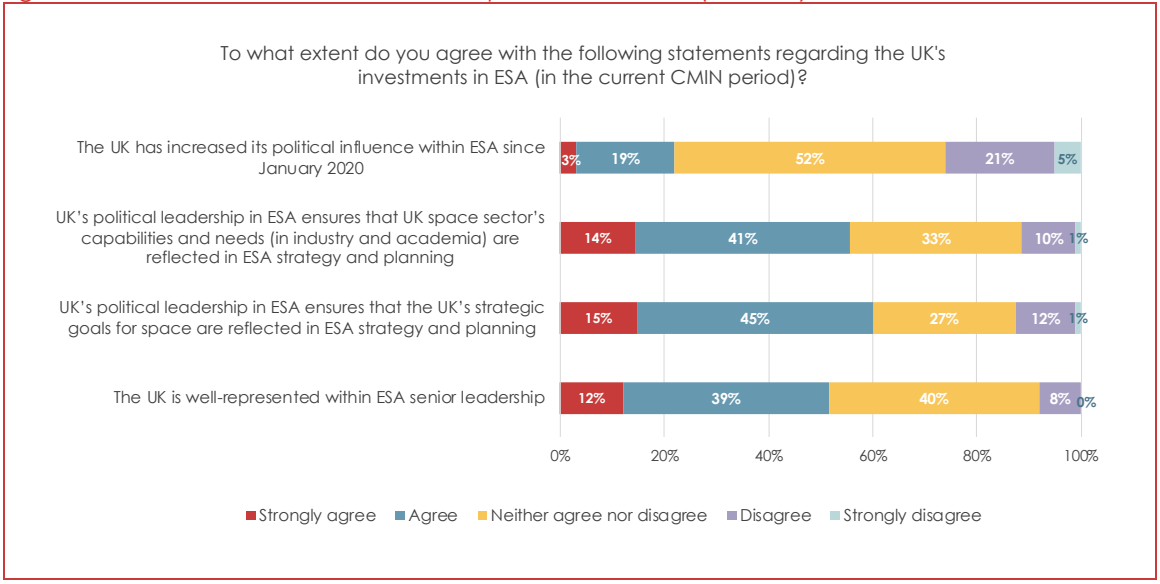
The UK is represented by a UKSA member of staff on all the relevant ESA Plenary and Programme Boards where strategic and financial decisions are made. It has specific leadership roles as chair of the Industrial Policy Committee (IPC) and chair of the sub-group 'Exploration and Utilisation Board' of the Programme Board for Human Spaceflight, Microgravity and Exploration (PB-HME). UK influence is further extended through former UKA staff taking senior leadership roles within 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 R&D and innovation ecosystem. Interviewees 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.

The extent of UK's influence has developed over many years and changes, particularly in the positive direction, occur slowly. Therefore, it is unsurprising that ESA contractors do not report significant effects in changes to UK's political influence during CMIN19 (Figure 42). With only around half of contractors (50-60%) agreeing that the UK is well-represented with ESA senior leadership and that UK's national and space sector's strategic goal, capabilities and needs are reflected in ESA' strategy and planning, this suggests that there may be more that UKSA could do to improve its level of influence and/or better communicate its role to the UK space community.

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 members states being reluctant to partner with the UK on Copernicus related contracts.

Figure 42 Views of UK ESA contractors: UK political influence (n=95-99)



ESA contractor survey

7.2.2 *Knowledge and technology leadership*

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

- The bibliometric analysis demonstrates the UK's strong scientific performance. 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 (reported in section 4.3.2)
- The UK plays a strong and often leading role in developing concepts for science missions, both in terms of designing the research and designing and building scientific instrumentation. In CMIN19 UK researchers are principal investigator (PIs) or co-investigator (Co-I) for the ARIEL (PI) and PLATO missions (Co-I), 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 tasked with developing ESA new strategy for space science driving ESA's science missions for 2035-2050. The UK was also well-represented (at a level greater than its percentage financial contributions) in the committee's Topical Teams, indicating that the UK's expertise and research interests will be well catered for the mandatory space science investments for many years to come. The UK is similarly well-represented on ESA's advisory committees. Beyond ESA, a UK academic 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. However, the UK fares less well against the comparator countries in terms of patenting in the space domain (Figure 30)

7.2.3 Standards and regulation

As a leading space nation, the UK is represented on relevant standards and regulation bodies, such as the UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) and the European Cooperation of Space Standardisation (ECSS). 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 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.

7.2.4 International partnerships (institutional and commercial)

ESA contractors provided details of numerous new international strategic partnerships (Figure 27) 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-ESA space agency.

At the mission level, working with ESA, the UK is engaging with other space agencies such as the SMILE mission with the Chinese National Space Administration and the Lunar Gateway mission with NASA and the JUICE mission with JAXA. At a strategic level the UK is developing bi-lateral relationships with Canada, Australia, the US and Japan (as listed in section 8.2).

7.3 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 ecosystem 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.

8 ESA added value

Summary

There is considerable added value to working via ESA and widespread agreement among stakeholders regarding the principal types of added value that derive from the UK's national membership of ESA. This has been confirmed by evaluation interviews, surveys and literature review.

- **Scale and indivisibility** – the minimum scale of public investments required to be a space-faring nation is enormous, such that for an economy the size of the UK, going alone is not feasible
- **ESA in-house coordination and technology capability** - the strategic coordination and technical capability within ESA far exceeds the capacity one might expect to establish in the UK
- **UK space economy** - many of the key 'upstream' space players are EU-headquartered businesses that maintain subsidiaries in the UK in part to maximise their access to ESA contracts. Any reduction in UK investment in ESA would likely lead to a switch in new investment by these companies from the UK to other ESA member states

8.1 Introduction

This section presents an overview of ESA added value, focusing on our qualitative data 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 three principal types of added value that derive from the UK's national membership of ESA.

8.2 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.

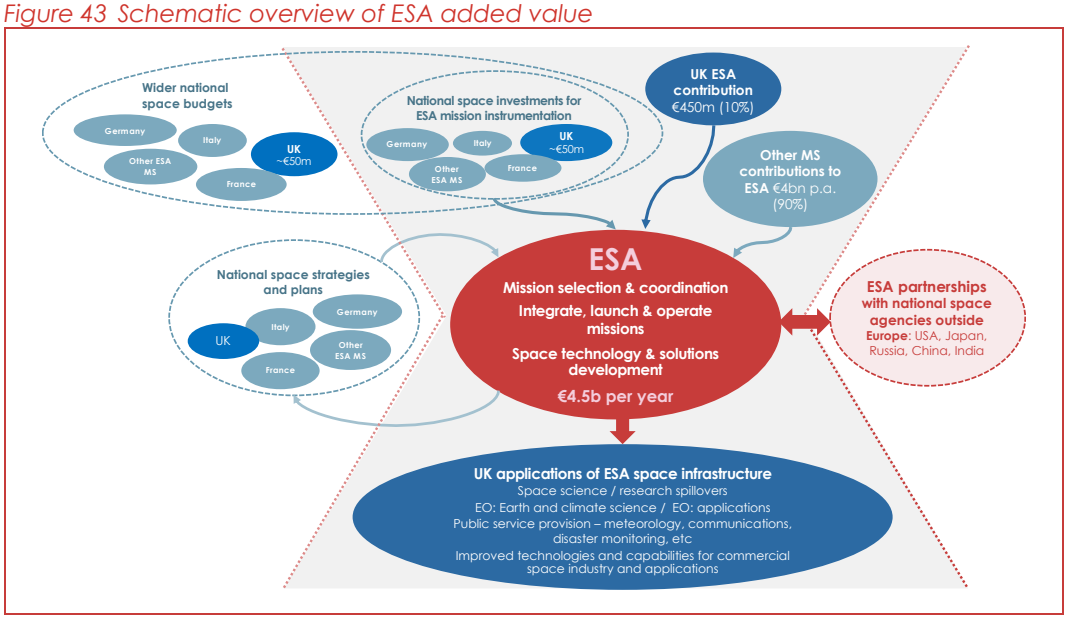
Individual space missions are developed over many years (10-20 years) and have development budgets running into the billions of euros, before reaching an operational phase. Furthermore, these costs are reliant upon decades of capability development and wider capital investment in the coordination structures, 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. For example, the UK government decided that the estimated £3bn-£5bn cost for a UK replacement for the European satellite positioning system (Galileo), access to which was lost to as a result of Brexit, was too costly and are currently seeking alternative ways to access the required capabilities.

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 Russia's ROSCOSMOS have been investing at scale for decades, there are several newer players that 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.[73] By contrast the UK's annual budget of around £0.5 per year (75% routed via ESA) is relatively small and, even within Europe, is smaller than the national budgets of France, Germany and Italy (Figure 13 in section 4.3.1).

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 from space science to civil security.

Figure 43 Schematic overview of ESA added value



Technopolis (2022)

While there are other possible options, 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 an important route to global space missions, with China, Japan, Russia and the USA (e.g. ISS, Lunar Gateway, SMILE[74]). This ESA-plus strategy was confirmed in the National Space Strategy. [75] The strategy will be delivered through four pillars, one of which is international collaboration. ESA remains at the centre of the UK's global partnerships, 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.

Another option would be to scale back support for various ESA optional programmes in order to finance UK national space programmes that are more closely aligned with UK strategic priorities. There are several downsides to a leaner approach to ESA. Firstly, the issue of the high

[73] This scale of investment is all the more noteworthy when one considers that India is classified as a Low and Middle Income Country by the OECD Development Assistance Committee making it eligible to receive official development assistance, including from the UK

[74] SMILE is a joint mission between ESA and the Chinese Academy of Sciences

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

cost of the mandatory activities that fund the basic operations of ESA and access to the mandatory programmes (including the Science programme), meaning the UK would then 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, EO, TIA and HRE which are of key strategic interest. 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 would have to increase the overall budget for the UKSA by a factor of two or more.

8.3 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,[76] 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. ESA's scientists and engineers are active participants in various development programmes and their expertise - both technical support and support in managing complex projects - is highly valued by 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 use of competitive procurement models even for basic technology has also meant that 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).

There are nevertheless downsides to ESA membership, as compared with a national programme. Member state investments via 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. 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.

[76] ESA employs c. 2,500 staff around the world, most of whom are based at its main centres of excellence in Europe

8.4 UK space economy

UK membership of ESA has underpinned growth in the UK space economy. While contract income from ESA amounts to a small share of the total UK space economy (around 3%), 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 (a sector with high levels of R&D investment) and while they have long-standing ties to the UK any reduction in UK investment in ESA would likely to lead to a switch in new investment from the UK to the EU and a gradual downsizing of these 'anchor' businesses in the UK, with 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.

In addition, the increases in national investment in ESA championed by successive science ministers have been used to persuade ESA to switch some of its technical support activities from 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.

9 Economic assessment

Summary

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, i.e. each £1m invested will generate a return of £11.8m, over time. If we take into account ESA overheads this ratio is 1:9.8

Based on 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.

In terms of employment, we estimate that the return of investment is 1:9.8, meaning that each £1m spend delivers 9.8 FTEs (person years employment) emerging from direct and indirect effects, and benefits from ESA-derived activities) (see Table 59). If we take into account overheads this ratio is 1:8.2.

9.1 Introduction

In this section, we explore the economic effect of ESA CMIN19 spend 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

9.1.1 *Overview of methodology used* [77]

The estimates of direct and indirect effects are based macro-econometric modelling using Cambridge Econometrics E3ME model and the planned ESA expenditure for CMIN19 in the UK.

The ESA-derived activities ('ripple effects') were collected via the survey of ESA contractors. As shown in 5.2.4 contractors have reported commercial benefits in terms of income and employment. The projected 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. As such, these estimates rely fully on primary data collected via the and do not make use of other assumptions or ratios from secondary data sources

[77] A detailed presentation is provided in *Impact Evaluation: Technical Report Annex* & methodology in Appendix F

Wider ESA-derived spillover benefits 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. Therefore, estimates of spillovers were based on those reported in the literature.[78]

9.2 Gross value added (GVA) impact

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, i.e., 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. Based on 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.

Table 19 summarises the main results in terms of GVA for each impact route. **It shows that the public return to investment is 1:3.4 based on direct and indirect effects, and benefits from ESA-derived activities, and measured as net GVA (i.e. accounting for additionality/ counterfactual).** This is in line with the evidence found in prior studies related to public investment in space related activities. A recent literature review shows that the public rate of return on investment in space-related activities (across multiple domains) ranged from 0.4-13.0, with a mean of 4.3 (across 24 studies).[79] Estimates in studies focused on ESA membership ranged from 1-6.3, with a mean of 3.1 (across 9 studies). Those studies to not tend to include spillover effects.

Furthermore, an effect of 1:8.4 is expected in terms of ESA-derived spillovers benefits (i.e. 2.5 times the direct and indirect effects, and benefits from ESA-derived activities). Note that given the timing of the evaluation, spillovers are estimated using figures from previous studies (as they have not materialised yet and are expected to emerge in the future). 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.

[78] As reported in the Literature Review delivered to UKSA during the inception phase of the M&E study

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

Table 19 GVA impact

Type of benefit	Ratio (Investment to GVA)	Grossed up estimates (based on projects 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 a 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**		

Source: Technopolis (2021). (*) Based on projected spend for CMIN19 investment period (**) Including a direct GVA effect of 1:49. (***) Spillovers are expected to materialise in the long-term and at this point in time, had to be estimated based on evidence from prior studies, and consequently relies in strong assumptions

9.3 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 FTEs (person years employment) emerging from direct and indirect effects, and benefits from ESA-derived activities) (Table 20). 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.

Further employment is expected from spillovers, but no ratios have been found in the literature to provide a (forecasted) estimate for those effects.

Table 20 Employment (FTEs)

Type of benefit	Ratio	Grossed up estimates (based on projects 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**		

10 Contributing to net-zero

Summary

Historically, where climate change is concerned, the focus of ESA and USKA has been the development of EO infrastructure in space to inform our scientific understanding of climate change and monitor key climate change variables. 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, more sustainable fuels and the small initiatives exploring options to reduce the emissions of the space sector. However, any returns from these activities may be out-paced by wider initiatives to de-carbonise the UK energy system and the balance of investment needs further consideration before actions are decided.
- UKSA could target a proportion of investment in space applications (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 activities would deliver from a net-zero perspective.

10.1 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.[80] The space industry is also contributing to climate change through its need to launch spacecraft, albeit this is very much less significant than carbon footprint of manufacturing. Moreover, the space launch programmes are currently based outside the UK, and as such are of less direct relevance at the current time, but will become more important as the UK's launch capabilities become available.
- **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 and monitoring climate change** and continues to provide new insights that enhance climate change models and improve monitoring activities and the design of government policies and mitigation measures.[81] These activities do not directly move us towards net-zero by actively reducing CO2 (or other greenhouse gases) in the atmosphere but do play a critical role in monitoring progress at a global level.
  - **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

[80] The space sector's GHG emissions resulting from CMIN19 investments were modelled and reported in the *Impact Evaluation: Technical Report Annex*

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

precision agriculture. While the major contributors in future years are likely to be 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.

10.2 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 and limited actions specially targeting the reduction of the GHG emissions from space activities. However, ESA has been investigating the issue of the space industry's GHG emissions, 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[82] and funding one or two smaller projects concerned specifically with the environmental performance of ESA contractors[83, 84]
- Funding research into more sustainable fuels or re-usable space hardware
- Funding feasibility studies relating to radical new energy technologies, such as space-based solar power (SBSP), though any implementation of this this technology is a very long-way in the future.[85, 86]

10.3 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. Missions, with high UK input, such as CO2M and TRUTHS will continue to improve our understanding of, and ability to monitor, 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 ToC. 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.

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-

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

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

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

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

[86] 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

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.

1.2 Modelling the GHG emissions of the UK space industry

To provide a baseline for future UKSA studies and evaluations, Cambridge Econometrics used its E3ME macro-econometric model[87] to estimate the carbon emissions associated with the UK-based industrial activity conducted under CMIN19 contracts.

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.

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

11 Levelling-up

Summary

- **As a new policy, levelling up was not part of the UKSA business case 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 (in the SE, SW, London, East of England) with a growing activity in Scotland 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, and 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 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 HRE) 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 segment via the TIA, EO and GSTP as well as space applications businesses (via TIA) who are not bound by the locations of the traditional space sector.

1.3 Levelling up and CMIN19

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.[88] 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.

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, ToC 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. In doing so, it is, nevertheless, important to acknowledge that 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.

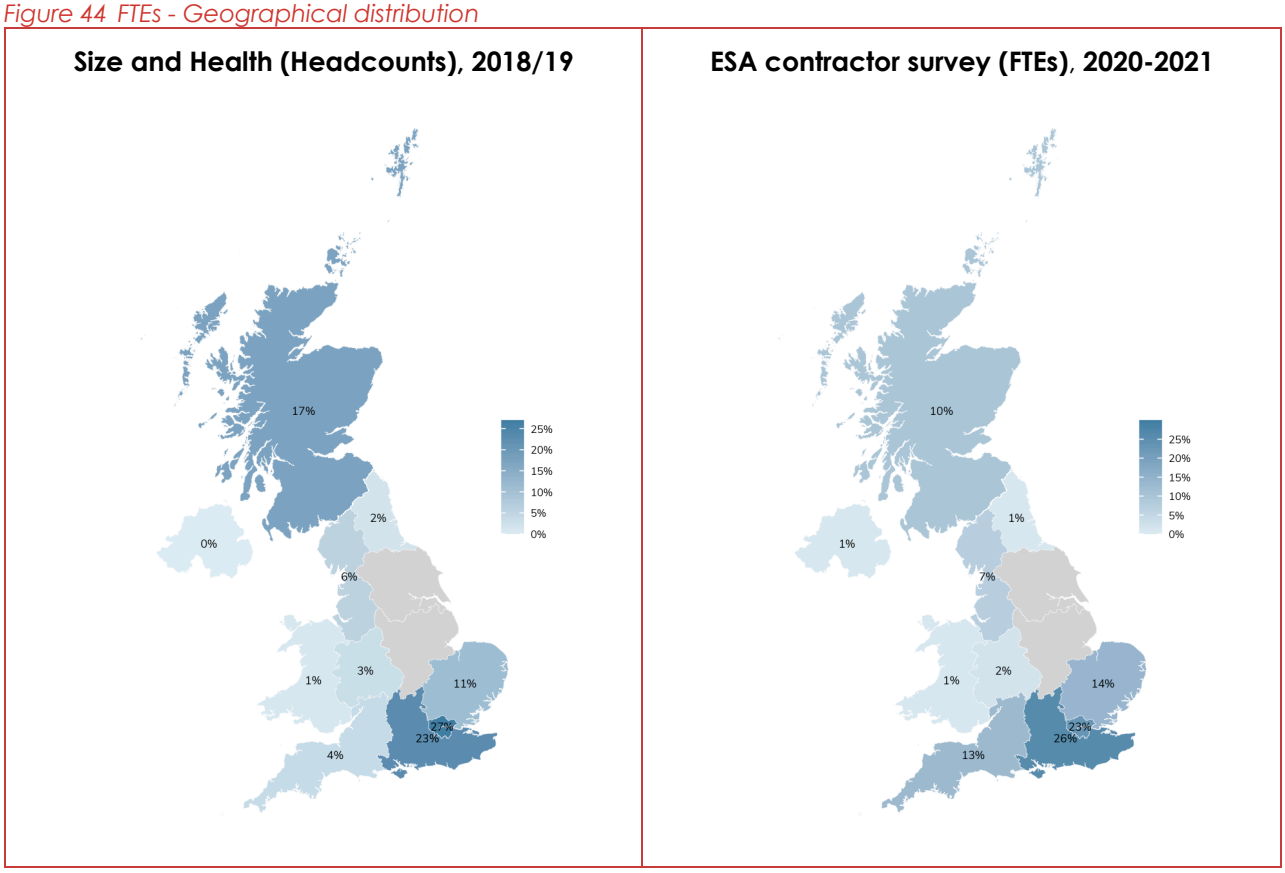
[88] https://www.gov.uk/government/publications/levelling-up-the-united-kingdom

1.4 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 CMIN19 period 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) (Figure 44). 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– 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 and associated employment is located in Stevenage and Portsmouth and Harwell.

Figure 44 FTEs - Geographical distribution



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

1.5 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. 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 the South of the UK. 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 UKSA 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.
- ESA's 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.[89, 90]
- 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 ESA funding to develop their world-leading small satellite launch technologies and bring them to market.

UKSA 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.[91] 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 UKSA has worked with the Knowledge Transfer Network (KTN) to develop an interactive portal that maps the location of the companies, universities, funding bodies and networks that form the UK Space sector.[92] The tool maps the location of more than 1,000 organisations[93] 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 the UK space industry, 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.

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

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

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

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

[93] 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

12 Summary and conclusions

12.1 Overview

The first implementation of the M&E framework collected evidence against an extensive set of indicators designed to encompass the breadth of expected impacts of UK's investments in 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 approach, the evaluation explored and tested the pathways to impacts outlined in the theories of change (ToC) for the eight ESA programmes under consideration 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.

12.2 Impact evaluation

Context

CMIN19 investments will be made over the five-year period from the start of 2020 to the end of 2024 and therefore this first impact evaluation of CMIN19 was undertaken at an early point in the investment lifecycle (35% of the way though) and at an early point in the impact generation timeframes:

- At this point in time, only approximately 20-25% of expected CMIN19 ESA contracts (by value) have been let and many have not yet finished. Therefore, the majority of the project work has either not yet started (i.e. contracts not yet placed) or not yet finished.
- Investment in space infrastructure is an inherently long-term endeavour. ESA missions can take 10-15 years to develop, spanning several of ESA's five-year investment periods. The missions will then be operational in space for a similar length of time after launch.

Therefore, this first evaluation could only consider the outputs of ESA investments, plus any early outcomes, generated to date by a sub-set of the intended UK CMIN19 investment.

The evaluation has identified positive effects in terms of outputs being generated by ESA contracts, some evidence of early outcomes and projected values for impacts.

It has also explored and validated the over-arching theory of change for UK investments in ESA and for each of the eight ESA programmes. This provides evidence that the expected pathways to impact are plausible and allows us to make 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 the five year period from January 2020 to December 2024 is €2,114m, with 90% of the budget assigned to the four large programmes: Science, TIA, EO and HRE[94]
- 675 ESA contracts with a total value of €392m have been let to date (i.e. between Jan 2020 and Jun 2021) to 281 UK organisations and 88% of the contracts are with industry
- Six organisations account for 50% of contracts (by value), reflecting the concentrated structure of the UK space industry

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

- Industrial co-funding is required for some funding mechanisms within the TIA, GSTP, NAVISP and CSTS programmes. Co-funding is agreed on a contract-by-contract basis and not systematically recorded by ESA or UKSA, however 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 contract value.
- **20-25% of the total planned investments had been made at the 21 month point of a five-year investment (i.e. 35% of the way though). While this suggests that UK contracts are running behind schedule, contracts vary greatly in size and a number of large contracts are expected for UK organisations in Science, EO and HRE that will change the total value considerably.**

Knowledge: outputs

- The main intended knowledge generation effects of ESA contracts are considered to be *outcomes* (rather than outputs) of ESA investment as they do not arise until ESA missions have been launched and are operational. Nevertheless, ESA contractors reported a total of 109 papers in the current CMIN19 period, indicating that the contract work itself can also lead to the generation of new knowledge. We note however, that some papers may also be the result of earlier related ESA contracts (but published since Jan 2021) due to the long-term nature of the development process for space infrastructure and the challenges in assigning specific outputs and outcomes to specific contracts.

Knowledge: outcomes (baseline)

- The quantity and quality of scientific knowledge generated from research using ESA space infrastructure 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 that can be monitored on an annual basis.
- The baseline data indicates that the majority of scientific knowledge outputs (84%) are generated by the missions in the Science programme, reflecting the fact that the Science programme is entirely focused on generating new knowledge about the Universe and Solar System. In terms of quality of research outputs, assessed in terms of citations, the UK performs well compared to other leading ESA member states. The UK also has a strong performance in international co-publication rates and rate of publications per £ invested compared to other large space-faring nations.

Prosperity: outputs

- As would be expected, ESA contracts are supporting a progression in the technology readiness level (TRL) of technologies being developed. In addition, around a half of respondents expect the outputs of their contracts to contribute to operational space infrastructure within the next 10 years
- ESA contracts support large numbers of collaborations; 86% of those responding to the evaluation survey reported at least one form of collaboration, the majority with businesses industry in the UK (69%), in other ESA member states (54%) and with businesses in non-ESA countries (23%). A smaller, but still significant, number reported collaborations with academia (48%). Therefore, ESA contracts are creating opportunities for technology and knowledge transfer between project partners and for new ideas and concepts for innovation to arise and for deeper partnerships to develop.

- 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 international partnerships expected from 2022 onwards
- Working for ESA also provides considerable intangible benefits for contractors. 58% ESA contractors, and all interviewed contracted, reported significant positive reputational and competitiveness benefits in international space markets. The ESA 'badge of approval' is highly valued by contractors as it demonstrates an organisation's technical and management capabilities to other customers and markets.

Prosperity: outcomes for ESA contractors

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

- The most frequently reported effect (reported by 89%) is new or improved employee skills and knowledge
- 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 follow-on sales in the future (2022 onwards)
- 20% have achieved employment benefits as result of follow-on sales and 32% expect employment benefits in the future (2022 onwards)
- 7% have accessed new markets to date and 18% expect to in future (2022 onwards)
- ESA contractors were able to provide estimates of the expected value of their follow-on sales (and are reported in the Economic Assessment section below)
- 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-out has received investment of £10m. A further eight spin-outs are expected in the future (from 2022 onwards). The qualitative data suggest that the reputational effect of ESA 'badge of approval' has played a role in securing private sector investment.

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 granted to UK organisations in the space domain and investment in UK space businesses.

Prosperity: usage and innovation benefits (spillovers)

- As already described, it is too soon for downstream usage and innovation effects to have been generated from CMIN19 investments. However, 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 the expectation of significant downstream benefits, with environmental protection the most frequently reported, followed by productivity benefits and security of assets on Earth.
- The downstream applications developed in the UK under the ESA TIA BASS programme provide examples of the innovative products and services that can be developed (based on existing ESA space infrastructure) and the type of downstream benefits they are targeting:

- Applications are under BASS cover a wide range of many application domains from smart cities, transport and finance to health, culture and the environment
- The majority of the applications supported (65%) were using EO data, followed by satcom capabilities (22%) and satnav capabilities (position, timing, navigation data) (7%)
- Applications are expected to provide economic benefits for both the companies developing the innovative products and services and the wider economy once in use by their customers. Environmental and social benefits are also expected from the products and services under development.

Outcomes: global influence

As the fourth largest investor in ESA 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 well-established space primes able to manufacture and operate the large-scale complex spacecraft for Science, EO, HRE and satellite communication and home to smaller and younger innovative and entrepreneurial space companies. Nevertheless, just over a half (50-60%) of ESA contractors think that that the UK is well-represented within ESA senior leadership and that the UK space sector's capabilities and needs and national policy goals for space are reflected in ESA strategy and planning, implying that there may be room for improvement. Influencing large inter-governmental organisations such as ESA is always a challenge as they need to balance priorities amongst members and adhere to formalised governance processes. In part, it may be a matter of perception and visibility of UKSA activities within ESA – this is addressed further in the *Process Evaluation Report*

- The UK is highly respected and valued within ESA for its scientific capabilities. The UK played a central role in the recent development of ESA's new long-term scientific strategy, with a UK academic as co-chair of the ESA Voyage 2050 senior committee and a large number of UK academics on the committee's thematic groups. This suggests that the UK's expertise and research interests will be well-catered for in space science investments for many years to come.
- There was a clear view that UK's wider international influence in space is due in part to, and enhanced by, its membership of ESA.

Outcomes: security and protection

The UK is a major contributor to two small ESA programmes – SSS and CSTS – that 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.

- These programmes support the UK's ambitions to be a global leader in these fields. The SSS programme and UK's national ambitions to take a lead in space weather forecasting and in 'clean space' 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 ESA in CMIN19 ensuring UK's access to space - both though enabling access to ESA's launch capability and accessing expertise to develop national launch capabilities.
- The UK's contributions to ESA's EO capabilities provide access to scientific understanding and data to support a wide range of environmental protection and public protection policies and actions.

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 21 Summary of ESA programmes and impact effects

	Increased global influence (Goal 2)	Increased prosperity and (scientific) knowledge			Increased security and protection (Goal 4 / Goal 5))		
		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

12.1 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**		

12.2 Attribution and additionality

- The **outputs** reported are in line with what is expected of the various ESA programmes and are a direct result of the activities within ESA contracts as 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 achieved to date (and the expected outcomes). 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 R&D and innovation in the space domain, giving them limited alternative options to work on space technologies and applications.
- For downstream applications and the social and economic impacts generated through their use, both attribution and additionality are partial. Detailed examinations of the programme theories of change validated the pathways to impact suggesting that future benefits are highly likely to be generated. However, the impacts will require further private (and possibly further public) investment both to commercialise new products and services and to support adoption by end-users and, in some cases, there will also be alternative solutions (including 'do nothing').
- The analysis of the theories of change also indicated that for outcomes arising from programmes with a high-level of scientific content (Science, HRE and elements of EO) – the knowledge and skills outcomes in particular - wouldn't occur without ESA investments as the space infrastructure they rely on wouldn't exist. Without ESA's contribution to the global scientific activity from space and its pooling of European national investments the totality of space infrastructure would be significantly reduced.

12.3 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.

- **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 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 off 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.
- **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 space 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.

12.4 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.

12.5 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.

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