Evaluating the benefits of the UK's investments in the European Space Agency

Technical annex

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Preface

The United Kingdom Space Agency commissioned RAND Europe and Ipsos UK in November 2023 to conduct monitoring, evaluation and benefits management for the UK's investments in the European Space Agency (ESA). This study aims to assess the impact, delivery, and value for money (VfM) of the UK's investments, underpinned by comprehensive benefits management. This aims to inform the accountability of the UK Space Agency's ESA programme spending and provide learning for programme teams, analysts and policymakers, focusing particularly on exploring the uncertainty around monetised benefits and the relative scale and uncertainty surrounding non-monetisable (quantified or otherwise) benefits.

This study began with a deliverable scoping out the study's initial phase, followed by a comprehensive monitoring and evaluation (M&E) framework to assess the benefits of the UK's investment in ESA. This document represents one part of the final deliverable to the UK Space Agency, which includes the process report, impact and value for money report and executive summary. This report was quality assured by Dr Susan Guthrie and James Black at RAND Europe and Chris Hale at Ipsos UK.

RAND Europe is the European arm of RAND, a non-profit research organisation aiming to help improve public policy and decision-making through objective research and analysis. This study is undertaken through RAND's Europe Space Hub (RESH), which brings together RAND's civil and defence space expertise to deliver space-related research for governments in the UK, Europe, the United States (US), Australia, and Japan.

The **expert advisory panel** for this study comprises space technology and policy experts: Dr Bonnie Triezenberg and Dr Peter Whitehead from RAND US, and Amanda Regan (independent, ex-ESA).

Ipsos UK is the British arm of the global market research organisation Ipsos, with extensive experience in theory-based and complex economic evaluations. Ipsos UK has expertise in multi-stranded programmes and policies, particularly in the innovation, net zero and environmental sectors, involving long-term process and impact/economic evaluations, plus advisory work on science and innovation policy.

For more information about the study, RAND, or Ipsos UK, contact:

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Purpose of the report

This report presents additional methodological and supplementary material accompanying the two main impact/value-for-money and process reports.

Structure

The annex includes the following sections:

- Annex A: Methodological note – briefly summarises each method used in the study.
- Annex B: Interview programme – approach and list of consultees.
- Annex C: Review of documentation.
- Annex D: Proportionality assessment – summarises the approach to determine the level of M&E assigned to each programme.
- Annex E: Theory of Change (ToC) – an updated logic model and narrative of the investment.
- Annex F: Impact and process evaluation indicators.
- Annex G: Scientometrics report.
- Annex H: Econometric analyses.
- Annex I: Economic evaluation approach.
- Annex J: Expert reviews of select programmes and missions.

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Abbreviations

ABS	Annual Business Survey
ADRIOS	Active Debris Removal/In-Orbit Servicing
BASS	Business Applications and Space Solutions
BCR	Benefit-Cost Ratio
BEIS	Department for Business, Energy and Industrial Strategy
BIC	Business Incubation Centres
CA	Contribution Analysis
CCI	Climate Change Initiative
CDI	Citation Distribution Index
CEOI	Centre for Earth Observation Instrumentation
CNI	Critical National Infrastructure
CNRS	Centre national de la recherche scientifique
CSA	Canadian Space Agency
CSC	Copernicus Space Component
CSFs	Critical Success Factors
CWTS	Centre for Science and Technology Studies
C3S	Copernicus Climate Change Service
DESNZ	Department for Energy Security and Net Zero
DfT	Department for Transport
DiD	Difference-in-differences
DSIT	Department for Science, Innovation and Technology
ECV	Essential Climate Variable
EEE	Electrical, Electronic and Electromechanical
ENDURE	European Devices Using Radioisotope Energy
EO	Earth Observation
EOEP	European Earth Observation Programme
EQs	Evaluation Questions
ESA	European Space Agency
EUI	Extreme Ultraviolet Imager
ExPeRTT	Exploration Preparation, Research and Technology

FDI	Foreign Direct Investment
FTE	Full-time Equivalent
FWCI	Field-Weighted Citation Impact
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GMES	Global Monitoring for Environment and Security
GSTE	Ground Segment Test Equipment
GSTP	General Support Technology Programme
GtR	Gateway to Research
GVA	Gross Value Added
HCP	Highly-Cited publications
HESA	Higher Education Statistics Agency
HMRC	His Majesty's Revenue and Customs
HMT	HM Treasury
HRE	Human and Robotic Exploration
IDBR	Interdepartmental Business Register
IP	Intellectual property
IPA	Infrastructure and Projects Authority
JAXA	The Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
LEO	Low Earth Orbit
M&E	Monitoring & Evaluation
MAG	Magnetometer
MAG	Microsoft Academic Graph
MIRI	Mid-Infrared Instrument
MOD	Ministry of Defence
MoU	Memorandum of Understanding
MRC	Medical Research Centre
MS	Member States
MSSL	Mullard Space Science Laboratory
NASA	US National Aeronautics and Space Administration
NavISP	Navigation Innovation Support Programme
NERC	Natural Environment Research Council
NOAA	National Oceanographic and Atmospheric Administration
NPV	Net Present Value
NSIP	National Space Innovation Programme
NSS	National Space Strategy

NSSP	National Space Science Programme
NSTP	National Space Technology Programme
NWP	Numerical Weather Prediction
OA	Open Access
OA	Output Area
OGD	Other Government Departments
ONS	Office for National Statistics
PAYE	Pay-as-you-earn
PMD	Post-mission disposal
PNT	Position, Navigation, and Timing
PT	Process Tracing
QCA	Qualitative Comparative Analysis
QED	Quasi-experimental Design
R&I	Research & Innovation
SCIF	Space Clusters Infrastructure Fund
SDiD	Staggered difference-in-differences
SEBP	Space Science and Exploration Bilateral Programme
SKIES	Skynet Integrated Enterprise Solution
SOHO	Solar and Heliospheric Observatory
SPF	Strategic Priorities Fund
SPICE	Spectral Imaging of the Coronal Environment
SPO	Spectrometer Pre-Optics
STFC	Science and Technology Facilities Council
SWA	Solar Wind Analyser
SWIMMR	Space Weather Instrumentation, Measurement, Modelling and Risk
TBE	Theory-Based Evaluation
ToC	Theory of Change
TRL	Technology readiness level
UCS	Union of Concerned Scientists
UKRI	UK Research and Innovation
UN	United Nations
UNFCC	United National Framework Convention of Climate Change
USB	Unlocking Space Business
VAT	Value Added Tax
VfM	Value for Money
VoI	Value of Information
WoS	Web of Science

Annex A. Methodological note

This section provides a summary of each method used in this evaluation.

A.1. Proportionality assessment

We conducted a proportionality assessment during the project's inception phase to inform our data collection activities. The assessment incorporated findings from an initial document review and secondary data analysis to provide a proportionate level of analysis to apply to each programme area. A detailed description of the approach to and outcomes of the proportionality assessment is presented in Annex D.

A.2. Impact evaluation

To approach the impact evaluation, we implemented Contribution Analysis (CA), Theory of Change (ToC) development and Value for Money (VfM) framing, which were relevant to various aspects of future UK Space Agency business cases. RAND led the impact evaluation using a pragmatic theory-based approach, as advised by the Magenta Book. This approach was appropriate given that the UK Space Agency's investment into ESA represents a complex intervention, funding various programmes with multiple interventions, long causal chains and operating within a changing context.

Throughout the project, CA served as an overarching framework for impact measurement, allowing us to synthesise results from programme and programme area levels up to the UK investment portfolio level. Contribution analysis explored attribution by assessing the programme's contributions to observed results and outcomes, developing plausible pathways to ultimate impacts. It provided a guiding framework for testing programme hypotheses and establishing a well-reasoned case for the contributions made by the UK's investments in ESA beyond alternative hypotheses.

The refinement of the ToC was conducted by identifying the key pathways to impact and articulating them as measurable and testable contribution claims (i.e. A equals B because of C). This process included an updated understanding of market barriers and incorporating assumptions, risks and external factors influencing the relationships between activities, outputs, outcomes and impacts.

A.3. Process evaluation

RAND led the process evaluation following best practice Medical Research Council (MRC) process evaluation guidance. This focused on how strengths and weaknesses in design, implementation, and contextual factors affected delivery, specifically within UK Space Agency processes. We identified improvements to portfolio and project management and benefits realisation through primary methods, including UK Space Agency process satisfaction and reviews of prior evaluations.

A.4. Programme-level synthesis

A set of programme reports covering the 'high-level monitoring and evaluation (M&E)' programmes were produced, resembling case studies and informed by the impact and process assessments. These reports presented programme-level analyses. They were structured around testing the ToC and associated CA hypotheses, illustrating the programmes and their progression through the ToC. The reports addressed process and impact evaluation questions, probing what worked well, what did not, for whom, and in what contexts. We synthesised the data collected from programme reports and broader data collection to aggregate the overall investment portfolio level into our process, impact and economic frameworks.

A.5. Economic evaluation (see Annex H and I)

Our economic assessment measured monetisable and non-monetisable benefits from the UK Space Agency's investment in ESA that have materialised or are expected to materialise. We compared these benefits to portfolio costs and overheads while establishing an economic evaluation framework. The benefits from the VfM framework were mapped to the ToC, ensuring alignment between impact and economic evaluations while establishing VfM-related causal pathways. Our assessment also considered improvements in intellectual property (IP), technologies, production methods, knowledge mobilisation, spinouts and non-monetary cross-sector effects, such as environmental and health benefits.

The evaluation captured progress towards long-term benefits, recognising that some benefits might only be realised in the very long term. We acknowledged the complexity of monetising all benefits and proposed various approaches to make sound judgments on value for money and return on investment. Furthermore, we evaluated the value and cost avoided due to investments in infrastructure, such as satellite networks and early warning systems, which reduced the risk of global disasters or other significant damage. Our work combined the probability of unwanted events occurring with the potential damage costs, forming a basis for evaluating interventions aimed at mitigating threats.

A.5.1. Conceptual framework and VfM workshop

The project team facilitated a workshop with the UK Space Agency and the Department for Science, Innovation and Technology (DSIT) to present and seek feedback on our conceptual framework. The workshop was split to cover a validation and discussion exercise for our proportionality assessment and the development of evaluation questions. We also used this to present preliminary adaptations to the ToC and seek feedback. The VfM workshop sought to refine and discuss the proposed VfM methods led by Ipsos and to understand the UK Space Agency's desired metrics and outputs.

A.6. Data collection

A **document review** involved an indexing process, in conjunction with secondary sources, to map sources to programmes and evaluation activities. This mapping focused on identifying sources useful for specific evaluation stages, assessing data completeness and prioritising key sources for developing the conceptual framework, particularly for the proportionality assessment. The review encompassed portfolio-level sources (e.g. contracts guidance documentation), programme-level sources (e.g. letters of support), wider published sources (e.g. annual business surveys) and monitoring and evaluation sources (e.g. past ESA evaluations). Following the inception phase, we developed data extraction templates based on the process, impact and economic evaluation frameworks, which our team utilised to extract data for evaluations and benefits realisation reporting, guided by the proportionality assessment.

Our analysis of UK Space Agency-held **secondary data** focused on linking and analysing datasets to answer the evaluation questions (EQs). **Interviews** were guided by clearly defined topic guides reflecting the evaluation framework. Conducted online and tailored to reduce the burden on consultees' time, the anticipated sample included UK Space Agency and ESA staff, UK ESA contractors and the indirect beneficiaries of contracts. We used the interview data to track support or evidence against each causal pathway in the ToC and alternative pathways, allowing us to systematically test the ToC using the interview data.

A.7. Scientometric analysis (see Annex G)

We explored scientific publications as an indicator of scientific performance and the benefits of ESA-funded programmes. We constructed a composite bibliographic database of papers funded by ESA from Scopus, Web of Science and OpenAlex. Using this database, we calculated a range of scientometric indicators to identify the UK's performance relative to other ESA countries. We divided these indicators into those looking at publication volume, international collaboration and citations. We used results from this analysis in conjunction with qualitative evidence to identify the UK's position among ESA countries in the published outputs of ESA-funded science.

A.8. Expert review (see Annex J)

We engaged four space science and technology experts to conduct reviews of three programmes evaluated at high/medium intensity, namely the Climate Change Initiative (CCI),[1] the Navigation Innovation and Support Programme within ESA (NAVISP) and Vigil. The selection of programmes was based on the availability of programme outcomes and the technological expertise required to assess the impact. The selection was agreed on with the UK Space Agency. For the review process, the RAND team put together programme 'fact sheets' with accompanying sources for optional review, e.g. resulting journal articles. The experts then scored it on the assessment criteria and provided an analysis.

[1] ESA Climate Office (2025a).

Annex B. Interview programme

Interviews were the primary data-collection method for capturing the rich qualitative data needed to answer the Evaluation Questions (EQs). We conducted a total of 94 online data collection interviews, which included 102 individual stakeholders across all thematic programme areas:

- Technology (n=6)
- Space Safety (n=18)
- Earth Observation (EO) (n=33)
- Commercial (n=4)
- Human and Robotic Exploration (HRE) (n=5)
- Navigation (n=7)
- Telecoms (n=7)
- Science (n=13).

Within each domain, our team interviewed various industry representatives, UK Space Agency and ESA programme managers and wider stakeholders, such as end users and policymakers. Many interviews were selected and contacted in collaboration with the UK Space Agency. In addition, we conducted 17 scoping interviews with stakeholders at the UK Space Agency, DSIT and ESA, including six related to EO, one related to commercial, one to HRE, one to Navigation, two to Space Safety, three to Technology and three to Telecommunications. The scoping interviews facilitated the project team's understanding of the programmes.

All data collection interviews lasted up to one hour and were conducted remotely using Microsoft Teams. All interviews were semi-structured, using clearly defined topic guides that reflected bespoke indicators for each domain and programme area. This included process questions about perspectives on inputs and activities, such as governance and management processes, and impact-focused questions to gather insights on the resulting outputs, outcomes and impacts stemming from ESA investment. For domain and programme-level interviews, notes were mapped to evaluation themes using a coding structure that aggregated up to the entire investment portfolio level. We conducted the coding using MaxQDA, a qualitative data analysis software.

We conducted all interviews in line with privacy and General Data Protection Regulation (GDPR) requirements. We informed interviewees that they would not be identified in reporting to ensure they felt comfortable sharing their experiences and insights and that we would not use direct quotations that would identify or be attributed to them. Before conducting interviews, we ensured that interviewees had received a privacy notice which set out how interviewees' data would be used, including their right to access, correct or erase their personal data. To maintain anonymity, we identify interviewees throughout this report using the format 'Int_XX_YY', where XX indicates an identification number allocated to each interviewee and

YY indicates the programme area of relevance. For example, INT_10_SCI indicates the 10th stakeholder interviewed within the Science programme.

Annex C. Review of documentation

Within our review of documentation and literature, we analysed various sources reporting descriptive information regarding ESA investment domains and the portfolio level of investments. Much of this information enabled us to create a highly detailed proportionality assessment alongside contextual information for each programme area, including contract data, business case information, findings from past evaluations and wider benefits of each analysed programme. All data sources have been directly shared between RAND Europe, Ipsos and the UK Space Agency via our shared data repository. Table below lists UK Space Agency-provided documentation received across programmes and at the investment portfolio level.

Table 1: UK Space Agency-held documentation

Document type	Document time period	Portfolio level	Programme level
ESA contracts awarded to UK-based organisations	From January 2015 to present	Received	Received
ESA contract change notices (CCNs) to UK-based organisations	From January 2015 to present	Received	Received
Any accompanying guidance documentation related to ESA contracts	From January 2015 to present	Partly Sourced	Not Applicable
ESA Financial Obligations	From January 2012 to 2028	Received	Received
UK Space Agency Financial Commitments until 2028	From January 2012 to 2028	Received	Received
Any accompanying guidance documentation related to ESA's financial obligations	From January 2012 to 2029	Partly Sourced	Partly Sourced
ESA contract award forecasts	From January 2012 to 2030	Received	Received
Current and historical ESA programme board reports	From January 2012 to present	Not Applicable	Received
Current and historical ESA programme proposals	From January 2012 to present	Not Applicable	Received
CMIN22* Full Business Case (FBC) and relevant annexes	Current CMIN 2022 FBC	Received	Received
CMIN22 FBC Cost-Benefit Analysis Model	Current CMIN 2022 FBC	Received	Received

Document type	Document time period	Portfolio level	Programme level
CMIN19 FBC Cost-Benefit Analysis Model	CMIN 2019 FBC	Received	Received
CMIN19 FBC Cost-Benefit Analysis Model	CMIN 2019 FBC	Received	Received
Comprehensive list of existing research and evaluations	From January 2012 to present	Received	Received
Other relevant evaluations in train	From January 2012 to present	Partly sourced	Partly sourced
Departmental appraisal, benefits realisation and M&E guidance	-	Received	Received

Source: UK Space Agency-held Documentation. RAND Europe Analysis. *ESA Council at Ministerial level (CMIN).

In total, we analysed **33 individual documents** spanning the various types provided by the UK Space Agency. In addition, we analysed **21 published and subscription sources** throughout the evaluation. These can be found below in Table .

Table 2: Document/data type by availability

Document type	Source
Companies House data	Publicly available
UK Innovation survey	Publicly available
Annual Survey of Hours and Earnings	Publicly available
Space Census Survey	Publicly available
Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal	Publicly available
Union of Concerned Scientists (UCS) Satellite Database	Publicly available
Comspoc's NEAT Tool	Publicly available
Higher Education Statistics Agency (HESA)	Published
Space skills survey	Published
Department for Business, Energy & Industrial Strategy (BEIS) M&E Framework	Published
Green book	Published
Magenta book	Published
Aqua book	Published
Infrastructure and Projects Authority (IPA) guidance on benefits realisation	Published
Uncertainty Toolkit for Analysts in Government	Published
Annual Business Survey	Access to the Office for National Statistics (ONS) Secure Research Service and accredited researchers required for access to survey microdata
Business Structure Database	Access to the Office for National Statistics (ONS) Secure Research Service and accredited researchers required for access to survey microdata

Document type	Source
Business Enterprise Research and Development Survey	Access to the Office for National Statistics (ONS) Secure Research Service and accredited researchers required for access to survey microdata
Other business databases (e.g. Crunchbase, Pitchbook)	Subscription required
Other bibliometrics datasets (e.g. Dimensions, Scopus, PlumX, Overton)	Subscription required
Patent databases (e.g. PATSAT)	Subscription required
Space-Track	Subscription required

Source: Document/data type by availability. RAND Europe Analysis.

Annex D. Proportionality assessment

This chapter presents the approach to the proportionality assessment. The evaluation team determined the level of M&E to assign each programme based on the evidence collected and the outcomes of the deliberative conceptual framework workshop with the UK Space Agency (note that this was written as part of the evaluation framework, hence using the future tense). The proportionality assessment was conducted between December 2023 and March 2024, incorporating evidence available during this period. While the proportionality assessment outlines intended M&E activities across the UK Space Agency ESA programmes in scope for this evaluation, it does not necessarily reflect M&E activities that occurred, due challenges in implementation discussed at the conclusion of this chapter.

D.1. Purpose

The proportionality assessment aims to assign an M&E level to each UK Space Agency ESA programme, programme area or domain through a structured and transparent process. M&E activities will include process and impact evaluation. Process evaluation involves analysis of programme implementation, addressing whether a programme is implemented as intended, whether the programme design works and what aspects of the programme and its implementation are working well.[2] Impact evaluation examines what changes have occurred related to the programme, the scale of these changes and the extent to which changes can be attributed to programme design and implementation.[3] VfM, as a part of the impact evaluation, compares the benefits and costs of the programme.

Different intensities of M&E are required due to the UK Space Agency's broad investment in ESA, covering some 98 programmes across nine domains (seven of which are recognised by ESA). Therefore, using resources to assess each programme with the highest possible intensity is neither feasible nor effective. However, the approach to assigning an M&E level must be systematic and transparent, providing clarity and accountability, considering how each programme's character and features (e.g. focus, lifecycle stage) influence the most appropriate type and intensity of M&E. **Additionally, while all programmes were in scope for the economic evaluation, some programmes were excluded from other evaluation activities due to planned standalone evaluations. Although programmes across Telecoms and Integrated Applications were initially excluded from the evaluation, several interviews were ultimately conducted**

[2] HM Treasury (2020).

[3] HM Treasury (2020).

for the domain and therefore it was not excluded in its entirety. The Space Transportation domain has been excluded in its entirety.

Each programme's assigned M&E level will determine the methodological approach used to evaluate it. Possible approaches include:

1. A document review
2. An analysis of secondary data
3. Interviews
4. Site visits and surveys
5. Bibliometric analysis
6. A business database analysis
7. The use of theory-based evaluation methods (TBE), e.g. the ToC
8. A quasi-experimental design (QED) or counterfactual design
9. A VfM assessment.

We conducted site visits with organisations with significant involvement in ESA (e.g. organisations at Harwell Campus). Bibliometric assessment involves statistical analysis of scientific research outputs, including scientific articles, books, publications, patents and other forms of intellectual property, where relevant. TBE methods assess the extent of change associated with a programme and why the change occurs, focusing on examining postulated causal chains related to the programme.[4] These causal chains are often described visually and narratively in a ToC, which illustrates how programme design and activities are thought to interact with contextual factors to produce outputs and outcomes. These causal chains can be assessed through TBE methods, including CA, process tracing (PT) and qualitative comparative analysis (QCA), which assess the extent to which observed impacts can be attributed to the programme. QEDs and counterfactuals also assess impact attribution but by comparison with a control programme or counterfactual scenario.

We developed three M&E intensities for the proportionality assessment. These include 'high', 'medium' and 'low', with different methodological approaches for each intensity. 'High' represents the most intensive M&E, employing all methodological approaches, whereas 'low' signifies the least intensive, comprising a selection of methodological approaches suited to examining programmes in less detail.

The methodological approach to each M&E level – high, medium and low – is detailed in Table below.

[4] HM Treasury (2020).

Table 3: Methods relating to the M&E level per programme

	M&E level		
Methodological approaches	High	Medium	Low
Document/literature review	✓ (all)	✓	✓
Analysis of secondary data	✓ (UK Space Agency & non-UK Space Agency held, subscription)	✓ (focus on UK Space Agency-held)	✓ (portfolio level, existing analysis)
Interviews	✓ (n=15–25)	✓ (n=10–15)	✓ (n=2–4; key stakeholders)
Site visits	✓ (1–2)	where visits to high M&E sites occur	where visits to high M&E sites occur
Bibliometric analysis	✓	✓	✓
Business database analysis	✓		
Synthesis with TBE	✓ (CA & PT/QCA)	✓ (CA, some PT)	✓ (high-level CA)
QED/counterfactual	✓	Possible	
Value for money approach	✓ (counterfactual)	✓ (comprehensive)	✓ (high-level)

Key: TBE = theory-based evaluation; QED = quasi-experimental design; CA = contribution analysis; PT= process tracing; QCA = qualitative comparative analysis. Source: [Methods relating to level of M&E programme]. RAND Europe Analysis.

A key function of the proportionality assessment is determining an M&E level for each programme and which methods may be most suitable based on the programme's characteristics. While we used all three M&E levels to categorise programmes, the reality of determining the appropriate M&E for each programme is that not all methodological approaches will be relevant or feasible for each programme. For example, many space programmes are characterised by extended benefit lead times. This commonly occurs with early-stage technologies that may not be deployed for years or decades, and as such, the full scale of the benefits of the technology is not present at the time of evaluation. This feature precludes certain methodological approaches, e.g. a counterfactual VfM approach; instead, it indicates that a lower-intensity evaluative approach and a higher monitoring function may be more appropriate and useful. In practice, the M&E levels overlap (creating low-medium and medium-high intensities), and programme characteristics, such as benefits lead time and programme duration, indicate whether a stronger focus on monitoring or evaluation is more suitable.

D.2. Methods

The evaluation team created an assessment tool to ensure a systematic approach to proportionately determining the M&E level and type. This tool consists of a series of assessment criteria applied to each programme or programme area. The UK Space Agency first identified provisional assessment criteria in the invitation to tender. An initial review of UK Space Agency documents, particularly business cases and existing M&E documents, pointed to additional criteria.

We collated, shared, and discussed initial assessment criteria with the UK Space Agency, DSIT and the expert advisory panel during the scoping interviews and the inception of the report delivery. This served to capture feedback and helped to identify priority criteria. Following these discussions, the evaluation team selected a final list of assessment criteria, highlighted in **bold** in Table 4 below.

Table 4: Candidate criteria for the proportionality assessment and their respective sources

Criteria Identified in the Invitation to Tender
• **The overlap with activities and outputs of historical ESA programmes and relevance to the UK's current and envisaged future investments in ESA programmes.** • **The quality and quantity of existing research and M&E activity in process (e.g. commissioned by ESA and other member states).** • **The current projected value of UK commitments to ESA programmes or programme areas.** • **The current projected value of UK commitments as a proportion of the programme's or programme area's total projected value.** • The level of uncertainty and technical risk associated with the programme, including possible negative consequences. • The extent to which the programme is novel, high profile or contentious. • **The extent to which the UK Space Agency can influence the approach to programme implementation or the size of programme-level investments in future years (e.g. how much of a legal requirement there is to comply with international financial obligations in the future).**
Criteria Identified Through Scoping Interviews, Expert Consultation and Document Review
• **Benefits lead-time.** • **Level of UK influence.** • **Alignment with UK National Space Strategy.** • **Alignment with other UK national strategies and priorities.** • **UK contractor involvement.** • Potential for reputational benefits. • Potential for collaborative benefits. • **Historical and projected socioeconomic benefits.** • **Feasibility of programme-level value for money assessment.**

Source: Candidate criteria for the proportionality assessment and their respective sources. RAND Europe Analysis.

The evaluation team developed working definitions for each assessment criterion, as seen in Table 5: Proportionality assessment criteria. They then reviewed UK Space Agency internal documents using said criteria, mapping evidence from the documents onto relevant criteria. Where evidence was absent for specific criteria at the programme level, additional evidence was sought from publicly available information, including the UK Space Agency and ESA websites and ESA supplier and contractor websites. When assessing each programme or programme area, the team first assessed the strength and coverage of data across the criteria. Programmes were then assessed qualitatively across all criteria to understand programme characteristics better. From this, a recommendation for the level of M&E was made, accompanied by a narrative rationale for the decision. These assessments were then presented and discussed with the UK Space Agency and DSIT in a workshop in February 2024. The workshop discussed the UK Space Agency's initial assessment of the M&E level and the recommended M&E level following the proportionality assessment. After the discussion, a final M&E level and approach for each programme or programme area were agreed upon, as presented in the following section.

Table 5: Proportionality assessment criteria

Proportionality Assessment Criteria Working definitions are given for subjective criteria. Working definitions were used to facilitate the identification of relevant information during document review and evidence mapping.	
Quantitative criteria	UK Space Agency cumulative spending to the end of 2022 (€m) UK Space Agency 2023 budget (€m) UK Space Agency Projected commitment (2024–2028) (€m) UK Space Agency Projected commitments (2029 onwards) (€m) UK Space Agency CM22 investment (£m) UK Space Agency contribution as a per cent of total ESA Member State amounts at CM22 Top five other Member States and their contribution as a per cent of total ESA Member State amounts at CM22
Qualitative criteria	**Working definition**
Level of UK influence	The UK's degree of influence in domain, programme or sub-programme **governance or implementation** (e.g. a leadership or oversight role), particularly regarding other ESA Member States' influence. This may also be informed by the UK's position relative to the top three member states (Italy, France, and Germany).
Level of UK involvement	The UK's degree of involvement in domain, programme or sub-programme **activities or services,** particularly regarding other ESA member states' involvement. This may include significant UK contractor involvement, key UK research or scientific personnel or researcher capacity, etc.
Programme overlap	How much the current domain, programme or sub-programme relates to, builds on or is informed by historical ESA programmes and their results and outcomes. This may include learning from successes and failures of other programmes and novel research questions building on prior work, etc.
Benefits lead time	Anticipated or projected time until a domain, programme or sub-programme produces its intended benefits or serves its intended function. This could include information on technological maturity (such as Technology Readiness Level [TRL], phase of project lifecycle [exploratory, proof of concept, operational, etc.], time to launch, implementation, operationalisation etc.).
Alignment with the National Space Strategy (NSS)	The degree to which domain, programme or sub-programme rationale, justification, business case and objectives align with those articulated in the UK National Space Strategy (NSS)[5], including the UK Defence Space Strategy.[6] This will involve information related to each programme's rationale and objectives and explicit or implicit mention of the NSS or its key areas, priorities or plans within each programme's rationale or objectives. It is also notable if there is no mention of NSS or NSS key areas or plans in a programme's rationale or objectives.
Alignment with other UK national strategies and priorities	The degree to which domain, programme or sub-programme rationale, justification, business case and objectives align with those articulated in other UK national strategies (present and historical), including Levelling Up,[7] UK Innovation Strategy,[8] UK Science and Technology Framework,[9] and the UK Geospatial Strategy 2030.[10] Alignment with other objectives and commitments (e.g., sustainable development goals, achieving net zero, and the Group of Seven (G7) Safe and Sustainable Uses of Space[11]) is also notable. This includes direct

[5] UK Government (2022b).

[6] Ministry of Defence (2022).

[7] UK Government (2022c).

[8] Department for Business, Energy & Industrial Strategy (2021).

[9] Department for Science, Innovation and Technology (2023).

[10] Geospatial Commission (2023).

[11] UK Space Agency (2021a).

Proportionality Assessment Criteria Working definitions are given for subjective criteria. Working definitions were used to facilitate the identification of relevant information during document review and evidence mapping.	
	mention of these strategies or indirect mention of key areas, priorities or plans concerning the programme's rationale or objectives.
Realistic ability to scale the investment level at the next ministerial	The extent to which the UK has discretion over the scale of future spending. This involves hard constraints, such as mandatory programmes with limited ability to rescale and soft constraints, including whether missions can be scaled up if additional investment is provided and, similarly, the possible consequences of downscaling investment, such as reputational costs.
Historical and projected socioeconomic benefits	Evidence of wide historic social and economic benefits, including job creation, industry involvement, business creation, product commercialisation, improvements in infrastructure, services and environmental sustainability. Similar benefits projected based on planned programmes or programme area activities are also relevant.
Feasibility of programme-level value-for-money assessment	The degree to which programme-level VfM assessment is possible given methodological constraints, namely whether impacts have been realised and are measurable. Therefore, this assessment depends on programme characteristics, including life cycle stage, benefits lead time, and the complexity/type of benefits realised or expected.

Source: Proportionality assessment criteria. RAND Europe analysis.

D.3. Proportionality assessment outcomes

This section presents the M&E level and approach determined through the proportionality assessment for all ESA programmes, programme areas and domains within the project's scope. Proportionality assessment findings and rationale for the M&E level for each programme are discussed in detail below.

D.3.1. Mandatory Programmes: Basic Activities & Scientific Programme

Involvement in mandatory programmes, including Basic Activities and the Scientific Programme, is a requirement for any member state (MS) participating in ESA. The scale of investment in mandatory programmes is fixed and determined by a set formula based on the size of each MS's economy. Basic Activities constitute a required part of ESA's 'membership subscription'. Investment in the activities supports ESA facilities, including laboratories, ground stations and control facilities. Investment also supports other ESA-wide resources, including networks, IT infrastructure and cybersecurity. Basic Activities also involve early-stage technology development efforts across ESA MSs.

In the proportionality assessment, evidence indicated that **Basic Activities** had a strong programme overlap with other ESA programmes. Due to their core functions, Basic Activities have a long history of supporting mission technology development and providing testing and data storage functions for other ESA programmes and missions. The benefits' lead times and UK involvement level vary as activities are diverse. Business cases noted that they support all NSS objectives because Basic Activities underpin all other ESA programmes. To date, no programme-specific M&E has been conducted for Basic Activities. No evidence was identified for other assessment criteria, including the UK involvement level, alignment with other UK national strategies or historical and projected socioeconomic benefits. VfM assessment indicated that for basic activities, there is little value added for a programme-specific VfM assessment due to the diversity of activities, outcomes and impacts.

Table 6: Summary of proportionality assessment evidence for Basic Activities

<table>
<tr><th colspan="6">Mandatory Programmes: Basic Activities</th></tr>
<tr><th colspan="6">Scale of Investment</th></tr>
<tr><td>Cumulative spending to end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024-2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Very high[12]</td><td>High</td><td>High</td><td>Moderate</td><td>High</td><td>High</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">
UK influence: UK investment is second highest after Germany, but the level of investment is fixed based on a set formula based on the size of the UK economy.
UK involvement: Variable due to diverse programme activities.
Programme overlap: A long legacy of supporting ESA mission technology development. Provides broad support for early-stage technologies as well as testing and data storage functions for other ESA programmes and missions.
Benefits lead time: Variable due to diverse programme activities.
Policy alignment: The business case notes that, as an underpinning programme, basic activities support all NSS objectives.
Existing M&E: None.
VfM: Little value is added for a programme-specific VfM analysis due to the diversity of activities, outcomes and impacts.
</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">No evidence has yet been identified for historical and projected socio-economic benefits. Evidence for other criteria is present but limited.</td></tr>
<tr><th colspan="6">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency assessment</th><th colspan="4">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th colspan="3">Explanation</th></tr>
<tr><td>Low</td><td>A high-budget but mandatory programme with no discretion over future spending. Activities underpin other programmes; it is worth making this more transparent through ToC work, but it is not worth standalone programme-level evaluation.</td><td>Low-medium</td><td colspan="3">This is a mandatory investment on which the UK's participation in ESA is contingent. It is a relatively large but fixed investment. Given this, there is no ability to re-scale this investment. However, given that basic activities are integral to the UK's wider participation in ESA, the activities should be examined in more granular detail to provide a clearer and more robust accounting of benefits.</td></tr>
<tr><th colspan="6">Final assessment</th></tr>
<tr><td colspan="2">Low-medium</td><td colspan="4">This programme will have a low-medium M&E level. The high budget for mandatory investment requires accountability, transparency and a greater understanding of benefits. TBE methods will provide greater clarity as to how Basic Activities support other programmes. The value of undertaking medium or high-level M&E is limited given the fixed nature of the investment.</td></tr>
</table>

Source: Summary of Proportionality assessment evidence for Basic Activities. RAND Europe Analysis.

The UK Space Agency's initial assessment indicated a low M&E level for Basic Activities due to the investment's fixed nature while noting that some TBE methods, such as the ToC, would help improve the understanding of benefits related to such activities. Likewise, the proportionality assessment concluded with a recommendation for low-level M&E for Basic Activities, citing similar limitations on the utility of intensive M&E related to the investment's fixed nature while emphasising that a clearer and more robust accounting of programme-related benefits is needed. It was agreed in the workshop that Basic Activities will undergo a low M&E level but with a more intensive focus on transparency and accountability through TBE methods.

The **Scientific Programme** is ESA's core scientific function. Scientific activities are determined by a competitive consultation process where scientists in ESA MSs submit proposals for scientific activities. The programme affords UK scientists access to €6bn in annual funding and collaboration opportunities with 80 ESA partner nations.[13] Scientific activities within the programme are variable, encompassing technological innovation, space infrastructure, maintaining launch services, improving spacecraft operations and fostering the sustainability of European space capabilities. Programme outputs are also highly variable, with correspondingly varied benefits.

Table 7: Summary of proportionality assessment evidence for the Scientific Programme

Mandatory Programmes: Scientific Programme					
Scale of Investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
Very high	Very high	High	Moderate	High	High
Summary of assessment criteria					
• **UK influence:** UK investment is second-highest after Germany, but the minimum level of investment is fixed as a proportion of Gross National Income (GNI). The UK is relatively influential in programme activities, particularly within scientific advisory structures. • **UK involvement:** Programme activities often result in contracts that support high-skill employment. • **Programme overlap:** Scientific activities often overlap and support other current and future ESA programmes. • **Benefits lead time:** Variable due to diverse programme activities, but long on average due to mission-oriented programmes. • **Socioeconomic benefits:** Wide-ranging benefits, including many commercial technologies, high-skill jobs and reputational benefits. • **Policy alignment:** This programme's varied scientific and research and innovation (R&I) activities overlap with the NSS and other UK strategies and priorities. • **Existing M&E:** M&E has been conducted previously, but all at the programme level. Examination of individual activities or missions within the programme may be useful. • **VfM:** It is unknown *ex-ante* which future missions the UK will be expected to lead on and deliver. Additionally, there is uncertainty around which research topics will have a wider impact, making it unsuitable for a programme-specific VfM approach.					

[12] Metrics under the scale of investment are presented according to quartiles – low, moderate, high and very high – to illustrate the relative level of investment across programmes.

[13] HM Treasury (2024).

Strength of evidence			
Evidence is strong for some criteria (alignment with the NSS and historical and projected socioeconomic benefits). However, it is patchier for other criteria (UK influence level, benefits lead time, relevance to other programmes, alignment with other UK priorities and the UK involvement level).			
Assessment			
Initial UK Space Agency assessment		Updated assessment with evidence to date	
M&E level	Explanation	M&E level	Explanation
Medium	High budget, both historical and projected. However, the current evidence base's limited nature justifies some concerted efforts to present value and VfM to the UK. The fact that it is a mandatory programme with limited discretion over future spending limits the value of evaluation in informing future investment decisions, which limits the value of this being 'high'.	Medium	This is a mandatory investment on which the UK's participation in ESA is contingent. It is a relatively large investment, but it does not have the option to change the investment level. However, the scientific and technological outputs of the programme offer the opportunity to undertake a more comprehensive assessment of benefits (i.e., via bibliometrics).
Final assessment			
Medium	This programme will undergo medium-level M&E. The high budget mandatory investment requires accountability and transparency. Scientific outputs and outcomes lend themselves to bibliometric/scientometric and network analysis. A cost-benefit approach may be feasible. There is interest in exploring diverse benefits, including international collaboration, soft power and national capability. The value and feasibility of undertaking high-level M&E are limited by the investment's fixed nature and the programme's wide variety of activities.		

Source: Summary of proportionality assessment evidence for the scientific programme. RAND Europe Analysis.

Despite mandatory and fixed investment, the UK significantly influences the Scientific Programme. The UK is overrepresented in ESA's scientific advisory structures and has contributed significantly to ESA's long-term scientific strategy, Voyage 2050.[14] Participation in the programme results in contracts for UK industries and research institutions, supporting high-skilled labour and significant scientific output for UK-based researchers.[15] The programme's benefits are diverse and have wide-ranging socioeconomic impacts, including improvements in water filtration systems, solar panels, insulation, optics, and cameras. The Scientific Programme aligns with the NSS, with scientific and technological advancements supporting NSS priorities, including fighting climate change, improving public services, modernising the transport system and making space more sustainable. Conducting scientific activities within ESA allows the UK to access resources and engage in partnerships, augmenting the capacity of what the UK could do alone.

While there is some existing M&E on the Scientific Programme as a whole, there may be benefits to examining individual missions within the programme. However, the programme is unsuitable for a programme-specific VfM approach, as activities are diverse, and it is unknown which future missions the

[14] Technopolis Group (2022a).

[15] HM Treasury (2024).

UK will be selected to lead and deliver. In addition, there is also a significant amount of uncertainty about which research topics within the programme will have wider impacts.

The UK Space Agency identified medium-level M&E as appropriate for the Scientific Programme due to its high budget and limited evidence base while noting that high-level M&E may be inappropriate due to the fixed nature of the investment. The proportionality assessment likewise recommended medium-level M&E with a similar rationale, noting that bibliometrics or scientometrics may be particularly useful for capturing the benefit of this programme. It was agreed in the workshop that medium-level M&E would be conducted for the Scientific Programme. Potential approaches involving network analysis and cost-effectiveness were noted as useful for examining this programme, along with methods that capture wider benefits, including international collaborations, soft power and national capabilities.

D.3.2. Human and Robotic Exploration (HRE)

The HRE domain includes four core areas: humans in lower Earth orbit (LEO), humans beyond LEO, lunar robotic exploration and Mars robotic exploration. Activities within these areas include basic and applied science. HRE is an envelope programme wherein investment is made at the domain level, which is then spread across programme areas. The current envelope also includes Exploration Preparation, Research and Technology (ExPeRTT), which supports mission feasibility and system definition studies and supports technology readiness level (TRL) progression for HRE technologies.

Table 8: Summary of proportionality assessment evidence for HRE

<table>
<tr><th colspan="6">Human and Robotic Exploration</th></tr>
<tr><th colspan="6">Scale of Investment</th></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Very high</td><td>Very high</td><td>High</td><td>Moderate</td><td>High</td><td>Moderate</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">• Scale of investment: Historic investment is high, but future investment is decreasing.
• UK influence: The historical focus has been strengthening UK leadership efforts, particularly for Rosali Franklin Rover.
• UK involvement: Variable and tied to the overall scale of the budget envelope.
• Programme overlap: There is a historical overlap between the International Space Station (ISS) and early robotic missions to the moon and Mars, but future activity will likely have different benefits.
• Benefits lead time: Some components have longer expected benefit lead times but with expected relevance to future programmes and potential for contractor involvement.
• Policy alignment: Broad alignment NSS; returning samples from Mars is a key objective of the NSS; supports efforts to pioneer scientific discovery and advance innovation, with wide potential socioeconomic benefits.
• Existing M&E: Some M&E to date. ESA also conducts M&E in this domain.
• VfM: Significant lead time and the exploratory and early discovery nature of this programme make a programme-specific VfM assessment likely to be highly complex, with a risk it will result in little added value.</td></tr>
</table>

Strength of evidence			
Evidence is strong for some criteria (benefits lead time and alignment with NSS) and patchy or scarce for other criteria (level of UK involvement and alignment with NSS). No evidence has yet been identified for other criteria (alignment with other UK national strategies and socioeconomic benefit).			
Assessment			
Initial UK Space Agency assessment		Updated assessment with evidence to date	
Level of M&E	Explanation	Level of M&E	Explanation
Low/medium	Historical and future investments by the UK are high. However, the long lead time to the realisation of benefits will limit the usefulness of evaluation at this stage, and there is limited overlap with historical investments. The UK is a relatively minor partner compared to the other Big Four Member States, which means ESA has a larger role in providing evidence of impact than some of the other programme areas. The priority for this programme area will be developing a monitoring/benefits realisation framework to provide the necessary assurance to UK stakeholders through this exercise – evaluation can be limited in scope.	Medium	Current and historic levels of investment are high, but presently, the UK has relatively less involvement and influence. The domain has potential long-term scientific and socioeconomic benefits, but many activities have long lead times. Alignment with some areas of the NSS and other UK national priorities is less clear. A more in-depth examination of the benefits may inform how the UK will consider this investment in the future. Accountability for previously high investments is also a consideration.
Final assessment			
Medium	This programme will undergo medium-level M&E, supporting accountability for high past investment and providing a strong accounting of benefits as benefits are realised now and into the future. Particular focus on the Rosalind Franklin Mars Rover, a priority activity for the UK, is of particular interest. Given the lifecycle stage of many programmes and long benefits lead times, certain methods, including a programme-level VfM assessment, may not be feasible at this stage, limiting the value of high-level M&E.		

Source: Summary of proportionality assessment evidence for human and robotic exploration. RAND Europe Analysis.

For the proportionality assessment, the strength of evidence was mixed, being strong and comprehensive for some criteria and patchier for others. The UK has historically been a high investor in HRE, with investment, as of CM22, projected to decline in the coming decade, subject to fund allocations at future ministerials. HRE is considered a UK leadership strength, particularly for the Rosalind Franklin Mars Rover, which remains a priority area. [16] Industry involvement varies across activities, with some having notable participation in the UK space industry, such as the partnership with Surrey Satellite Technology Ltd for the lunar Pathfinder.

There is an internal overlap among HRE programmes, and historically, there has been some overlap between HRE activities and missions involving the International Space Station and early lunar and Mars missions.

[16] ESA (2024).

Benefits lead times are expected to be longer for HRE than other domains and programme areas, given programme complexity and current TRLs. Though some benefits, including employment, are realised during technology development stages, most benefits are expected to occur once missions are underway. HRE activities, particularly those related to the ISS and Mars, strongly align with the NSS. Returning samples from Mars is highlighted as a priority area within the NSS. As HRE activities are characterised as pushing the boundaries of human exploration, they are seen as supporting NSS objectives related to inspiring future generations.

The existing quality and quantity of M&E was judged as medium. The initial UK Space Agency assessment indicated low to medium-level M&E for HRE, given the scale of historic investment. The proportionality assessment indicated medium-level M&E for HRE, noting that accountability for historically high investment is important, and a benefits mapping approach may help understand present and future benefits, given long lead times. It was agreed in the workshop that HRE would undergo medium-level M&E, with a particular interest in capturing benefits related to inspiration and cultural impact. M&E approaches should complement, not duplicate, efforts undertaken by ESA. Current accounting of benefits will be important for ESA's strategic decision-making regarding the scale of future investment in HRE.

D.3.3. Earth Observation

European Earth Observation Programme (EOEP) & FutureEO

FutureEO, previously the EOEP, is ESA's cornerstone EO programme. Investment in FutureEO is mandatory for other EO programmes and programme areas. The programme has five main activity areas: foundations and concepts, research and small missions, mission management, ground segment, and EO for society. These activities support EO efforts towards addressing major science, societal and environmental challenges.

Table 9: Summary of proportionality assessment evidence for EOEP & FutureEO

Earth Observation: EOEP & FutureEO					
Scale of Investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
Very high	Moderate	Moderate	Low	Moderate	Moderate
Summary of assessment criteria					
• **Scale of investment:** Investment in this area is mandatory for investment in other EO programmes. • **UK influence:** The UK is active in EO leadership structures within ESA and has successfully guided ESA EO activities towards UK priorities. • **UK involvement:** The UK is a leader in EO with significant scientific and technical capabilities and notable UK contractor involvement. • **Programme overlap:** A long-standing programme with relevance and overlap with other programmes within the EO portfolio. • **Benefits lead time:** EO programmes' lead time is slightly longer than that of other domains due to generally lower TRLs.					

• **Socioeconomic benefit:** Historically, EOEP programmes have contributed to various commercial technologies, particularly in radar, optics and imaging. FutureEO is expected to have wide benefits across agriculture, climate and weather. • **Policy alignment:** There is strong alignment between EO programmes, the NSS and other UK priorities, particularly concerning climate change and net zero initiatives. • **Existing M&E:** ESA programme M&E is recent and considered high-quality. • **VfM:** The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making due to improved access to data.			
Strength of evidence			
This programme area has strong evidence across criteria, including a good balance across EOEP and FutureEO.			
Assessment			
Initial UK Space Agency assessment		**Updated assessment with evidence to date**	
M&E level	**Explanation**	**M&E level**	**Explanation**
Medium	Significant past and future investments by the UK. While the most recent evidence on impact (commissioned by ESA) is relatively high quality for this programme, there is scope to build upon this by developing a robust ToC, linking this to other EO missions and wider outcomes and impacts. A robust Green Book-friendly VfM framework is also lacking, which is a limitation of previous ESA-commissioned studies.	Medium	Participating in other programmes within the EO portfolio is a mandatory investment with less room to change the investment at future ministerials. EO is a strength of the UK, with strong leadership in EO science and technology development, including significant UK contractor involvement. Medium-intensity M&E can inform future activities and investments and provide more robust evidence of the benefits of EO to the UK, how these arise (ToC), and how the UK can best position their future involvement in ESA EO.
Final assessment			
Medium	This programme will undergo medium-level M&E. Historical and planned investment is high, and more intensive M&E will support accountability for this investment. Furthermore, EO is a UK strength and strategic priority, and M&E can support impact assessment and inform the nature and scale of future activities. The utility of high-level M&E is limited as this is a mandatory investment for participation in other ESA EO programmes.		

Source: Summary of proportionality assessment evidence for EOEP & FutureEO. RAND Europe Analysis.

The EOEP and FutureEO programmes have strong and comprehensive evidence across proportionality assessment criteria, with the UK being among the top five MS for the scale of investment, fourth after Germany, Italy and France. EO is considered a strength in Europe, ESA and particularly in the UK, where there is significant UK space industry involvement.[17] The most recent EOEP, EOEP 4, resulted in contracts with 71 UK-based organisations with a total of £133m awarded. This activity and involvement result in wider socioeconomic benefits, particularly in creating and maintaining high-skill jobs.[18] In addition, EO

[17] Technopolis Group (2022a).

[18] Technopolis Group (2022b).

activities are expected to provide wide benefits through environmental and weather monitoring improvements, sustainability efforts, and resiliency to extreme weather events.

As a longstanding programme, there is significant overlap between EOEP and FutureEO activities and other ESA programmes, particularly within the EO portfolio. Data sharing among EO programmes supports learning and benefits realization across programmes. Technologies range from early stage to mature, resulting in mixed benefits lead times within the programme. EO activities are expected to provide wide benefits through improvements to environmental and weather monitoring, improve sustainability efforts, and increase resiliency to extreme weather events. The programme strongly aligns with the NSS and other UK national strategies and priorities. Maintaining and building on the UK's strength in EO is a priority area outlined in the NSS, supporting and growing the UK space sector, including significant specialist capabilities in EO. Activities within the programme strongly align with UK climate change and net zero priorities, as many EO technologies will improve climate modelling and weather forecasting. EO programmes are of interest for VfM assessment, particularly concerning the benefits of more timely data.

The initial assessment from the UK Space Agency indicated medium-level M&E for this programme area due to the scale of the investment, noting the utility of high-level M&E is limited due to recent high-quality M&E. The programme currently lacks robust VfM assessment, which is particularly interesting for programme-level VfM. The proportionality assessment likewise indicated medium-level M&E due to the scale of the investment, noting that the mandatory nature of the investment limits the utility of high-level M&E. As EO is a strength of the UK, medium-level M&E, including a strong VfM component, will support the accounting of benefits and inform future strategy and investment in this area. It was consequently agreed in the workshop that the programme would undergo medium-level M&E.

Global Monitoring for Environment and Security (GMES) Space Component and Copernicus Space Component (CSC)

Copernicus (previously GMES Space Component) aims to capture and make available information to improve environmental management, including climate change mitigation. The CSC comprises sentinel satellites that provide a unified system for EO data, supporting climate research, monitoring and policymaking.

Table 10: Summary of proportionality assessment evidence for GMES & CSC

Earth Observation: GMES & CSC					
Scale of Investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
High	Moderate	Moderate	Moderate	Low	Low
Summary of assessment criteria					
• **UK influence:** The UK is a relatively small player in this area, and this investment accounts for a minimal portion of total investment in ESA. • **UK involvement:** This programme area is considered important for upstream EO contractors in the UK.					

<table>
<tr><td colspan="4">Programme overlap: There is notable overlap with other EO programmes. Data from Copernicus is used widely, both within the space sector (e.g. with other EO activities) and outside of the space sector (e.g. in Defra and Living Wales).
Benefits lead time: Data from these technologies is currently used, with benefits within the space sector and wider socioeconomic benefits.
Policy alignment: Strong alignment with the NSS and other national priorities, particularly related to fighting climate change and improving public services with space technology.
VfM: The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making due to improved access to data.</td></tr>
<tr><th colspan="4">Strength of evidence</th></tr>
<tr><td colspan="4">More evidence has been identified for some criteria (socioeconomic benefits, benefits lead time, alignment with the NSS and other national strategies and ability to rescale investment) and less for others (UK involvement and influence) and for some components (e.g. Copernicus) more than others.</td></tr>
<tr><th colspan="4">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency assessment</th><th colspan="2">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th>Explanation</th></tr>
<tr><td>Low/medium (TBC in conceptual framework workshop)</td><td>While historical investments are high, CM22 investment was low due to the (temporary) disassociation with Copernicus. The benefits of Copernicus have been outlined in significant depth in previous reporting commissioned by the EU. This may need to rise to 'Medium', given difficult decisions may need to be made about future investment amount (with relevant evidence presented underpinning this decision) – to be discussed with the EO team.</td><td>Low-medium</td><td>Investment in this programme area is minimal. UK involvement and influence are less than in other programme areas, and there is a weak overlap with the NSS and other UK priorities. However, given the broad applications of some programmes (e.g. Copernicus data), there may be potential for a more in-depth assessment of VfM to capture the wider socioeconomic benefits arising from these activities and provide accountability for historical investment.</td></tr>
<tr><th colspan="4">Final assessment</th></tr>
<tr><td>Low-medium</td><td colspan="3">This programme will undergo low-medium level M&E. Some benefits assessment is warranted to support accountability for relatively high investment prior to the temporary dissociation of the UK from Copernicus following Brexit. Given the wide benefits across sectors, an assessment of VfM and its wider socioeconomic benefits may be possible. A stronger focus on monitoring than evaluation is likely appropriate for CSC given the UK's recent dissociation and subsequent re-entry into the programme, which would likely bias evaluative assessment.</td></tr>
</table>

Source: Summary of the proportionality assessment evidence for GMES & CSC. RAND Europe Analysis.

The strength of evidence was mixed across assessment criteria. More evidence was found for benefits lead time, socioeconomic benefits, alignment with the NSS and other UK national strategies and policies compared to other criteria, namely level of UK involvement and influence. More evidence was also found for CSC than for GMES.

Historical spending on GMES and CSC is high. However, following temporary dissociation from CSC related to Brexit, it is currently much smaller and projected to decrease throughout the coming decade.[19]

[19] UK Space Agency internal data on ESA Contributors Financial Obligations 2024.

Likewise, the UK was historically a leader in CSC development. However, this is no longer the case following dissociation.[20] As such, the relatively small scale of UK investment gives the UK less influence in this programme area. This programme area is nonetheless seen as a critical anchor for the UK's EO industry, with UK businesses winning £300m in contracts related to this programme area from 2014 to 2020.[21]

Both GMES and CSC have notable overlap with historical and current ESA programmes. In particular, data from CSC augments the capacity of other EO programmes and contributes to scientific productivity within the EO portfolio.[22] Data from CSC are also commonly used within the public sector, for example, in informing operations with the Department for Food and Rural Affairs (Defra) and Living Wales.[23] EO data from CSC is anticipated to have wide applications in the public sector, with 88 use cases identified and potentially relevant to 32 agencies.

The initial assessment from the UK Space Agency indicated a low-medium level of M&E for the GMES and CSC programme area. The benefits of CSC are well documented, limiting the utility of intensive assessment in this area. However, uncertainty over the scale of future investment may warrant greater scrutiny and accounting of benefits. The proportionality assessment likewise indicated low-medium M&E, based on the relatively small scale of future investment and less evidence of alignment with the NSS and other UK national strategies and priorities. However, as the benefits arising from this programme area, particularly from CSC, are used widely, there is potential for more in-depth VfM analysis to capture wider socioeconomic benefits. It was decided in the workshop that the GMES and CSC programme area would undergo low-medium level M&E with a focus on monitoring, acknowledging that the UK's temporary dissociation from CSC may bias a strong evaluative component. However, some accounting of benefits and assessment of VfM may serve an important accountability function.

Aeolus-2

Aeolus-2 will be a highly specialised satellite that captures wind profile component observations and informs climate research and weather forecasting. Aeolus-2 will serve a similar function to Aeolus-1, which is being retired, offering improved resolution and reduced error rates.

[20] ESA (2022).

[21] CM22 Business Case: Earth Observation Programme – Internal Document.

[22] CM22 Business Case: Earth Observation Programme - Internal Document.

[23] Government Digital Service, Cabinet Office and Geospatial Commission (2022).

Table 11: Summary of proportionality assessment evidence for Aeolus-2

<table>
<tr><th colspan="6">Earth Observation: Aeolus-2</th></tr>
<tr><th colspan="6">Scale of Investment</th></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Low</td><td>Low</td><td>Moderate</td><td>Moderate</td><td>Moderate</td><td>High</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">

UK influence: The UK is a major investor in this programme, with high investment (relative to other MS) planned for the coming years.
UK involvement: The programme will have significant UK contractor involvement, particularly from Airbus.
Programme overlap: This is a follow-on programme from Aeolus-1.
Policy alignment: This programme strongly aligns with several NSS objectives, particularly improving public services for weather forecasting.
Socioeconomic benefits: The programme is expected to provide broad socioeconomic benefits, particularly to the UK Met Office and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).
VfM: The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making because of improved access to data.

</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">Evidence is strong across most criteria, though less evidence has been identified for the level of UK influence and ability to re-scale investment.</td></tr>
<tr><th colspan="6">Assessment</th></tr>
<tr><th colspan="3">Initial UK Space Agency assessment</th><th colspan="3">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th colspan="2">Explanation</th><th>M&E level</th><th colspan="2">Explanation</th></tr>
<tr><td>Low/medium (TBC in conceptual framework workshop)</td><td colspan="2">Relatively high future investment amount but very long timeframes to impact limit potential evaluability, and some reasonably good work past work has been done to present the value of Information. However, there is some potential value in Aeolus-1 and other similar missions, which should be explored. Consider the potential for merging M&E reporting with FutureEO and other missions.</td><td>Low</td><td colspan="2">As a new but follow-on programme, there are relatively longer benefits lead times at present, limiting the utility of high-intensity M&E at this stage. Given the wide potential socioeconomic benefits and the expectation of high UK contractor involvement, establishing a strong but uncertainty-aware monitoring plan will be important for future M&E, particularly regarding measuring wider socioeconomic benefits, including those expected for the UK Met Office and EUMETSAT. It may be advantageous to merge M&E with other early-stage EO programmes (e.g. Digital Twin).</td></tr>
<tr><th colspan="6">Final assessment</th></tr>
<tr><td>Low</td><td colspan="5">This programme will undergo low-level M&E. While the scale of investment is high, most benefits will not be realised until launch, limiting the present value of high-level M&E. However, there is interest in examining the benefits realised from Aeolus-1.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for Aeolus-2. RAND Europe Analysis.

Strong evidence was identified across criteria, though the evidence was slightly patchier for the level of UK influence and the ability to rescale the investment. The UK is among the top five MSs for investment scale, fourth after Germany, France and Italy. The first Aeolus mission had significant involvement from the UK space industry, notably Airbus and a wider team of businesses, including several small and medium-seized enterprises (SMEs).[24]

Aeolus-2 is a follow-on mission to Aeolus-1 and is, therefore, central to continuing to collect detailed observations on wind component profiles. The Aeolus programme also links to the UK and ESA's wider interest in deorbiting satellites to promote space safety. Aeolus-1 demonstrated ESA's deorbiting capabilities through its successful return to Earth by assisted re-entry in July 2023.[25] Direct benefits from Aeolus-2, including access to higher-quality wind data, will not be realised until the programme's scheduled launch in the coming years. Nevertheless, data from the first Aeolus mission continue to provide benefits, particularly to meteorology.[26] Aeolus-2 is anticipated to sustain and expand this function, improving forecasting abilities for the UK Met Office and EUMETSAT.

The Aeolus programme strongly aligns with the NSS and other UK national priorities. Improved wind observations with higher resolution and reduced error rates will improve public services through improved meteorology, including improved capabilities for severe weather prediction, with important implications for disaster preparedness and mitigation. Higher-quality data will also improve climate models, supporting climate science and mitigation efforts.

The initial UK Space Agency assessment indicated low-medium level M&E for Aeolus-2 due to high project investment. However, the utility of high-level M&E is limited because few benefits are realised before launch. The proportionality assessment indicated a low level of M&E due to long lead times for benefits. However, as investment is high, a strong monitoring framework is of interest to provide robust indicators and accountability in future assessments. It was agreed in the workshop that Aeolus-2 would undergo low-level M&E with a strong focus on monitoring. There is also interest in exploring the benefits realised from Aeolus-1.

Digital Twin Earth

The Digital Twin Earth programme aims to facilitate the design and implementation of Digital Twin ecosystems, which will help visualise, monitor and forecast natural and human activity on Earth. This modelling is useful for developing and testing novel EO technologies and simulating how changes in technology and human behaviour may affect Earth's climate within the context of sustainable development.

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[24] Technopolis Group (2022b).

[25] ESA (2023).

[26] Technopolis (2022b).

Table 12: Summary of proportionality assessment evidence for Digital Twin Earth

<table>
<tr><th colspan="6">Earth Observation: Digital Twin Earth</th></tr>
<tr><th colspan="6">Scale of investment</th></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Low</td><td>Low</td><td>Low</td><td>Low</td><td>Low</td><td>High</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">• UK influence: This is a new programme. The UK is a major contributor compared to other MS, but the overall scale of present and future investment is small.
• UK involvement: UK science and technology actors have made key contributions to precursor activities, likely positioning themselves for future involvement and benefit.
• VfM: The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making due to improved access to data.</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">Little evidence has been identified for many criteria, except for the level of UK involvement.</td></tr>
<tr><th colspan="6">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency assessment</th><th colspan="4">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th colspan="3">Explanation</th></tr>
<tr><td>Low</td><td>There is a low projected future investment amount, but no specific M&E has been undertaken to date. A new programme with limited activity undertaken to date will limit evaluability, so the focus may be limited to drawing up a benefits realisation framework. Consider the value of merging M&E with that of FutureEO and other missions (DTE, Aeolus, CSC, TRUTHS?).</td><td>Low</td><td colspan="3">A new programme limits the utility of high-intensity M&E but emphasises the need for a strong monitoring framework from the outset, particularly given the potential for significant UK contractor involvement and programme steer. It may be advantageous to merge M&E with other early-stage EO programmes (e.g. Aeolus-2).</td></tr>
<tr><th colspan="6">Final assessment</th></tr>
<tr><td>Low</td><td colspan="5">This programme will undergo low-level M&E, given the relatively low level of investment. As a new programme, the utility and feasibility of more intensive M&E is limited. M&E for this programme will focus on monitoring.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for Digital Twin Earth. RAND Europe Analysis.

The assessment was limited due to little evidence identified for many criteria. The UK is a major investor in Digital Twin, but the overall scale of the investment is small. UK science and industry have contributed to programme precursor activities. Therefore, they are well positioned to define and develop commercial and pre-commercial applications, which is expected to strengthen their positioning in related markets.[27]

The initial assessment from the UK Space Agency indicated a low level of M&E for Digital Twin due to the overall small-scale investment. In addition, as a new programme, it will be some time before benefits are realised, limiting the feasibility of many approaches and indicating that a benefits realisation framework

[27] CM22 Business Case: Earth Observation Programme – Internal Document.

may be most useful at this stage. The proportionality assessment likewise indicated low-level M&E with a similar rationale, noting the importance of a benefits realisation framework given the high level of anticipated UK space sector involvement. It was decided in the workshop that the programme would undergo low-level M&E.

Earth Watch (TRUTHS)

The Traceable Radiometry Underpinning Terrestrial- and Helio-Studies (TRUTHS) mission is expected to improve radiation estimates by one order of magnitude, supporting other ESA EO missions and improving climate modelling capabilities, thus supporting net zero efforts.

Table 13: Summary of proportionality assessment evidence for TRUTHS

<table>
<tr><th colspan="6">Earth Observation: TRUTHS</th></tr>
<tr><th colspan="6">Scale of investment</th></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>High</td><td>Low</td><td>High</td><td>Low</td><td>High</td><td>Very high</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">UK influence: The UK is the foremost investor in this programme and is significantly involved in its leadership and direction.
Programme overlap: There is notable overlap with other EO activities and wider UK priorities regarding EO within ESA.
Benefits lead time: This is a new programme. Benefits are expected to be realised in the coming decades.
Policy alignment: There is a strong alignment with the NSS and other UK priorities, particularly regarding climate and net zero.
Socioeconomic benefit: There is strong potential for wide socioeconomic benefits across industry, science and environment, as well as reputational benefits for UK EO capabilities.
VfM: The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making due to improved access to data.</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">Strong and comprehensive evidence across criteria.</td></tr>
<tr><th colspan="6">Assessment</th></tr>
<tr><th colspan="3">Initial UK Space Agency assessment</th><th colspan="3">Updated assessment with evidence to date</th></tr>
<tr><td>M&E level</td><td colspan="2">Explanation</td><td>M&E level</td><td colspan="2">Explanation</td></tr>
<tr><td>High</td><td colspan="2">High investment by the UK relative to other Member States means that the UK needs to lead in developing the evidence. The current evidence base is limited and will likely come under scrutiny ahead of future investment decisions, despite the strategic commitment that has already been made in the past two ministerials. Consider the potential for merging M&E</td><td>High</td><td colspan="2">This programme is a major investment for the UK. The UK is likewise heavily involved in this programme's leadership, management and implementation. However, as the programme is relatively immature, developing a monitoring framework is appropriate, as it may not yet be feasible to undertake all aspects of high-intensity M&E at this stage. As this is a standout investment and strategic priority, merging M&E for this</td></tr>
</table>

	reporting with FutureEO and other missions.		programme with other EO programmes may not be appropriate.
Final assessment			
High	This programme will undergo a high level of M&E, given the scale of UK investment relative to other MS. Given that this is a new programme, some approaches may not be feasible as many benefits will not be realised until after launch. A strong monitoring framework is appropriate at this stage. There is interest in assessing the benefit of more timely data, improved forecasting capabilities, and wider related benefits, particularly climate and net zero priorities.		

Source: Summary of proportionality assessment evidence for TRUTHS. RAND Europe Analysis.

Strong and comprehensive evidence was found across all criteria. The UK significantly influences the programme via its leadership and direction as the primary investor, providing nearly 90% of the total investment.**Error! Bookmark not defined.** Given the level of investment and influence in the programme, there is significant support among the UK space sector for this programme, with many major UK space companies, including Airbus and Surrey Satellite Technology Ltd (SSTL), examining how the programme may fit into their business and value chain, potentially contributing to high levels of UK involvement in this programme.[28]

Data from TRUTHS is expected to improve the performance of other missions through cross-calibration, supporting improvements in data accuracy across the EO portfolio.[29] It is expected to grow industrial and scientific capabilities within and outside the space sector. The scale of the UK's investment and leadership role is expected to bring significant involvement from the UK space industry, providing the opportunity to join more ESA missions and thereby generating economic and reputational benefits for UK companies. UK investment and leadership also afford the UK scientists working in ESA the opportunity to join the TRUTHS mission advisory group, expanding their scientific contribution.[30] Outside of the space sector, data from TRUTHS are expected to be used widely. The data will be particularly useful for climate modelling and assessment, supporting UK priorities for fighting climate change and reaching net zero emissions. Beyond climate, TRUTHS data are expected to provide valuable information to the insurance, civil engineering, and agri-tech sectors, among others.

The initial UK Space Agency assessment indicated a high level of M&E for TRUTHS based on the scale of the UK's investment relative to other MS and the consequent need to support M&E efforts and accountability for spending. The proportionality assessment likewise indicated a high level of M&E for the programme with a similar rationale. However, given that the programme is in an early stage of development and most benefits are not expected to be realised until after launch, some M&E approaches may not be feasible at this stage. A strong monitoring framework is suggested. It was agreed at the workshop that TRUTHS would undergo high-level M&E focusing on monitoring. There is interest in exploring benefits related to more timely and higher-quality data from this programme.

[28] UK Space Agency (2021b).

[29] CM22 Business Case: Earth Observation Programme – Internal Document.

[30] CM22 TRUTHS Business Case Annex A – Internal Document.

CLIMATE SPACE/Climate Change Initiative (CCI)

The CCI is a research and development programme within ESA that focuses on tracking long-term satellite data for the Earth's climate system, resulting in the reporting of Essential Climate Variables. The research supports improved scientific understanding of climate and generates data which underpins climate modelling. The data generated from the programme support the United Nations (UN) Framework Convention on Climate Change and the International Panel on Climate Change in monitoring and assessing Earth's climate systems.

Table 14: Summary of proportionality assessment evidence for CLIMATE SPACE/CCI

Earth Observation: CLIMATE SPACE/CCI					
Scale of investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
Moderate	Low	Low	Low	Low	Very high
Summary of assessment criteria					
• **UK influence:** Although the UK is a lead investor in this programme, the total investment is relatively small. • **Programme overlap:** There is a strong overlap with the Climate Change Initiative and other climate-related EO activities, as well as a notable overlap with other EO activities and wider UK priorities concerning EO within ESA. • **Policy alignment:** There is a strong alignment with some aspects of the NSS and other UK priorities, particularly those related to climate change and net zero. • **Socioeconomic benefits:** Wider socioeconomic and environmental benefits are expected. • **VfM:** The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making due to improved access to data. • **Existing M&E:** Limited existing M&E.					
Strength of evidence					
Little evidence has yet been identified for this programme's criteria, except for programme overlap, alignment with NSS and historical and projected socioeconomic benefits.					
Assessment					
Initial UK Space Agency assessment			**Updated assessment with evidence to date**		
M&E level	Explanation		M&E level	Explanation	
Medium/high (TBC in conceptual framework workshop)	While investments are medium in scale, there is limited/no M&E evidence to date, even though the UK takes a leading role in this area. The programme would benefit from a robust ToC, linking to other EO investments, and a concerted effort on the impact/VfM framework. The programme has a reasonably long history, so benefits from earlier investment should		Medium/high	While this remains a small overall investment for the UK, the UK is a major player in this programme. As a longer-standing programme with limited M&E to date, a robust ToC and a strong benefits framework are appropriate. More intensive VfM will support accountability for past investments and activities.	

<table>
<tr><td></td><td>already have begun to be realised – so there is potential value in considering past investment and activity.</td><td></td><td></td></tr>
<tr><td colspan="4">Final assessment</td></tr>
<tr><td>Medium/High</td><td colspan="3">The programme will undergo a medium-high level of M&E. As a leader in the programme, the UK likewise needs to lead on M&E. There is considerable interest in capturing the benefits related to climate change and net zero. More intensive M&E will likely be feasible, given that the programme has a reasonably long history.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for CLIMATE SPACE / CCI. RAND Europe Analysis.

The assessment was limited due to minimal evidence identified for many criteria. Although the UK is the lead investor in the programme, the overall scale of investment is small compared to other programmes and programme areas. The UK has a strong history of leadership in CCI, having scientific leadership in over 30% of the activities and involvement in around 85% of the projects. Furthermore, the UK manages ESA's Climate Office in Harwell.[31] There is a strong overlap between CCI activities and other programmes in ESA's EO portfolio. The programme strongly aligns with the NSS for its socioeconomic benefits, which support priority areas such as climate change and net zero.

The initial assessment from the UK Space Agency indicated medium-high M&E for CLIMATE SPACE/CCI due to the UK's lead role in the investment, lack of existing M&E and long history of benefits, which may facilitate accounting for past benefits and investment. It was also noted that this programme is of interest for an impact and VfM framework where it may be appropriate to examine its links to other ESA EO programmes. The proportionality assessment likewise indicates medium-high M&E due to the UK investment and leadership role and the need to provide accountability and fill the gap in M&E for this programme. It was agreed in the workshop that this programme will undergo medium-high level M&E. Capturing benefits associated with climate change and net zero efforts is of particular interest.

Industrial Innovation (InCubed-2)

Investment in InCubed-2 is a public-private partnership which provides co-funding to support the development of products and services using Earth Observation. InCubed supports activities in three areas: space segment, ground segment and data segment. The programme guarantees a geo-return of at least one, and the UK has significant power to determine how much money is spent on the programme.[32]

[31] CM22 Business Case: Earth Observation Programme – Internal Document.

[32] CM22 Business Case: Earth Observation Programme – Internal Document.

Table 15: Summary of proportionality assessment evidence for InCubed-2

<table>
<tr><th colspan="6">Earth Observation: InCubed-2</th></tr>
<tr><th colspan="6">Scale of investment</th></tr>
<tr><th>Cumulative spending to the end of 2022</th><th>2023 Budget</th><th>Projected Commitment (2024–2028)</th><th>Projected commitments (2029 onwards)</th><th>UK CM22 Investment</th><th>% of total MS amounts at CM22</th></tr>
<tr><td>Low</td><td>Low</td><td>Low</td><td>Low</td><td>Low</td><td>Low</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">• Scale of investment: Historic investment is low and is due to decrease further, subject to investment decisions at future ministerials.
• Ability to re-scale investment: The UK has considerable control over the level and scale of involvement in the programme.
• UK involvement: This is a commercialisation programme with strong potential benefits for contractors bringing technologies to the market.
• Existing M&E: Limited existing M&E.
• VfM: The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making due to improved access to data.</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">Little evidence has yet been identified across the criteria programme, except for the scale of investment, the level of UK involvement and relevance to other programmes.</td></tr>
<tr><th colspan="6">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency assessment</th><th colspan="4">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th colspan="3">Explanation</th></tr>
<tr><td>Low/medium (TBC in conceptual framework workshop)</td><td>Relatively low historic and a very low projected future investment amount, but no specific M&E undertaken to date. Consider the value of merging M&E with that of FutureEO and other missions (DTE, Aeolus, CSC, TRUTHS?).</td><td>Low</td><td colspan="3">This is a minimal investment, and future investment is also small. There is notable contractor involvement and potential economic benefit for close-to-market technologies, providing an opportunity for benefits mapping and some VfM to support accountability for historic investments. However, intensive VfM is likely inappropriate, given the scale of investment. It may be advantageous to merge M&E with other EO programmes with small UK investment. However, note that this programme is in a different lifecycle stage than Aeolus 2 and Digital Twin.</td></tr>
<tr><th colspan="6">Final assessment</th></tr>
<tr><td>Low</td><td colspan="5">This programme will undergo low-level M&E. The small scale of investment limits the utility of more intensive examination, and it was determined that it is not a priority area for M&E compared to other EO programmes.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for InCubed-2. RAND Europe Analysis.

The assessment was limited by the minimal evidence identified for many criteria. As its historical and planned investment is small, the UK is a relatively minor player in this programme. This programme has historically been attractive to industry as it commonly fosters innovation for technologies close to the market.[33] There is interest in conducting programme-level VfM for InCubed-2, as it may be possible to assess the impact of timely decision-making due to improved access to data.

The initial assessment from the UK Space Agency indicated low-medium level M&E for InCubed-2 due to low historical and planned investment, but lack of existing M&E made the programme of interest above low-level M&E. The proportionality assessment indicated a low level of M&E due to the small scale of the investment. It was decided in the workshop that the programme would undergo low-level M&E due to the small scale of the investment, as other programmes within EO are of greater interest for more intensive M&E.

D.3.4. Telecommunications and Integrated Applications

Business Applications and Space Solutions (BASS)

BASS is a commercially oriented programme that offers funding to businesses across sectors interested in using space to develop new commercial products and services.

Table 16: Summary of proportionality assessment evidence for BASS

<table>
<tr><th colspan="6">Telecommunications and Integrated Applications: BASS</th></tr>
<tr><td colspan="6">Scale of investment</td></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Moderate</td><td>Low</td><td>Moderate</td><td>Low</td><td>Low</td><td>High</td></tr>
<tr><td colspan="6">Summary of assessment criteria</td></tr>
<tr><td colspan="6">Scale of investment: The UK is a major player in this investment – second after Italy.
UK involvement: A history of facilitating projects with UK industry partners.
VfM: This programme area will likely result in multiple socioeconomic benefits, but they will likely be hard to quantify and largely fall outside the space sector. Nevertheless, these programme areas are of interest in applying a programme-specific VfM approach, particularly looking at the technology spillovers outside of the space sector that have a wider impact on society.</td></tr>
<tr><td colspan="6">Strength of evidence</td></tr>
<tr><td colspan="6">Little evidence has yet been identified across all criteria except for socioeconomic benefits.</td></tr>
<tr><td colspan="6">Assessment</td></tr>
<tr><td colspan="3">Initial UK Space Agency assessment</td><td colspan="3">Updated assessment with evidence to date</td></tr>
<tr><td>M&E level</td><td colspan="2">Rationale</td><td>M&E level</td><td colspan="2">Rationale</td></tr>
<tr><td>Low/medium (TBC in conceptual framework workshop)</td><td colspan="2">TBC – limited evidence has been produced to date (given that this is still a relatively new programme), but further exploration is needed on ongoing ESA activity. Wider social impacts will be expansive and challenging to present comprehensively, given the fund covers applications</td><td>Low-medium</td><td colspan="2">This is a medium-scale investment with potential for broad socioeconomic benefits, many outside the space sector. With little M&E to date, further examination of this investment and its benefits is appropriate. Programme-specific VfM will be important for capturing wide benefits.</td></tr>
</table>

[33] CM22 Business Case: Earth Observation Programme – Internal Document.

	for a wide range of non-Space sectors. Consider overlapping this with the ongoing M&E of the UK national Unlocking Space for Business programme.		
Final assessment			
Low-medium	This programme will undergo low-medium level M&E. The potential for wide spillover benefits is of interest for M&E, particularly for VfM assessment. The utility of more intensive M&E is limited by other M&E, which will likely occur for this programme.		

Source: Summary of proportionality assessment evidence for BASS. RAND Europe Analysis.

The assessment was limited due to little evidence identified for many criteria. The UK is a major player in this programme and in the investment, contributing nearly 16% of the total budget, second after Italy.[34] The programme has a history of significant UK space industry involvement, including CGI UK and Tandem UK, producing wider socioeconomic benefits by supporting railways' digitalisation and addressing mobility and transport poverty.[35] Due to wide applications and spillovers, there is interest in a programme-level VfM assessment, though benefits are likely to be challenging to quantify.

The initial assessment from the UK Space Agency indicated a low-medium M&E level, which will be confirmed during the conceptual framework workshop due to the potential for wide benefits and the lack of evaluation to date. The proportionality assessment likewise indicated low-medium M&E with a similar rationale. It was decided in the workshop that the programme would undergo low-medium M&E.

Moonlight

Moonlight aims to launch several satellites into orbit around the moon beginning in 2028. These satellites will facilitate other activities planned for the moon, including science, communication, navigation and data sharing.

Table 17: Summary of proportionality assessment evidence for Moonlight

Telecommunications and Integrated Applications: Moonlight					
Scale of investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
Low	Low	Moderate	Low	Moderate	Very high
Summary of assessment criteria					
• **UK influence:** The UK is a major player in this investment – second after Italy. Together, they comprise nearly 80% of the total programme investment. • **UK involvement:** Presents an opportunity for UK industry to play a leading role in future lunar exploration.					

[34] UK Space Agency internal data on ESA Contributors Financial Obligations 2024.

[35] UK Space Agency (2025).

<table>
<tr><td colspan="4">

Policy alignment: Identified as an important area for driving growth related to existing UK strengths. It will demonstrate UK navigation capabilities and is expected to be a strong opportunity for international partnerships.
VfM: The programme is in its early stages, so it is unlikely to be suitable for a programme-specific VfM analysis.

</td></tr>
<tr><th colspan="4">Strength of evidence</th></tr>
<tr><td colspan="4">No evidence has yet been identified for most assessment criteria, except for alignment with NSS and level of UK involvement.</td></tr>
<tr><th colspan="4">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency assessment</th><th colspan="2">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th>Explanation</th></tr>
<tr><td>Low</td><td>Despite the high projected budget for the future, there will be minimal value in undertaking significant efforts to evaluate the programme at this early stage in its evolution. This means activity should be limited to building a monitoring/benefits realisation framework and frameworks for undertaking future impact/VfM evaluation).</td><td>Low/medium</td><td>This is a new programme. The UK is a major player, and future investment is high. Given the programme stage, there is little to evaluate to date. Establishing a strong monitoring framework will be appropriate to provide accountability for the scale of planned investment.</td></tr>
<tr><th colspan="4">Final assessment</th></tr>
<tr><td>Low</td><td colspan="3">This programme will undergo low-level M&E. While future spending is high, the utility of more intensive M&E is limited due to the early stage of the programme.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for Moonlight. RAND Europe Analysis.

The assessment was limited due to the minimal evidence identified for many criteria. The UK is a major player in this investment, contributing nearly 40% of the current budget.[36] The programme offers the potential for UK industry to lead in lunar capabilities, and there is already strong involvement from the UK space industry, including a consortium led by SSTL.[37] The programme strongly aligns with key NSS objectives, including significant collaboration potential, playing to the UK's strengths and positioning the UK well for future market opportunities in space.[38] The early stage of the programme limits the feasibility of programme-level VfM analysis.

The initial assessment by the UK Space Agency indicated low-level M&E for Moonlight, noting the sizeable future investment and suggesting a monitoring framework is most appropriate at this stage, given that the programme is new. The proportionality assessment indicated low-medium M&E given that future investment is high and the need for future accountability for this investment through a strong monitoring approach. It was decided in the workshop that the programme would undergo low-level M&E, given the programme stage.

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[36] UK Space Agency internal data on ESA Contributors Financial Obligations 2024.

[37] UK Space Agency (2025).

[38] CM22 Full Business Case.

D.3.5. Navigation

Navigation Innovation and Support Programme (NAVISP) (Phase 3 Elements 1, 2 & 3)

NAVISP supports the European Position, Navigation and Timing (PNT) landscape and the development of PNT technologies that complement, upgrade or replace current capabilities.

Table 18: Summary of proportionality assessment evidence for NAVSIP

<table>
<tr><th colspan="6">Navigation: NAVISP</th></tr>
<tr><th colspan="6">Scale of investment</th></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Moderate</td><td>Low</td><td>Moderate</td><td>Low</td><td>Moderate</td><td>Very high</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">• UK influence: The UK is the foremost investor across all Phase 3 Elements.
• Policy alignment: Focus on NSS aspects of growing and levelling up the economy, defence, and delivery of services for UK citizens.
• Socioeconomic benefits: Past programme activities have resulted in new products and services and the growth of commercial entities. There are also broad historical and projected socioeconomic benefits – including environment, energy efficiency, mobility and transportation, crime reduction and healthcare.
• VfM: This programme could produce some benefits that could be included in VfM quantitatively, specifically around lowered costs due to improved PNT technology and other applications on PNT. These may be hard to measure quantitatively but should feature qualitatively in the overall VfM analysis.</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">No evidence has yet been identified for most assessment criteria, except for alignment with NSS and socioeconomic benefits.</td></tr>
<tr><th colspan="6">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency assessment</th><th colspan="4">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th colspan="3">Explanation</th></tr>
<tr><td>Medium</td><td>Despite this being a relatively new programme that will present challenges, and the UK undertaking the highest proportion of investments relative to other MS, it also needs to take leadership in M&E. The fact that this is a scalable programme also means there is a need to gain evidence to understand the optimal level of spend (so a VfM framework is particularly relevant here).</td><td>Medium-high</td><td colspan="3">The UK is a major investor in this programme, and as such, there is a need for accountability. However, this is a relatively new programme with few benefits realised yet. Programme-level VfM will be important for capturing socioeconomic benefits expected within and outside the space sector and informing optimal spending for future investment.</td></tr>
</table>

Final assessment	
Medium-high	This programme will undergo medium-high M&E. As the UK is the foremost investor, a strong monitoring framework is needed to support accountability and future impact assessment. The utility of high-level M&E is limited as the programme is new and has had little time to achieve impact.

Source: Summary of proportionality assessment evidence for NAVSIP. RAND Europe Analysis.

The assessment was limited due to little evidence identified for many criteria. The UK is the foremost investor across all Phase 3 Elements, contributing nearly one-third of the current budget for Element 1, over one-quarter of the current budget for Element 2 and over 40% of the current budget for Element 3.[39] PNT is significant for the UK economy, estimated to underpin £314bn of the UK's Gross Domestic Product (GDP).[40] The programme has wide socioeconomic benefits due to the many applications of PNT across sectors, including environment, energy efficiency, transportation and healthcare. For example, PNT technologies are believed to support crime reduction efforts by offering an alternative to the currently used Global Navigation Satellite Systems (GNSS).

The programme aligns strongly with the NSS through various capabilities that support defending UK national interests and delivering for UK citizens. It also strongly aligns with other UK national strategies, particularly related to climate change and net zero, through its potential to support energy efficiency by improving the synchronisation of electric grids.[41] [Error! Bookmark not defined.] Due to these impacts, there is potential for both qualitative and quantitative VfM.

The initial UK Space Agency assessment indicated medium-level M&E for NAVISP due to the scale of the investment and, given the scalability, an interest in understanding the programme's impacts to inform future investment. The proportionality assessment indicated medium-high level M&E for this programme due to the scale of the investment. Establishing a strong monitoring framework will be important for accountability and monitoring impact, particularly related to priority policy areas. It was decided in the workshop that NAVISP will undergo medium-high level M&E. There is interest in establishing a monitoring framework for long-term socioeconomic impact.

D.3.6. Space Safety

COSMIC

COSMIC is a core aspect of ESA's space safety activities. It includes the deployment of small satellites which serve as a means of testing and commercialising innovative space safety sensors. COSMIC is also based partly on providing sensors, research and services, e.g. for space weather and space debris monitoring, to improve the protection of CNI from incidents, improving understanding and providing data to the sector.

[39] UK Space Agency internal data on ESA Contributors Financial Obligations 2024.

[40] CM22 full business case.

[41] Ministry of Housing, Communities and Local Government (2025).

Table 19: Summary of proportionality assessment evidence for COSMIC

Space Safety: COSMIC					
Scale of investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
Not reported	Not reported	Not reported	Not reported	Low	Moderate
Summary of assessment criteria					
• **UK involvement:** Several projects (e.g. Destructive Re-entry Assessment Container Object [DRACO] and Visdoms) may provide growth benefits for UK companies. • **Programme overlap:** Considered a core aspect of the Space Safety programme. • **Policy alignment:** Space safety, particularly leadership in space safety, is a key NSS priority. • **Socioeconomic benefits:** Spillover benefits anticipated from improving space-debris-removal capabilities.					
Strength of evidence					
No evidence has yet been identified for most assessment criteria, except for UK involvement and alignment with the NSS.					
Assessment					
Initial UK Space Agency assessment		Updated assessment with evidence to date			
M&E level	Explanation	M&E level	Explanation		
TBC in conceptual framework workshop	TBC – to consider the overlap and merging presentation of M&E with other elements of the Space Safety portfolio. ESA should ideally take a leadership role in the M&E for this element.	Low	The UK is a relatively small player in this programme. A lack of evidence hinders definitive assessment, but the UK Space Agency indicates that ESA should lead M&E in this area. Low-level M&E is therefore provisionally proposed to prevent duplication of effort unless a specific assessment of UK benefits is sought beyond that likely included in ESA M&E.		
Final assessment					
Low	This programme will undergo low-level M&E. The small scale of the investment limits the utility of more intensive M&E. In addition, ESA may undertake M&E in this area, limiting the added value of additional M&E at this time.				

Source: Summary of proportionality assessment evidence for COSMIC. RAND Europe Analysis.

The assessment of this programme was limited by the minimal evidence identified for most of the assessment criteria. The UK is not a major player in this investment but is among the top five MSs. Several projects within the programme have substantial involvement from UK space companies. The programme inherently aligns strongly with the NSS as debris removal is an NSS priority area. As debris removal has spillover benefits, the programme is expected to have wider benefits.

The UK Space Agency did not indicate a level of M&E during their initial assessment but noted that ESA should be leading M&E efforts for this programme. The proportionality assessment indicated low-level M&E due to the small scale of investment and ESA's potential role in leading M&E. It was decided in the workshop that COSMIC would undergo low-level M&E as Active Debris Removal/In-Orbit Servicing (ADRIOS) is a higher priority among smaller-scale investments in the space safety domain.

Vigil

Vigil is a novel spacecraft aiming to capture observations of solar weather and storms. This information is expected to help protect spacecraft and the Earth from extreme solar weather by acting as an early warning system.

Table 20: Summary of proportionality assessment evidence for Vigil

<table>
<tr><th colspan="6">Space Safety: Vigil</th></tr>
<tr><th colspan="6">Scale of investment</th></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Not reported</td><td>Not reported</td><td>Not reported</td><td>Not reported</td><td>Moderate</td><td>Very high</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">• UK influence: The UK is the foremost contributor – providing over half of the total investment.
• Benefits lead time: Several years to launch, with benefits expected in the coming decades.
• Policy alignment: This is a focus of mission leadership, playing to the UK's strength in predicting space weather. The primary objective is to protect the Critical National Infrastructure – acting as a successor to Solar and Heliospheric Observatory (SOHO) – which will be only one of two missions supporting space weather prediction alongside the US National Aeronautics and Space Administration (NASA)/ National Oceanographic and Atmospheric Administration's (NOAA) Lagrange, contributing to wider socioeconomic benefits.
• VfM: This is a key area of interest for a programme-specific VfM analysis. There is existing literature on the economic impact of space weather, and improved space weather monitoring can support reducing this.</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">No evidence has yet been identified for some assessment criteria, except for UK involvement, UK influence, benefits lead time, alignment with NSS and historical and projected socio-economic benefits.</td></tr>
<tr><th colspan="6">Assessment</th></tr>
<tr><th colspan="3">Initial UK Space Agency assessment</th><th colspan="3">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th colspan="2">Explanation</th><th>M&E level</th><th colspan="2">Explanation</th></tr>
<tr><td>High</td><td colspan="2">High projected investment, with the UK taking a significant leadership role. There are very long timeframes until full benefits are expected to be realised, but a robust ToC, benefits realisation and VfM framework are needed. It also has the potential to supplement impact evaluation with evidence of historical impacts from previous Space Weather missions. Consider overlap with COSMIC.</td><td>High</td><td colspan="2">The UK is this programme's major investor and leader, warranting an intensive M&E level. Long benefits lead time will preclude some M&E activities, making it the appropriate stage to establish a strong monitoring framework. As this is a signature investment, programme-specific M&E is warranted.</td></tr>
<tr><th colspan="6">Final assessment</th></tr>
<tr><td colspan="2">High</td><td colspan="4">This programme will undergo high-level M&E due to the relatively high level of investment and the UK's leadership role in the programme. Given that the programme is early in its life cycle, a stronger focus on monitoring and benefits mapping is likely most appropriate.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for Vigil. RAND Europe Analysis.

Evidence was found to inform some criteria, including UK influence and involvement level, benefits lead time and socioeconomic benefits. Vigil is also mentioned in the NSS and the Severe Space Weather Preparedness Strategy.

The UK is a major investor in Vigil, providing the highest per cent of the investment compared to other MS.[42] Vigil is also a priority area for UK leadership efforts, along with TRUTHS and the Rosalind Franklin Mars rover. The programme is also expected to bring in significant UK space industry involvement, notably from Airbus Defence and Space.[43] This programme has notable overlap with the SOHO mission, which likewise collects observations on solar flares. Without Vigil, there would be no replacement capability within ESA, with only one US mission otherwise collecting this information critical to solar storm forecasting.[44]

Vigil is a new programme, and most programme benefits are not expected to be realised until after the launch, which is planned for 2031 with a mission lifespan of 20 years. Vigil is anticipated to have important socioeconomic benefits, namely protecting critical national infrastructure from extreme solar weather events. This damage mitigation function is expected to provide significant cost savings.[45] This programme aligns with the NSS, as it addresses a critical aspect of space safety, a priority area for UK space activities and leadership. Finally, Vigil is a key area of interest for programme-specific VfM analysis as there is existing economic literature on space weather, allowing for impact assessment.

The initial UK Space Agency assessment indicated high-level M&E for Vigil due to the relative scale of the investment and the UK's leadership role. However, the programme's early stage makes a stronger monitoring focus appropriate. There is some interest in assessing historical impacts from previous space weather missions. The proportionality assessment likewise indicated high-level M&E based on a similar rationale. It was agreed in the workshop that Vigil would undergo high-level M&E.

ADRIOS

ADRIOS will provide space debris removal functions, including removal of ESA-owned objects. This will develop and demonstrate debris removal capabilities and solidify the debris removal value chain. The programme aims to foster future market opportunities for institutions and the private sector for debris removal services. The programme's expansion at CM22, which will incorporate two in-orbit servicing missions to extend the life of geostationary satellites.

Table 21: Summary of proportionality assessment evidence for ADRIOS

Space Safety: ADRIOS					
Scale of investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
Not reported	Not reported	Not reported	Not reported	Low	High

[42] UK Space Agency internal data on ESA Contributors Financial Obligations 2024.

[43] CM22 Full Business Case – Internal Document.

[44] CM22 Full Business Case – Internal Document.

[45] CM22 Full Business Case – Internal Document.

<table>
<tr><th colspan="4">Summary of assessment criteria</th></tr>
<tr><td colspan="4">• **UK influence:** The UK is a major player in the scale of investment – second only after Italy, which contributes nearly one-third of the total budget.
• **VfM:** This programme is of key interest for a programme-specific approach to VfM. There is a fair amount of literature on the economic cost of space debris and the total quantity. Despite the long lead time of these benefits and given that it is a first-of-a-kind mission, there may be a limit on what assumptions can be made about future clearances of space debris. However, this is a key quantitative or qualitative area of interest in the VfM assessment.</td></tr>
<tr><th colspan="4">Strength of evidence</th></tr>
<tr><td colspan="4">No evidence has yet been identified for nearly all assessment criteria, except for the UK's influence.</td></tr>
<tr><th colspan="4">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency assessment</th><th colspan="2">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th>Explanation</th></tr>
<tr><td>Low/medium (TBC in conceptual framework workshop)</td><td>TBC – these new missions have long timeframes to full benefit realisation and few comparable historical programmes to usefully provide supplementary evidence. It would be useful to build upon impact and VfM appraisal frameworks that have already been conducted in recent relevant literature.</td><td>Low-medium</td><td>The UK is a major player in this investment. Long benefits lead time will preclude some M&E activities, making it the appropriate stage to establish a strong monitoring framework. Programme-level VfM is of key interest.</td></tr>
<tr><th colspan="4">Final assessment</th></tr>
<tr><td colspan="2">Medium</td><td colspan="2">This programme will undergo medium-level M&E. Despite relatively long benefits lead times, there is interest in greater intensity M&E for this programme due to its current performance and the need for assessment to inform future spending. Programme-level VfM analysis is of interest, supported by economic literature on the cost of space debris.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for ADRIOS. RAND Europe Analysis.

The assessment of this programme was limited by the minimal evidence identified for most of the assessment criteria. The UK is a major contributor to ADRIOS. The programme strongly aligns with the NSS, as space debris removal is a key strategic area, particularly UK leadership in debris removal. Due to the availability of economic literature on the costs of space debris, this programme is of interest for programme-level VfM analysis. However, the feasibility of programme-level VfM analysis may be limited by extended benefits lead times.

The initial UK Space Agency assessment indicated low-medium level M&E for ADRIOS due to extended benefits lead times and little programme overlap. However, there is interest in VfM approaches that are relevant to space debris. The proportionality assessment likewise indicated low-medium level M&E with a similar rationale. It was decided at the workshop that ADRIOS will undergo medium-level M&E due to the scale of the programme, its current performance and the role M&E can play in informing future spending, as the UK is a major financial contributor.

D.3.7. Technology

General Support Technology Programme (GSTP) (Elements 1, 2 & 3), Electrical, Electronic and Electromechanical (EEE) & European Devices Using Radioisotope Energy (ENDURE)

GSTP supports technological maturation, fostering the development and testing of leading-edge technologies. The GSTP covers programmes from TRL 3 and up and includes a range of technologies from individual components to full satellites. EEE provides project support and technical expertise for parts development, manufacturing, application and testing. ENDURE involves improved radioisotope heat and power system capabilities needed to explore the outer Solar System and challenging planetary environments.

Table 22: Summary of proportionality assessment evidence for the GSTP

<table>
<tr><th colspan="6">Technology: GSTP</th></tr>
<tr><th colspan="6">Scale of investment</th></tr>
<tr><td>Cumulative spending to the end of 2022</td><td>2023 Budget</td><td>Projected Commitment (2024–2028)</td><td>Projected commitments (2029 onwards)</td><td>UK CM22 Investment</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Moderate</td><td>Moderate</td><td>Moderate</td><td>Low</td><td>Moderate</td><td>Variable</td></tr>
<tr><th colspan="6">Summary of assessment criteria</th></tr>
<tr><td colspan="6">
• UK influence: The UK is a major player in Endure, contributing 89% of total MS amounts at CM22.
• UK involvement: There is considerable industry involvement in this programme area, though the degree to which this involves UK industry, science and other beneficiaries is highly dependent on the technologies within the portfolio.
• Programme overlap: There is a significant overlap between technologies in the GSTP portfolio and other ESA programmes.
• Policy alignment: GTSP is a more generalised technology development support programme that broadly but indirectly supports NSS objectives by facilitating the development of technologies that address NSS objectives and acting as a source of funding for technologies in middle TRLs, thereby facilitating technological maturity.
• VfM: This does not seem suitable for a programme-specific VfM analysis, given the long lead time and the challenge of attributing any future impacts directly to the programme. Since it focuses on early-stage technology/concept development, it is unlikely to produce the type of impact that could be monetised as part of VfM. However, this does not mean that non-monetisable benefits will not be considered as part of the wider VfM assessment.
</td></tr>
<tr><th colspan="6">Strength of evidence</th></tr>
<tr><td colspan="6">There is strong evidence for benefits lead time but less for programme overlap, UK influence, UK involvement and alignment with the NSS and other national strategies. No evidence has yet been identified for other assessment criteria, including the ability to re-scale investment and historical and projected socioeconomic benefit.</td></tr>
</table>

Assessment			
Initial UK Space Agency assessment		Updated assessment with evidence to date	
M&E level	Explanation	M&E level	Explanation
Low/medium (TBC in conceptual framework workshop)	The GSTP's long history means that, at the programme level, there is a benefit of considering success stories due to past investments (although at the individual contract level, the technologies vary significantly with limited overlap between specific benefits of historical and future investments). The added value of further M&E should be considered, given the currently available evidence (GSTP evaluation for the UK Space Agency is deemed low quality, but this element of the CM19 evaluation was better). At a minimum, a robust long-term monitoring framework needs to be in place, given that technology development will continue indefinitely into the long term.	Low-medium	This programme area involves varied activities with potentially wide socioeconomic benefits. However, it focuses on less mature technologies with longer lead times, precluding some M&E activities and providing challenges for VfM analysis. Programme-specific M&E would be challenging, given lead times. Establishing a strong monitoring framework would be useful at this stage, providing the foundation for accountability.

Assessment	
Low-medium	This programme will undergo low-medium level M&E. Utility and feasibility of more intensive evaluation, particularly programme level VfM analysis, is limited by long benefits lead times. A low-medium intensity approach can assess some historic impacts while focusing on developing a strong monitoring framework.

Source: Summary of proportionality assessment evidence for the GSTP. RAND Europe Analysis.

The UK is a significant contributor to the GSTP's Element 1 'develop' but a relatively minor contributor to Elements 2 and 3 and EEE.**Error! Bookmark not defined.** The UK is a major player in ENDURE, contributing 89% of the total budget at CM22.[46] As the GSTP facilitates technological maturity and development, there is considerable industry involvement in the programme area, though the degree of involvement depends on the technologies within the portfolio. There is a significant overlap between technologies in the GSTP portfolio and other ESA programmes, as many technologies matured through the GSTP were later utilised in other programmes. As the GSTP generally focuses on middle-range TRLs (3–7), technologies within the programme generally have longer benefit lead times.[47] Given its industrial focus, the programme is considered to have good returns for job creation, providing benefits to the UK.

Regarding policy alignment, the GTSP is a more generalised technology development support programme. As such, it broadly but indirectly supports NSS objectives by facilitating the development of technologies that address NSS objectives and particularly acts as a source of funding for technologies in middle TRLs, thereby facilitating technological maturity. EEE shows some alignment with the NSS in its focus on securing supplies of EEE breadboards. ENDURE likewise shows some alignment to the NSS in supporting

[46] UK Space Agency internal data on ESA Contributors Financial Obligations 2024.

[47] Databuild Consulting (2017).

radioactive heat and power units from Europe, positioning ESA to supply these to future ESA, NASA, and Japan Aerospace Exploration Agency (JAXA) missions.[48] Limited information is available concerning the alignment of these programmes with other UK national strategies. However, as GSTP includes a broad technological portfolio, developing technologies within this programme area will likely contribute to wider UK strategic objectives. Given the early stage of technologies within the programmes, there are unlikely to be impacts which could be monetisable for VfM, limiting the feasibility of programme-level VfM analysis.

The initial UK Space Agency assessment indicated low-medium level M&E for these programmes, noting that it is of interest to capture the historical benefits of the programme and suggesting a monitoring approach would be beneficial for indicator assessment and supporting future evaluation. The proportionality assessment likewise indicated low-medium level M&E for these programmes, noting the limited utility and feasibility of medium or high-level M&E given the long lead times for technologies within these programmes. It was agreed in the workshop that these programmes would undergo low-medium level M&E focused on monitoring. As the programme guarantees geo-return, there is interest in assessing this in greater detail through historical programme data.

D.3.8. Commercial

ScaleUp

ScaleUp programmes support ESA's commercialisation activities, fostering the development of new business ideas through ESA Business Incubation Centres (BIC). These centres support space innovation and the development of upstream and downstream products and technology by promoting technology transfer and patenting.

Table 23: Summary of proportionality assessment evidence for ScaleUp

Commercial: ScaleUp					
Scale of investment					
Cumulative spending to the end of 2022	2023 Budget	Projected Commitment (2024–2028)	Projected commitments (2029 onwards)	UK CM22 Investment	% of total MS amounts at CM22
Low	Low	Low	Low	Low	Low
Summary of assessment criteria					
• **Scale of investment:** The UK is a minor player in this investment, outside of the top five MS contributors. • **Socioeconomic benefits:** Historical evidence indicates this programme is a strong driver of business growth, particularly start-ups and incubators, which have attracted significant external investment and created hundreds of Full-Time Equivalent (FTE) jobs.					
Strength of evidence					
No evidence has been identified for nearly all assessment criteria except for UK involvement and historical socioeconomic benefits.					

[48] CM22 Full Business Case – Internal Document.

<table>
<tr><th colspan="4">Assessment</th></tr>
<tr><th colspan="2">Initial UK Space Agency Assessment</th><th colspan="2">Updated assessment with evidence to date</th></tr>
<tr><th>M&E level</th><th>Explanation</th><th>M&E level</th><th>Explanation</th></tr>
<tr><td>TBC in conceptual framework workshop</td><td>Since ESA's Commercialisation team is undertaking this new programme, decent monitoring procedures are likely already in place, which should limit duplication. To be explored with ESA.</td><td>Low</td><td>The new programme limits the utility of high-intensity M&E at this stage. ESA is also undertaking M&E for this programme, limiting the added value of additional M&E unless there is a need to examine the particular UK benefits that are unlikely to be fully captured in ESA M&E.</td></tr>
<tr><th colspan="4">Final assessment</th></tr>
<tr><td>Low</td><td colspan="3">This programme will undergo low-level M&E. The small scale of the investment, with monitoring procedures already in place, limits the utility of higher intensity M&E. Learnings from the evaluation of this programme will be important for informing ESA's ability to be nimble and agile in supporting the commercialisation of space technologies, services and products.</td></tr>
</table>

Source: Summary of proportionality assessment evidence for ScaleUp. RAND Europe Analysis.

Assessment of this programme area was limited given the minimal evidence identified to support most criteria. This is a new programme where the UK is a minor player in this investment, outside of the top five MS contributors.[49] The UK Space Agency BIC has historically produced notable socioeconomic benefits through its commercialisation function. In its lifetime, it has helped 105 start-ups sign contacts, gain significant external investment and create over 500 full-time equivalent (FTE) jobs.[50]

In the initial assessment, the UK Space Agency did not assign a level of M&E to ScaleUp, noting that it is a new programme where monitoring procedures are likely to be in place due to its commercialisation function. The proportionality assessment indicated low-level M&E for ScaleUp due to the investment's small scale and existing monitoring procedures. It was decided in the workshop that ScaleUp would undergo low-level M&E, noting that because this is an area in which ESA is attempting to be nimbler in supporting commercial viability, there are important opportunities to learn from this programme.

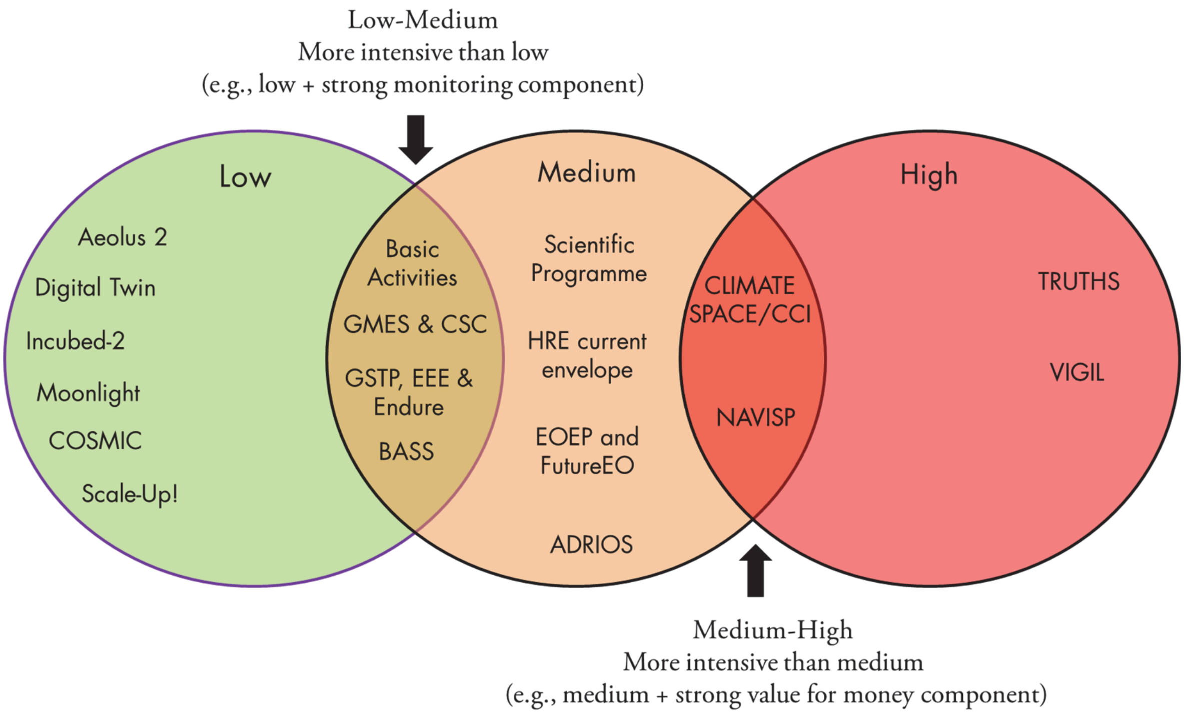
D.3.9. Summary of proportionality outcomes – programme-level methods

Based on the outcomes of the proportionality exercise discussed in depth above, each programme was assigned a level of M&E to indicate the level of resources needed and the type of methodological approaches that will be used to monitor and evaluate the programme. Figure 1 below summarises the level of M&E assigned to each programme.

[49] UK Space Agency internal data on ESA Contributors Financial Obligations 2024.

[50] CM22 Full Business Case – Internal Document.

Figure 1: Venn diagram of the M&E level assigned to each programme



Source: RAND Europe analysis.

However, as previously stated, the level of M&E serves as an indicator of the methods to be used at a programme level. Specific methods have been chosen for individual programs based on requirements outlined in the detailed proportionality assessment discussion.

Although the proportionality assessment outlined the intended level of M&E activities across the UK Space Agency's ESA programme portfolio, implementation of M&E activities varied in practice. While the scale and intensity of M&E activities across programmes generally corresponded to the level of M&E intensity indicated in the proportionality assessment, several challenges limited the full realisation of those intentions. Firstly, the complexity of the UK Space Agency's ESA programme portfolio, encompassing programmes at various stages of maturity and with varied timelines for benefits realisation, resulted in difficulties reaching stakeholders in programmes that had completed a few years earlier and in collecting data on newer programmes with no or very few outcomes. Additionally, respondent burden, due to heavy stakeholder consultation as a part of other evaluations and national surveys, was a barrier to capturing a representative sample of consultees for this evaluation. Despite these challenges, the proportionality assessment was valuable in guiding M&E activities and supporting effective use of evaluation resources across the UK Space Agency's ESA programme portfolio.

Annex E. Theory of change (ToC)

E.1. Overview and context

This section consists of a visual presentation that presents the ToC in one image and a wider narrative ToC that explores the logic in more detail. The ToC (both the logic model and narrative together) articulates the rationale for and intended outcomes and impacts of the UK Space Agency's ESA investments and captures the underlying assumptions.

This is the second iteration of the ToC, following Technopolis' ToC created in their 2022 evaluation framework.[51] Key updates are discussed later in this section, though no fundamental changes were made.

E.2. Rationale

E.2.1. Investment/portfolio-level analysis of ToC – future Strategic Case(s)

This level of analysis aims to provide evidence supporting the intervention's rationale. This includes addressing the question, 'Why couldn't expected outcomes and benefits be achieved another way?' It is essential to examine market failures to answer this question and determine why alternative approaches would not yield the desired outcomes and benefits, including considering:

- **Departmental strategic fit**: Providing evidence to demonstrate alignment with relevant DSIT published strategies and policy documents (the NSS, wider DSIT priorities, UK innovation strategy, UK S&T framework). This is also an important aspect of the Green Book guidance for developing future business cases for ESA investment.
- **Alignment to wider government priorities**: For non-DSIT business cases, this section would usually show how the case for change aligns with the cross-cutting themes, outcomes and objectives of Other Government Departments (OGDs), as demonstrated in the government's Public Value Framework. Future business cases will likely require an evidence base to demonstrate alignment with relevant policy documents (e.g. Strengthening the Union, Net Zero).
- **Benefits sought**: Providing an evidence base to help present within a strategic case. M&E and benefits realisation plans are the most sizeable/critical overarching investment-level benefits, including a link to overarching objectives, benefit type/category and prime beneficiary(ies).

[51] Technopolis Group (2022a).

- **Dependencies, constraints and assumptions**: Providing an evidence base to inform descriptions of the main dependencies (elements broadly within the UK Space Agency's control and key to the success of ESA investment but beyond its scope), constraints (external conditions imposed on the investments, within which it must be delivered and over which the business case has no control) and assumptions (current unknowns which, if clarified, could assist planning and delivery).
- **Risks**: Providing an evidence base for key investment-level strategic risks (events, causes and effects, likelihood, and impact scores), including assessing the urgency of those risks and the value of their reduction/elimination to the government.

The above points are directly addressed in later sections of this chapter in the context of the ToC.

E.2.2. Programme-level analysis of ToC and programme-level VfM analysis – future Economic Case(s)

It is worth highlighting the value of ToC and VfM level analyses at the programme level for DSIT/UK Space Agency decision-making in the future:

- **Longlist and shortlist option development**: Providing an evidence base to inform the development of a longlist of investment options with a process that aligns as closely to the HM Treasury (HMT) options framework as is feasible in this context. In practice, this will likely involve assessing optional programmes put forward by ESA against critical success factors (CSFs) (most importantly, strategic fit, VfM/benefits and supplier capacity/capability) and overarching investment objectives (likely to be linked to delivery of NSS) for different options relating to:
    - Programme scope
    - Programme solution
    - Programme delivery agent (national vs ESA)
    - Implementation
    - Funding.[52]
- In practice, M&E is an opportunity to provide evidence for the current portfolio of programmes with respect to the extent to which they meet CSFs and NSS to help articulate the above.
- **Appraisal of shortlisted options**: Providing evidence to inform the assumptions used to appraise shortlisted options. The development of programme-level VfM evaluation frameworks will feed into the plan for data collection activity for the M&E. Because future appraisal will require presenting VfM of different shortlisted options (different mixes of optional programmes), the main focus for VfM evaluation should be to provide a framework and evidence base to assess costs and benefits at the programme level, referencing the results of the proportionality assessment, rather

[52] NB: if ESA is the obvious preferred delivery agent, preferred implementation and funding options will already be pre-determined at the long-list stage.

than attempting to provide an overarching investment-level net present value (NPV)/ benefit-cost ratio (BCR). The next chapter explores this further.

E.3. Visualisation of the ToC

The ToC is a critical tool in the evaluation approach, providing a guiding framework and a shared understanding of the investment portfolio's goals and the means of achieving them. Although not all aspects of the ToC may apply uniformly across the portfolio, each domain level should be able to identify its expected pathways and impact within parts of the ToC.

The ToC employs a 'logic model' approach, sequentially encapsulating the programme's inputs, activities, outputs, outcomes, and impacts from left to right. While designed to be read from left to right, this does not suggest a simple linear progression between these aspects. Numerous non-linearities and feedback loops will feature within the portfolio's operation beyond the pathways stemming from the original objectives.

Following the 2019 framework, the evaluation team anticipates the programme's results to occur within four broad time windows per project. Each project timeline and its results will vary, but these windows provide a general guide for the evaluation:

- The building phase covers 'activities' and 'outputs', coinciding with the completion of the infrastructure and expected to yield outputs 2–5 years post-award.
- The short-term (4–6 years post-award) relates to short-term outcomes.
- The medium-term effects (7–8 years post-award) involve a combination of medium-term outcomes and some early impacts.
- The longer-term objectives (9+ years post-award) are associated with programme impacts.

E.3.1. Summary of key changes

The evaluation team have made several adjustments to the 2019 ToC (**Error! Reference source not found.**):

- Visual changes have improved the ToC's readability. These include simplifying the links from objectives to outcomes and within impacts with block arrows to avoid 'arrow soup' and considering the numerous possible connections between these factors. The flow of the ToC now moves left to right, with arrows linking objectives to impacts, as highlighted in both business cases. Arrows have also been added from outputs to outcomes, illustrating direct influences as found in the 2022 business case.
- Notably, the commercialisation activity, absent in CM19, was introduced in CM22 and is now included here. The inputs section now includes bid writing support and the integrated transformation programme.
- Other additions include the procurement of three astronauts and the reflection of the levelling-up and net zero priorities through end-use cases and the application of space technology. The last

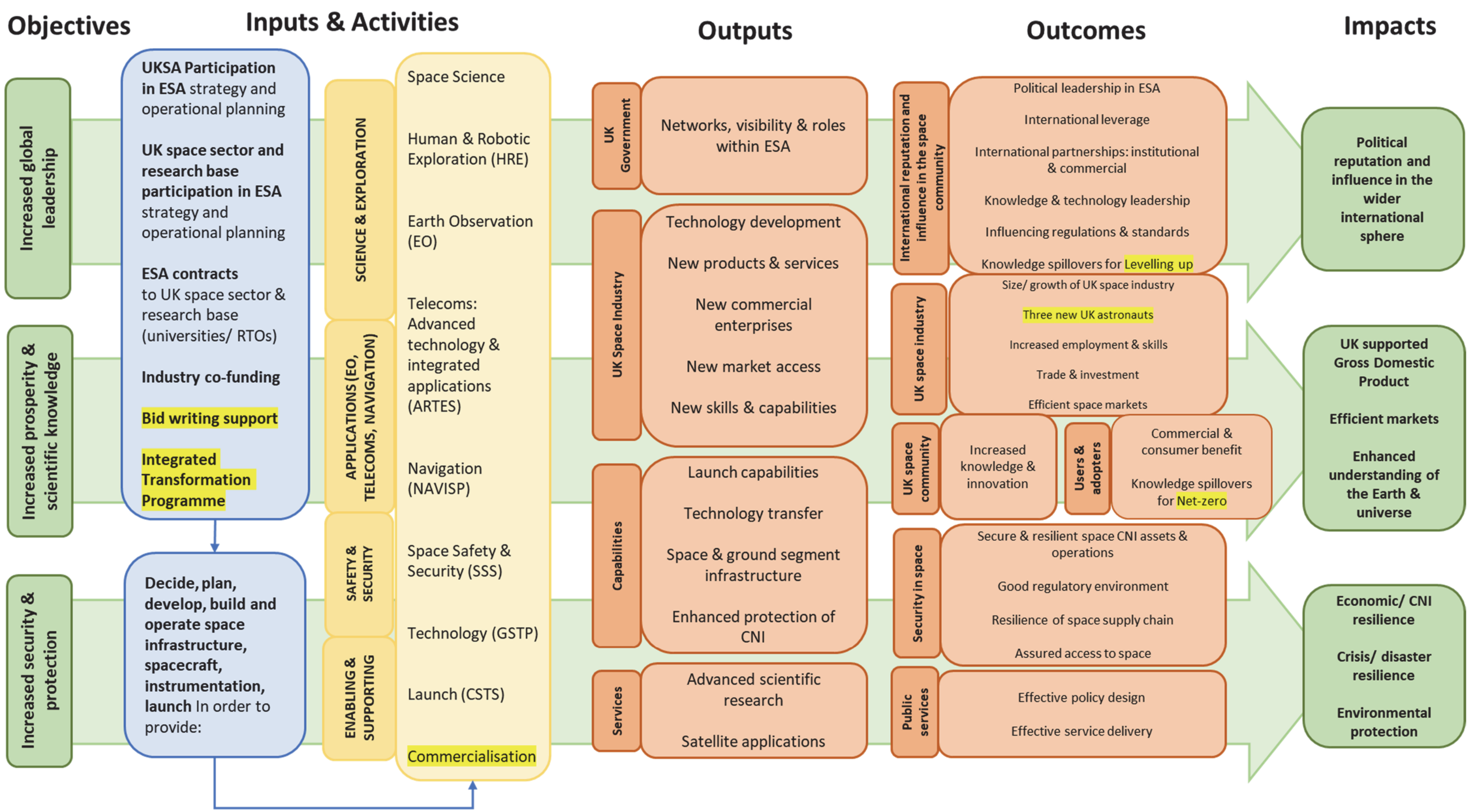
study explored the latter via modelling, with examples of ESA and UK Space Agency activities in understanding and measuring climate change.

Other subtle changes are not reflected here. For instance, investment decisions in the ToC have and will continue to evolve (e.g. EO investment being reduced, increases to HRE, now moving into investment in scale-up under 'other' programmes).

E.3.2. Systems-level ToC

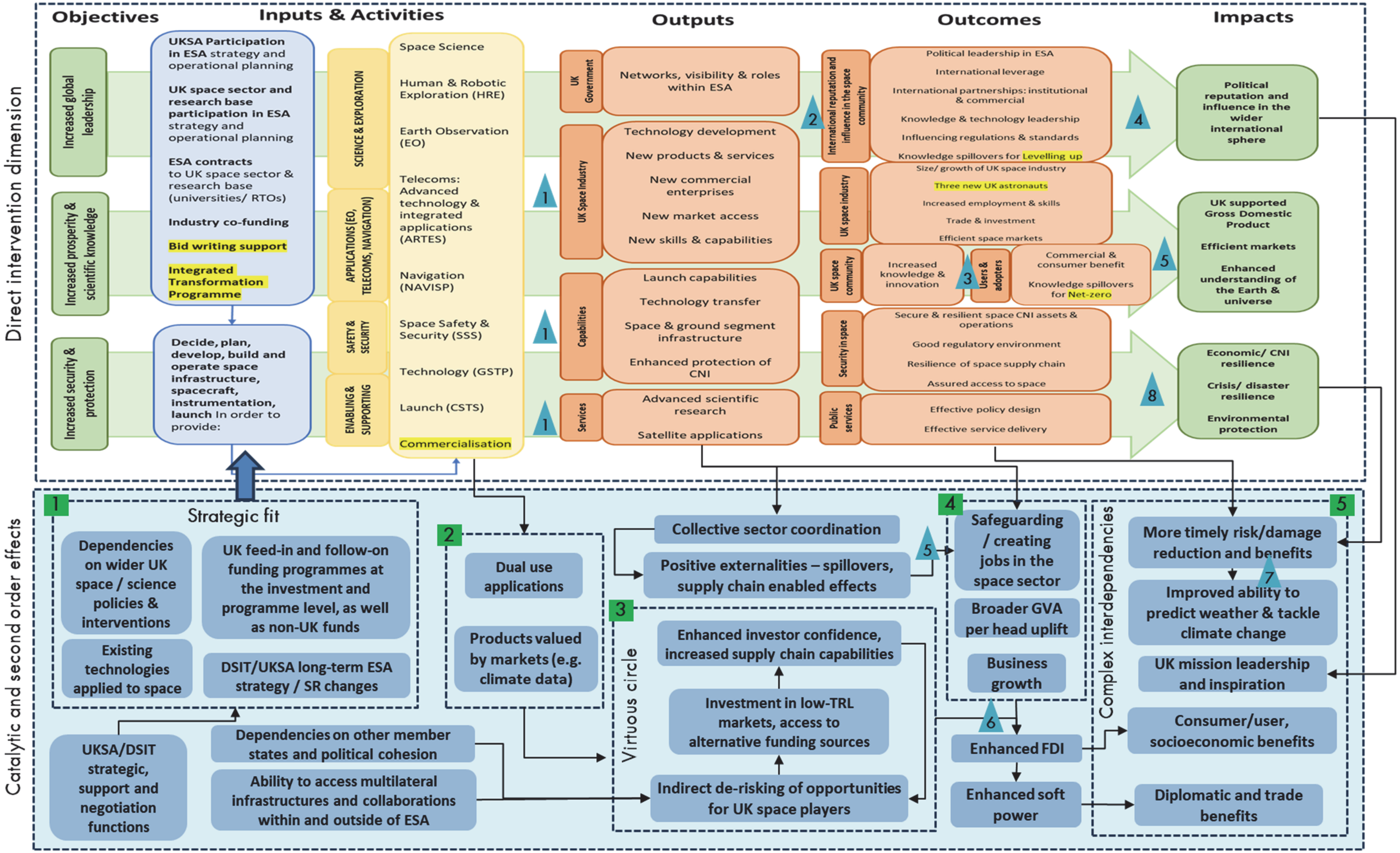
The evaluation team have also added a 'systems' view to the ToC, highlighting key feedback loops – the 'virtuous circles' that an intervention seeks to create/strengthen and the 'vicious circles' that it disrupts (**Error! Reference source not found.**). This aims to explicitly clarify the second-order/catalytic effects of external influences on ESA investment, which the team can subsequently test via its data collection. The following sections explain key sub-systems (numbers in green boxes) and impact pathways (numbers in blue triangles [some are repeated as they cover multiple parts of the ToC]).

Figure 2: Updated ToC – the UK's investments into ESA



Source: Refined from the evaluation of UK Space Agency's investments in ESA (Technopolis 2022). Note: additions are highlighted in yellow.

Figure 3: UK investments into ESA – system-level ToC



Source: RAND Europe. Note: Yellow highlight (new additions from 2021 ToC), key sub-systems (numbers in green boxes) and impact pathways (numbers in blue triangles)

The numbers in the green boxes in the systems-level ToC denote specific interdependencies/sub-systems:

1. **Strategic fit**: This articulates a Green Book emphasis on how a particular intervention is supported by others and, in turn, supports them. This understanding helps assess the strategic fit of the UK's ESA investments (e.g. by asking programme leads how coherently policy works to support their technology domain). UK Space Agency and DSIT actions (e.g. negotiation with ESA and within the UK Government on spending) influence the strength of the strategic fit aspect. In this case, there have been and continue to be many space (and space adjacent) policies and programmes that influence both the inputs (ESA strategy) and activities (other space R&D programmes), including the following:

   a) **Dependence on wider policy drivers,** including the CM19 business case, the NSS, the UK Innovation Strategy and the UK S&T framework. Specific elements of the S&T framework, such as the Space Workforce Action Plan, Private Investment Framework for Space, and Space Industrial Plan, are particularly relevant. Indirect policy drivers include the UK government's growth agenda to reduce regional inequalities and the commitment to achieving net-zero greenhouse gas emissions. It is important to note that there may be crossover activities or outcomes with efforts such as the Ministry of Defence (MOD)'s SKYNET Integrated Enterprise Solution (SKIES)/Skynet-6 programme, which are designed for dual civilian and military use. Non-UK interventions include many Horizon Europe work programme funds[53] and international agreements such as the Memorandum of Understanding (MoU) on Space Cooperation with South Korea.

   b) **Feed-in and follow-on programmes:** This shows the interdependencies between other UK investments to ensure the UK sector has the capabilities and technologies to remain competitive enough to deliver ESA programmes within the UK.

      i. At the portfolio level: Major UK Space Agency technology and capability-building investments are crucial. Examples include the National Space Technology Programme (NSTP), National Space Innovation Programme (NSIP), and Unlocking Space Business (USB) initiatives. Other examples include the Space Clusters Infrastructure Fund (SCIF) and Space Ecosystem funding, among others in the 'Unlocking Space' family. Newer UK Space Agency programmes also worth considering are Unlocking Space for Investment, Unlocking Space for Government and the national element of the Connectivity in Low Earth Orbit programme. Support for basic sciences, such as the Science and Technology Facilities Council's (STFC) space science and astronomy programme and some Strategic Priorities Fund (SPF) initiatives, also fall under this category.

      ii. At the domain/programme level: Several UK Space Agency initiatives influence the domain or programme level. For instance, the Centre for Earth Observation Instrumentation (CEOI) supports EO, the Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) programme, supported by the Natural Environment Research Council

[53] European Union Agency for the Space Programme (2024).

(NERC)/STFC and other departments such as the Department for Transport (DfT), the MOD and the Department for Energy Security and Net Zero (DESNZ), supports space weather and EO via SPF.

c) **Development of an ESA long-term strategy:** The development of ESA's long-term strategy is a significant aspect in guiding the direction of the UK's contributions to ESA's initiatives. This strategy helps to further align ESA's activities with the broader objectives and needs of the UK space sector.

d) **Existing technologies applied to space:** This refers to spin-in technologies developed in other wide-ranging industries and application areas that are subsequently adopted and customised for use in space and space-related activities. Examples of this were explored as part of planned data collection activities and highlighted in case vignettes.

2. **Assumed value of activities leading to outputs**: ESA contracts have one customer: ESA. However, those and others also produce solutions and insights for other applications, whether for defence, health or the arts, etc. The evaluation team assumes that ESA contracts' results are then valued by the markets they are sold to and/or attract investment for commercialisation into those markets. This aspect of the ToC was assessed by exploring companies' success in commercialising their ESA-contract-related work within and outside of their intended markets.

3. **Virtuous circle**: Based on the typical rationale for public R&I investment, the evaluation team assumes that de-risking space R&I in target markets for UK companies led to further initial investment in low-TRL markets from various funding sources. This then contributes to enhanced investor confidence and building supply chain capabilities in those markets, enabling further de-risking of those entities. This is reminiscent of how we might expect any new technology or sector to develop. In this case, the evaluation team looked to directly measure supply chain capability via our economic analyses (supply chain analysis, new entrants) supported by qualitative work within each programme area to assess to what extent the UK's ESA investment enabled this. This circle is supported by the assumed value of activities (see previous paragraph) and depends on continued investments and collaboration by/with other member states within and outside ESA. The team assessed whether those factors bolster the virtuous circle in our qualitative work.

4. **Economic drivers**: The sector's successful coordination to deliver on ESA contracts and activities and the associated positive externalities (e.g. stronger supply chain [i.e. increasing the productive capacity of the supply chain], spillovers to other sectors) then confers direct economic benefits both to participating companies and their supply chains. These factors relate closely to North Star metrics (e.g. jobs created/safeguarded), though our analysis will focus on Gross Value Added (GVA) per head uplifts. Alongside benefits from the virtuous circle, these lead to enhanced Foreign Direct Investment (FDI) after successful international collaboration and proven business models. FDI and UK-based investment should lead to more competitive UK bidders and supply chains and higher productivity. In turn, this could translate into soft power benefits in the scientific context, particularly around the UK's reputation internationally as a partner of choice for cutting-edge space

technology development. Data collection with businesses and wider ESA stakeholders will aim to assess some of these potential effects.

5. **Complex interdependencies**: The ToC outcomes and impacts lead to and are underpinned by second-order effects. These are naturally more difficult to define as they occur much further to the right of the ToC and rely on other benefits in the impact pathways. However, it is helpful to articulate these second-order impacts as they reflect both the ambitions laid out in the UK Space Agency's ESA business cases and wider policy documents, e.g. the NSS. A key benefit around more timely information leading to risk and damage reduction may occur due to the outcome of 'security in space', leading to a better ability to predict weather and the implications of climate change as those issues relate to critical national infrastructure (CNI). A consequence of soft scientific power and political reputation gains may be stronger UK mission leadership and wider inspiration effects. Socio-economic benefits may occur at any stage of the logic chain. However, they will be assessed at the aggregate level as to the overall changes and results brought about at the investment level and any wider benefits around trade/diplomacy. The analysis across tasks fed into this.

The next section outlines the key impact pathways through the ToC, by which the systems above influence and are influenced.

E.4. Impact pathways

This study has identified eight impact pathways in the logic chain (i.e. 'x' causes 'y' because of 'z'). These may be called impact/causal pathways, contribution claims and/or working hypotheses. In essence, they are the key statements of how the investment aims to work to bring about its original objectives. The M&E collected evidence against these statements to test their logic and provide a robust assessment of how well the investment has performed compared to its stated purpose, including how it might have achieved its goals via unexpected and alternative means.

Much of these were developed from strategic UK Space Agency documents, including the 2019 and 2022 business cases, CM 2019 and 2022 reports, and the logic described in the ToC. The statements below do not cover every potential impact pathway; they are just the most strategically significant (i.e. those relating to the main objectives of the UK's ESA investment from the CM22 business case).

E.4.1. Working hypotheses

These hypotheses represent the intended function of the UK's investment in ESA. These are mapped to the system level ToC (**Error! Reference source not found.**, see blue triangles with numbers corresponding to those below [some cover multiple parts of the ToC, hence are repeated]).

1. Access to, and the delivery of, ESA contracts ***lead to*** more and better technological advances than would the equivalent national investment on its own ***because of*** the level of technical support, user engagement and international networks of excellence available via ESA and the consequent economies of scale, scope and speed benefiting UK businesses.
2. The UK's investment in ESA and contractors participating in ESA programmes ***lead to*** UK contractors having better access to national and international collaboration than they otherwise

would outside of ESA membership ***because of*** the more favourable legal terms of ESA collaboration (e.g. no Value Added Tax (VAT) charged, international collaboration not subject to trade barriers or restrictions) that in turn allows for more knowledge and Intellectual Property (IP) sharing.

3. UK contractors' collaborations in, contributions to and direct involvement in ESA missions ***lead to*** knowhow and knowledge spillover into enabling supply chains and the UK economy as a whole ***because of*** capabilities built via mission involvement and support programmes and the UK's current political leadership in ESA ensures that the UK's strategic goals and industrial and academic capabilities are reflected in ESA strategy and planning.
4. The UK's political leadership in ESA and its international leverage and partnerships ***lead to*** bolstering the UK's status as a global science superpower, and its political leadership in space matters globally (e.g. in space standards and regulations) ***because of*** the reputational effect of the UK's ESA membership, its ESA roles and the fact that the UK's investments support future missions of the calibre of the James Webb Space Telescope (JWST) on which UK technology and expertise are showcased internationally.
5. Follow-on commercial activities and investments from ESA contracts ***lead to*** growth in the national space sector at a higher rate than might otherwise have been realised (employment, new skills, products and services, leading to a wide range of commercial and consumer benefits) ***because*** the investments were designed to build on existing UK strengths (as set out in the NSS), capturing new markets, and attracting and stimulating investment in the UK's regional growth space clusters, also via the growth of enabling supply chains.
6. Capability, coordination and capacity gains in the UK space sector ***lead to*** increased private UK and foreign investment for UK companies to bring products to market ***because of*** the UK's successes in influencing ESA to create investor forums and other activities that aim to support fundraising activities for UK contractors, additional support post-contract from ESA and the reputational benefits of working with ESA.
7. Investments into ESA, particularly via the EO programme, ***lead to*** a contribution to the UK's net zero agenda ***because*** the investments allow the continued development of Earth Observation infrastructure (Vigil, TRUTHS) that will inform our scientific understanding of climate change and monitor key climate change variables.
8. The development of outputs from programme activities, including services and infrastructure that can predict space weather, ***leads to*** improved crisis, economic and CNI resilience ***because of*** efforts such as Vigil, the Rapid and Resilient Crisis Response accelerators, and 4S.

E.4.2. Alternative pathways

An impact might occur through many different paths. Data collection tools were designed to be as inclusive as possible to all those paths (known and unknown). However, the evaluation team anticipated some alternative pathways based on prior experience evaluating R&I interventions and those scenarios explored in the CM business cases. The team explored these alternatives using qualitative self-reported counterfactual questions, e.g. 'Could you have achieved 'X' mission capability had you not been involved in this ESA-enabled collaborative contract?' This approach was used alongside the QED work planned as part of the VfM evaluation.

Alternatives to ESA for running optional programmes include:

- **National programmes**: The UK could focus on developing and managing its space initiatives independently or collaborating with other partners, such as the US.
- **Private sector partnerships**: Engaging with private companies in the space industry could provide access to new technologies and resources.
- **Alternatives to 'foot-in-the-door' commitments:** To achieve similar benefits as the current 'foot-in-the-door' amounts committed to some optional programmes, the UK could consider:
    - Bilateral agreements with other space-faring nations to collaborate on specific projects.
    - Fostering domestic innovation through targeted investments in research and development.
- **Early warning signs for reevaluating investments:** To detect early warning signs that an investment may no longer provide returns, the DSIT/UK Space Agency may monitor market conditions or technology trends that may impact the project's viability and shifts in national or international priorities that could affect funding or collaboration opportunities.

Three hypothetical indicative scenarios for the UK's involvement in space programmes are:

- **Stopping national programmes and 'going all in' on ESA:** This approach would involve fully committing to ESA-led initiatives, potentially benefiting from increased collaboration and resource sharing. However, it may limit the UK's ability to pursue its specific national priorities. Though improbable, this scenario is helpful to understand what steps between current practice and this extreme might look like, e.g. what would a significantly increased investment in ESA look like?
- **Exiting ESA and focusing on national programmes with other partners:** In this scenario, the UK would withdraw from ESA and pursue space initiatives independently or with partners like the US. This approach could provide more control over national priorities but may reduce access to resources and expertise available through ESA. Again, this is an unlikely scenario, but it provides the language to ask stakeholders what unique benefits ESA brings alongside existing bilateral cooperation that could not otherwise be achieved.
- **A middle ground – adjusting optional spending:** This scenario involves reevaluating and refocusing optional spending within ESA to concentrate on select domains. This approach could balance leveraging ESA's resources and expertise while maintaining the flexibility to pursue national priorities. This scenario reflects the current approach to ESA membership and the one the evaluation will most likely inform.

E.5. Contextual factors

Underpinning the system-level ToC and associated pathways are the ever-changing market barriers, assumptions, risks and drag factors affecting investment outcomes. We accounted for these contextual factors in our qualitative data collection and desk research in particular programme areas and when such factors are cross-sector (e.g. inflation). We also considered these factors as part of the overall contribution analysis in articulating how much these factors have affected the successes of the UK's contribution to ESA. In practice, most of these factors likely play a part in our interpretation of the economic evaluation and the analysis itself.

E.5.1. Market barriers/enablers

Regarding public intervention in the space industry, barriers/enablers include:

- **Public goods not valued by markets**: This can be mitigated by outputs such as improved climate data.
- **Positive externalities:** These include spillovers into the UK economy from ESA work. Negative externalities can include factors such as space debris.
- **Information and coordination failure**: This involves asymmetric information and collective action issues.
- **Market-driven myopia / short-termism**: This is not yet highlighted as a risk in this case but will vary across programmes.
- **Enablers of public intervention: UK Space Agency Investment:**
    - In the context of the space industry, **the supply chain needs to be 'top and tailed'**, addressing both ends of the development spectrum. SMEs express interest in scaling up and venturing into Ground Segment Test Equipment (GSTE) low-TRL areas. These areas require significant investment to develop and mature the technology. Investing in low-TRL areas to diversify markets is a relatively new approach. This strategy involves nurturing innovative technologies in their early stages to broaden the range of potential market opportunities.
    - The UK Space Agency is pivotal in enabling public intervention in the space industry. The UK Space Agency's investments can lead to **more timely risk and damage reduction** than without intervention. It can also result in more timely benefits for the UK space industry. Moreover, the UK Space Agency's involvement indirectly de-risks opportunities for UK players. While this de-risking might be less direct than in the UK's programmes, it operates on the same principle. By investing in and supporting the development of space technologies, the UK Space Agency helps to mitigate the risks that individual companies might face, thereby encouraging greater innovation and growth within the UK's space industry.

E.5.2. Key assumptions

This section outlines the key assumptions about the UK's participation in ESA and its impact on the UK space industry. These assumptions include leveraging international government space R&D spending, reputational benefits for contractors, sustained benefits from past investments, alignment with the NSS and the expectation of positive returns:

- **Leveraging international government space R&D spending:** A central assumption is that the UK's participation in ESA will help UK entities compete for and win R&D contracts tendered by other national governments outside ESA programmes. This is particularly significant when collaboration with the US is involved, as it allows the UK to access a larger pool of resources, expertise and funding opportunities.
- **Reputational benefits for contractors:** It is assumed that contractors' involvement in ESA projects will leverage reputational and standard economic benefits. Participation in ESA initiatives can enhance a contractor's credibility, brand value and attractiveness to potential clients and partners.
- **Sustained benefits from past investments:** The assumption is that past investments in the space industry will continue to reap benefits over time, aligned with the original long-term strategic objectives. However, questions may arise regarding whether these benefits will persist with or without further support, the potential for investments or intellectual property to be taken overseas, and the implications of acquisitions by non-UK entities.
- **Alignment with the NSS:** It is assumed that activities within ESA frameworks will align with the goals outlined in the NSS based on areas of national capability. Ensuring this alignment continues is crucial for maintaining the strategic relevance of the UK's involvement in ESA.
- **Positive returns and minimal negative effects:** The final assumption is that the UK's participation in ESA will yield positive returns, with minimal adverse effects from displacement (e.g. increased company profits with no increased productivity) or negative spillovers.

E.5.3. External influences, risks and drag factors

This section examines the external influences, risks and drag factors that impact the UK space industry. These include investment risk challenges, constraints on upstream supply chain companies, reliance on ESA contracts, changes to the UK Space Agency budget, reputational and collaborative risks, under-return in the geo-return, process drag and duplication, overly optimistic impact forecasts by contractors and various drag factors:

- **Investment risk challenges:** Investment risks significantly impact the private sector's capital investment provision in the space industry. These challenges stem from technical and commercial uncertainties and risks that can deter private sector investment.
- **Constraints on upstream supply chain companies:** Companies in the upstream supply chain can only enter certain programmes that provide payload and platform confidence. This limitation can restrict the opportunities available to these companies and impact their growth potential.
- **Reliance on ESA contracts:** A large proportion of the industry relies on ESA contracts and other public contracts. This dependency can expose companies to potential risks associated with changes in public funding or strategic priorities.
- **Changes to the UK Space Agency budget:** Changes to the UK Space Agency budget due to spending reviews and internal priorities, such as the unlikely funding increase for launch, can impact the level of support available for various space programmes and initiatives.

- **Reputational and collaborative risks:** Reputational and collaborative risks can arise when the UK agrees to undertake a project with another country and then backs out. While the UK Space Agency may be willing to take a reputational hit if justified, managing these risks is crucial for maintaining strong international partnerships and the UK's reputation.
- **Under-return in the geo-return and low representation of SMEs:** Challenges related to under-return in the geo-return and low representation of SMEs are a large risk to the UK space industry.
- **Process drag and duplication:** Process drag and duplication can occur with the authorisation of funding mechanisms. The UK Space Agency and ESA may ask companies for the same information, leading to inefficiencies and delays in the funding process.
- **Overly optimistic impact forecasts:** Contractors may be overly optimistic in their impact forecasts, which can lead to unrealistic expectations and potential misallocation of resources.
- **Drag factors:** Several drag factors can impact the UK space industry, including:
  - Impact time lags (in some areas) – slow speed of investment for commercialisation and operational delays, such as in launch.
  - Inflation.
  - Legal obligations on certain committed investments, which may be less beneficial but are obligatory.
  - Historical decisions, e.g. not investing in space transportation, may contribute to the UK lagging behind some member states in the space industry.

Annex F. Impact and process evaluation indicators

The following tables show how the evaluation was operationalised in terms of linking specific evaluation questions to data collection indicators and sources, as well as links to the contribution analysis.

F.1. Impact indicator framework

Table 24 outlines the key metrics used to address the impact evaluation questions. The data sources cited were purposefully broad and were refined as data collection methods were developed.

Baseline measures were set, as agreed with the UK Space Agency, for those where it was possible to do so (i.e. qualitative perceptions may only be baselined during interviews). However, in the case of measures like quantitative spend data, the metric was baselined more imminently.

Table 24: Impact evaluation framework

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
1. To what extent are the UK's investments in ESA programmes improving policy/decision making in the UK?	a. To what extent can the evidence available underpin the future appraisal of specific programmes ahead of future Spending Reviews and ESA investment decisions?	• Quality and quantity of data points or evidence-based findings generated from the UK's investments in ESA programmes. • The number of instances where this evidence has been used in past Spending Reviews and ESA investment decisions. • Citations of ESA investments and their outputs in space policy documentation e.g. the Space Industrial Plan. • Qualitative perceptions around the potential utility of the M&E evidence having future policy influence (i.e. on future Spending Reviews and ESA investment decisions).	• CM business cases • Past evaluations • Interviews	Hypothesis 5 – specifically the policy decisions that underpinned the investment choices.
2. Capability and capacity building	a. What difference has the UK's ESA investments made to date in inspiring, attracting, and retaining talent to upskill the UK workforce?	• The number of jobs retained and created in the UK space sector attributed to the UK's ESA investments. • Qualitative perceptions around the benefits of the UK's ESA investments towards inspiring, attracting, and retaining talent to upskill the UK workforce. • Qualitative perceptions around the effectiveness of training programmes, internships and fellowships, and the retention rates of individuals in the UK space sector.	• CM business cases • Past evaluations • Domain level documentation • Interviews with key stakeholders • Business Structure Database • Annual Business Survey	Hypothesis 5 – evidencing growth in terms of talent attraction.
	b. Have industrial participants developed increased capabilities to develop new space technology, products and missions?	• Increases in TRLs and commercial readiness levels (CRLs) in specific technology areas. • The number of new products, and progress towards missions developed by industrial participants due to the UK's ESA investments. • The increase in the number of patents or IP filed by industrial participants in the space sector. • The number of new collaborations or partnerships between industrial participants and research institutions or other organisations in the space sector. • The increase in the number of skilled employees or experts hired by industrial participants in the space sector. • Qualitative perceptions around capability increases.	• Documentation review (Domain level documents, CM business cases, annual reports, project reports) • Interviews with key stakeholders (industrial participants, research institutions) • Business Structure Database • Annual Business Survey	Hypothesis 3 – evidencing knowhow and knowledge spillover, and whether capabilities have indeed been built because of ESA involvement.

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
	c. To what extent have the UK's ESA investments led to a greater quantity or quality of international collaborations and partnerships?	• The number of new international collaborations and partnerships established as a result of the UK's ESA investments. • The proportion of these collaborations and partnerships that have resulted in successful projects, technology development, or knowledge exchange. • The number of joint research projects or publications resulting from these international collaborations and partnerships. • Qualitative perceptions around the level of satisfaction with the outcomes of international collaborations and partnerships. • The extent to which these international collaborations and partnerships have contributed to the UK's space sector growth or recognition.	• Document review (Domain level documents, business cases, past evaluations, project reports) • Interviews with key stakeholders (industrial participants, research institutes and government agencies – UK Space Agency & ESA).	Hypothesis 2 – evidencing whether access to collaboration has improved or not and the mechanism underpinning that.
	d. To what extent has it enhanced the reputation and influence of UK space, industry and research institutions?	• The number of mentions or acknowledgments of UK space, industry, and research institutions in international space-related publications or media. • The increase in international collaborations and partnerships involving UK space, industry, and research institutions. • Qualitative perceptions of the reputation and influence of UK space, industry, and research institutions.	• Document review (ESA documents, domain level documents, previous evaluations). • Interviews with Key stakeholders (UK Space Agency, ESA, industry, international stakeholders).	Hypothesis 4 – measuring whether any change to the UK's status is because of ESA membership.
	e. To what extent have UK organisations been able to leverage contracts and investment opportunities, including collaborations and knowledge-transfer?	• The number and value of contracts awarded to UK organisations due to the UK's investments in ESA. • The number of additional investments attracted by UK organisations as a result of their involvement in ESA programmes. • The number of new collaborations and knowledge-transfer activities initiated by UK organisations in the context of ESA programmes. • Qualitative perceptions around the proportion of these collaborations and knowledge-transfer activities that have resulted in successful projects, technology development, or capacity building. • Qualitative perceptions around the level of stakeholder satisfaction with the contracts, investments, collaborations,	• Document review (Domain level documents, CM Business cases, past evaluations, project level reports) • Interviews with key stakeholders (UK organisations & industries, research institutes, UK Space Agency) • Georeturn data	Hypothesis 6 – whether investments are indeed because of specific ESA benefits (e.g. reputation) and/or UK follow-on support.

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
		and knowledge-transfer opportunities leveraged by UK organisations.		
	f. What difference has the UK's ESA investments made so far in stimulating innovation and commercial opportunities through data science and space technology?	• The number of new innovative products, services, or technologies developed by UK organisations as a result of the UK's investments in ESA (including examples of TRL increase) • The number of new commercial opportunities or market segments accessed by UK organisations due to their involvement in ESA programmes (including examples of CRL increase). • The increase in the number of patents & IP filed by UK organisations. • The number of new collaborations or partnerships between UK organisations and other stakeholders in data science and space technology sectors. • Qualitative perceptions relating to increased innovation and commercial opportunity.	• Document review (CM Business cases, domain level documents) • Interviews with key stakeholders (UK Space Agency, UK industries)	Hypothesis 5 – measuring the extent to which markets and sectors have grown and why. Hypothesis 1 – evidencing if and how technological advances have been supported via ESA.
3. To what extent has the UK's ESA investments contributed to the growth of the UK space sector?	a. To what extent has the UK's ESA investment supported the development of the space sector supply chain?	• The number of new suppliers or subcontractors in the UK (originating in and/or moving to the UK) space sector as a result of the UK's investments in ESA. • The increase in the revenue or market share of UK suppliers or subcontractors in the space sector due to ESA investments. • The number of new collaborations or partnerships between UK organisations and suppliers or subcontractors in the space sector. • Qualitative perceptions related to the impact of the UK's ESA investments on the development of the space sector supply chain. • The number of new products, services, or technologies developed by UK suppliers or subcontractors as a result of the UK's investments in ESA.	• Document review (size and health surveys) • Interviews with key stakeholders (UK Space Agency, UK industries) • Business Structure Database • Annual Business Survey	Hypothesis 3 – scale of supply chain improvements (e.g. in productivity) and how ESA programmes enabled this over other factors.

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
	b. To what extent has the UK's ESA contribution been able to incentivise private sector investment in the UK space sector?	• The amount of new private sector investment attracted to the UK space sector • The number of new private sector investors entering the UK space sector due to the UK's investments in ESA. • Qualitative perceptions surrounding the impact of the UK's ESA investments on attracting private sector investment. • The number of new projects, products, services, or technologies developed by UK organisations as a result of private sector investment attracted by the UK's ESA contributions.	• Document review (CM Business cases, past evaluations, domain level documents) • Interviews with key stakeholders (UK Space Agency, UK industries)	Hypothesis 6 – whether investments are indeed because of specific ESA benefits (e.g. reputation) and/or UK follow-on support
	c. To what extent is industry more willing to invest in space R&D activities as a result of the UK's contribution to ESA?	• The amount of industry investment in space R&D activities as a result of the UK's investments in ESA. • The number of new industry investors participating in space R&D activities due to the UK's investments in ESA. • The number of new R&D projects initiated by industry as a result of the UK's investments in ESA. • Qualitative perceptions around the impact of the UK's ESA investments on incentivising industry investment in space R&D.	• Document review (CM Business cases, past evaluations, domain level documents) • Interviews with key stakeholders (UK Space Agency, UK industries)	Hypothesis 6 – whether investments are indeed because of specific ESA benefits (e.g. reputation) and/or UK follow-on support
4. To what extent has the UK's ESA investments contributed to the development of technological advancements?		• The number of new technologies or innovations developed as a result of the UK's investments in ESA (Including TRL development) • The increase in the number of patents & IP filed by UK organisations in relation to these new technologies or innovations. • The number of these new technologies or innovations that have been successfully commercialised or adopted in the space sector (including CRL increase). • Qualitative perceptions around the contribution of the UK's ESA investments to technological advancements. • The number of research papers or publications citing the use or impact of these new technologies or innovations.	• Document review (CM Business cases, past evaluations, domain level documents) • Interviews with key stakeholders (UK Space Agency, UK industries)	Hypothesis 1 – evidencing if and how technological advances have been supported via ESA.
5. What socio-economic benefits have been realised from technological development and resulting solutions, derived from the UK's ESA investments?		• The number of new jobs created in the UK space sector and beyond. • The increase in the revenue or market share of UK organisations in the space sector.	• Document review (CM Business cases, past evaluations, domain level documents)	Hypotheses 6&7 – whether and how socio-economic benefits

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
		• The number of technological developments and solutions that have led to improvements in societal or environmental conditions (e.g., through applications in climate change monitoring, disaster management, etc.) • Qualitative perceptions around the socioeconomic benefits derived from these technological developments and solutions. • Research papers or publications citing the socioeconomic benefits of these technological developments and solutions.	• Interviews with key stakeholders (UK Space Agency, UK industries)	have occurred as a result of ESA membership, around net-zero, CNI resilience etc.
6. To what extent would the benefits resulting from the UK's ESA investment have come about in its absence, or by other means? (Counterfactual)	a. What alternative scenarios exist as to how the UK invests in ESA, and, as far as is possible, what would have been the benefits and drawbacks of implementing each over the last CM period? (e.g. All in on ESA, cutting ties with ESA, somewhere in between).	• Qualitative perceptions around the uniqueness or irreplaceability of the benefits derived from the UK's ESA investments. • Qualitative perceptions of alternative investment scenarios • Qualitative perceptions around the feasibility and desirability of each alternative scenario	• Interviews with key stakeholders (UK Space Agency, ESA, UK industries) • Document review (CM Business cases, past evaluations).	All – considering the counterfactual where appropriate and robust, as well as self-reported.
7. Overall, what can be learned from this M&E exercise that analysts in the UK Space Agency, DSIT and other government decision makers can use to aid and improve future investment and programming decisions?		• Lessons learned identified from this M&E exercise, including successful strategies, challenges encountered, and areas for improvement. • Lessons learned that can be integrated into the decision-making processes of the UK Space Agency and DSIT. • Qualitative perceptions surrounding the usefulness and applicability of this M&E exercise and lessons learned in improving future investment and programming decisions.	• M&E reports and findings from this exercise. • Interviews with key stakeholders (UK Space Agency, DSIT).	All

Source: RAND Europe analysis.

F.2. Process indicator framework

Table 25 presents the measures by which the process evaluation questions were answered.

Table 25: Process evaluation framework

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
1. How has the UK Space Agency governed, set up, supported and enabled the delivery of aligned and complementary UK-ESA programmes/projects?	a. Was the UK Space Agency able to implement the portfolio as intended? Including support activities (e.g. ESA bid writing support)?	• The number and type of projects, programmes, and support activities implemented by the UK Space Agency as part of the portfolio. • The proportion of projects, programmes, and support activities that have been implemented as planned or intended. • The number of deviations or changes made during the implementation of the portfolio and their reasons. • Qualitative perceptions around satisfaction with the implementation of the portfolio by the UK Space Agency.	• Document review (UK Space Agency portfolio level documents, business cases, past evaluations, annual project reports) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Hypothesis 1-3 – specifically the 'because' aspects of the statements, ensuring the mechanisms to deliver impact actually occurred.
2.	b. To what extent is the portfolio of investments relevant to national priorities in innovation and research (i.e. NSS)?	• The number and type of projects, programmes, and support activities in the portfolio that align with the priorities of the NSS. • The proportion of the portfolio's total investment that is allocated to projects, programmes, and support activities aligned with the NSS. • Qualitative perceptions around the relevance of the portfolio to national priorities in innovation and research.	• Document review (UK Space Agency portfolio level documents, CM business cases) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Hypothesis 5 – focusing on the latter third of the statement around alignment to the NSS.
3.	c. Was the programme implemented as intended across the domain areas?	• The number and type of projects, programmes, and support activities implemented across the domain areas as part of the programme. • The proportion of these projects, programmes, and support activities that have been implemented as planned or intended across the domain areas. • Qualitative perspectives around the satisfaction of the implementation of the programme across the domain areas.	• Document review (UK Space Agency portfolio level documents, domain level documents, CM business cases) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Hypothesis 1-3 – As above, with a focus on the domain level.

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
4. Are the current funding mechanisms associated with ESA investment appropriate for achieving the programme's aims?	a. What alternative funding approaches exist that could represent better value for money, and what are their strengths and weaknesses compared to the current funding model?	• Types of alternative funding approaches identified. • Qualitative perceptions around the estimated value for money of each alternative funding approach, including their potential costs, benefits, and overall impact. • Qualitative perceptions around the strengths and weaknesses of each alternative funding approach in comparison to the current funding model. • Qualitative perceptions around the feasibility and desirability of each alternative funding approach.	• Document review (UK Space Agency portfolio level documents) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Elements of the 'because' elements around delivery. Also counterfactual and alternative hypotheses for funding options.
5. To what extent does the UK space sector view the UK's ESA contributions and support mechanisms positively? How has this changed over time?	a. What elements of ESA investment work well and not so well for the sector?	• Qualitative perspectives on the type of elements of ESA investment that work well for the sector, including funding mechanisms, project selection, and support activities. • Qualitative perspectives on the type of elements of ESA investment that do not work well for the sector, including challenges, inefficiencies, or areas for improvement. • The level of stakeholder satisfaction with the elements of ESA investment that work well and not so well for the sector. • The number of successful projects, programmes, or support activities that can be attributed to the elements of ESA investment that work well for the sector. • The number of projects, programmes, or support activities that faced challenges or inefficiencies due to the elements of ESA investment that do not work well for the sector.	• Document review (project and domain level documents) • Interviews with key stakeholders (participating organisations)	Mainly 1-6 as to the delivery and support mechanisms, and how these work to deliver impact.
	b. To what extent has ESA investment successfully driven private sector investment in space? How could this be improved?	• The amount of private sector investment attracted to the UK space sector as a result of ESA investments. • The number of new projects, products, services, or technologies developed by UK organisations as a result of private sector investment attracted by ESA investments. • Qualitative perceptions of the impact of ESA investments on attracting private sector investment.	• Document review (domain level documents, past evaluations) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Hypothesis 6 – specifically how investment has been driven and mechanisms.

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
6. To what extent have the UK's ESA investment priorities adjusted and adapted to changing political landscapes, technological needs and sector needs?		• The number and types of adjustments made to the UK's ESA investment priorities in response to changing political landscapes, technological needs, and sector needs. • The proportion of the UK's ESA investments allocated to projects, programmes, and support activities that address these changes. • Qualitative perceptions of the adaptability of the UK's ESA investment priorities to changing contexts. • The number of successful projects, programmes, or support activities that can be attributed to the UK's ESA investments that have adapted to changing political landscapes, technological needs, and sector needs. • The number of challenges or missed opportunities faced by the UK space sector due to the UK's ESA investment priorities not adapting to changes.	• Document review (domain & project level documents, CM business case, past evaluations) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Hypothesis 5 – how not only NSS goals were aligned to, but wider technology and sector needs also.
7. To what extent has the UK Space Agency and DSIT's communications around ESA investments been effective in both attracting suppliers to apply for ESA contracts, and in disseminating the results of ESA investments to the public and wider government?		• The number of suppliers applying for ESA contracts as a result of the UK Space Agency and DSIT's communications. • The level of awareness and understanding of the results of ESA investments among the public and wider government • The number and type of communication activities undertaken by the UK Space Agency and DSIT related to ESA investments. • Qualitative perceptions of satisfaction with the effectiveness of the UK Space Agency and DSIT's communications around ESA investments.	• Document review (CM business case, dissemination material, past evaluations) • Analysis of media coverage, website analytics or feedback. • Interviews with key stakeholders (UK Space Agency, participating organisations)	Hypothesis 4 – how effective the reputational mechanism is for attracting suppliers and for dissemination.
8. How has the UK Space Agency / DSIT used monitoring, evaluation and learning to drive continuous improvements in planning and delivering the UK's contributions to ESA?	a. To what extent did problems/issues arise during the delivery or M&E of the portfolio and how could they be addressed?	• The number of and types of previous M&E work that has been conducted. • The number and types of problems identified by previous M&E. • The impact of these problems or issues on the overall success or effectiveness of the portfolio. • The number and type of actions taken, or strategies implemented to address these problems or issues. • Qualitative perceptions around the level of stakeholder satisfaction with the effectiveness of the actions taken or strategies implemented to address the problems or issues.	• Document review (Past evaluations) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Mainly 1-6 as to the delivery and support mechanisms, and how these work to deliver or hinder impact.

Evaluation question	Sub-evaluation question	Indicator	Data source	Primary working hypotheses link
9.	b. What changes could be made to internal processes to improve delivery and the realisation of benefits?	• The number and type of potential improvements or strategies identified to prevent or mitigate similar problems or issues in the future. • The estimated impact of these improvements or changes on the delivery and realisation of benefits. • Qualitative perceptions around the feasibility and desirability of implementing these improvements or changes to internal processes.	• Document review (Past evaluations) • Interviews with key stakeholders (UK Space Agency, participating organisations)	Based on the above row, what might be reasonably expected to change within the UK Space Agency's power.
10. To what extent are the benefits the UK achieves through its investments in ESA a direct result of its membership?	c. Could similar outcomes and impacts be achieved through national programmes or bilateral partnerships with other Space-faring nations? If so, at what cost?	• The level of stakeholder perception of the feasibility and desirability of achieving similar outcomes and impacts through national programmes or bilateral partnerships with other Space-faring nations. • The number of successful projects, programmes, or support activities that have been implemented through national programmes or bilateral partnerships with other Space-faring nations and resulted in similar outcomes and impacts.	• Desk research • Interviews with key stakeholders (UK Space Agency, participating organisations)	All hypotheses will test overall contribution. Alternate hypotheses will explore the question of similar outcomes.

Source: RAND Europe analysis.

Annex G. Scientometrics report

G.1. Objectives

Scientific publications serve as additional sources for indicators of scientific performance and benefits from ESA-funded programmes. This methodological Annex provides an overview of scientometric analysis to explore the quantity and quality of the UK's ESA-funded scientific outputs in this study.

Scientometrics has been a part of previous evaluations of the UK Space Agency's contributions to ESA. However, previous scientometrics work has been somewhat limited regarding the methods accepted by academic scienometricians.[54] This report offers a scientometric evaluation of the UK's contributions to ESA, specifically the publications resulting from them, employing a simple and replicable methodology drawing on best practices within the field.

G.2. Selection of ESA-relevant papers

The first task was to select relevant papers (i.e. scientific publications) for analysis.[55] One option was to consult Gateway to Research (GtR), a repository of publications that UK grant recipients report to UK Research and Innovation (UKRI). As such, this implies strong attribution to the funding interventions that support those grants. This study could not rely on this dataset because it explored publications funded by a non-UK research institution, ESA. Instead, this study relied on funder acknowledgements – fields within the publications meta-data that indicate the specific funding source/contract. This indicator is the strongest form of attribution outside reporting databases like GtR. However, there are limitations to this approach, including irregular reporting of acknowledgements (e.g. different naming conventions) or a lack of reporting. We have used iterative searching methods to identify different ways of acknowledging ESA funding, including by contract number and programme name.

Additionally, while previous evaluations have used Scopus and Dimensions,[56] papers were selected for this study by searching OpenAlex, an open-source bibliographic database, for publications reporting ESA

[54] There are a few exceptions to this. For examples, see: Koksalmis, Emrah., & Gulsah Hancerliogullari Koksalmis (2023).

[55] Other reports have done something similar, which form the basis for our work here. Technopolis (2022) conducted a previous evaluation of the impact of the UK Space Agency, for which they matched ResearchFish data to dimensions, finding 3,098 articles and book chapters.

[56] Technopolis Group (2022c).

funding.[57] OpenAlex was chosen due to its completeness and size relative to other bibliographic databases, such as Scopus and Web of Science (WoS).[58,59] This is the case across the board but is especially true for open access (OA) publications,[60] non-English publications (which sets it aside from, for instance, Scopus and WoS, which have substantial and well-documented English-language biases and is especially important for an evaluation of an international research funder such as ESA).[61] OpenAlex also has the advantage of being open source, enabling data sharing with clients and the public so research evaluations can be open to replication and response.

A starting dataset was downloaded on 26 September 2024 from OpenAlex, resulting in 8,114 results.[62] However, this number was lower than expected compared to previous analyses, so we supplemented OpenAlex data with WoS and Scopus data. Doing so was a response to the limitations of OpenAlex in terms of funder data (i.e. acknowledgements). Whereas Scopus and WoS extract funding data from the authors' funder acknowledgement, funding information in OpenAlex is drawn from FundRef, an open repository of funding information which, while freely accessible for an open-source project like OpenAlex, is limited. This may have certain disadvantages regarding the database's coverage of certain funding agencies. For instance, we explored the papers funded by international space funders, finding that OpenAlex consistently reports fewer papers for these funders than Scopus and WoS. In the case of ESA funding, Scopus reported 24,173 ESA-funded records, and WoS reported 18,260, compared to the 8,114 papers attributed to ESA in OpenAlex at the time of data collection (this has reduced further since, and is 7,790 at the time of writing).

We also downloaded data from Scopus and WoS and extracted DOIs from all papers reporting them to address this discrepancy. Papers were collected from OpenAlex on 27 November 2024, which matched these DOIs. We added these papers to the original database of papers reporting ESA funding in OpenAlex and removed duplicates, resulting in **a final database of 26,797 papers connected with ESA funding via funding acknowledgements.** We then used this dataset to compare the UK's publication outputs to those of other ESA member countries.

G.3. Data Analysis

Data analysis was based on three work streams, each with its own indicators building on existing scientometric work in RAND Europe and best practices in academic scientometrics.[63] These workstreams were developed to support the objectives described above.

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[57] Priem et al. (2022).

[58] Alperin et al. (2024).

[59] Céspedes et al. (2025).

[60] Simard et al (2024).

[61] Alonso-Alvarez & Jan van Eck (2024).

[62] OpenAlex Works (2025).

[63] See guidelines such as the Leiden Manifesto (Hicks et al) and the Swedish Research Council guidance for bibliometrics (Sjöstedt et al) which recommend a range of strategies drawn from in this methodology.

The three work streams were:

1. *Publication output* measures the number of publications in each programme area, with comparisons made across countries and institutions:
    a. The number of publications.
    b. The Compound Annual Growth Rate (CAGR), showing the average yearly growth of publications across a specified timeline.[64]
2. *Partnerships and collaboration* measure the amount of collaboration on scientific outputs:
    a. The International Collaboration Rate (ICR), showing a given country's share of publications, including at least one additional country.
    b. The top collaborators, countries and institutions, showing the most common collaborations between pairs of ESA countries.
3. *Impact* measures citations of scientific outputs as a proxy for impact on science:
    a. Field-Weighted Citation Impact (FWCI) by number of publications, country, ESA investment and research institution. FWCI is a measurement of citations that normalises the citations of a paper against papers from the same year and field. A score of '1' results from having the expected number of citations given the year and field, and anything below or above '1' indicates a lesser or greater than expected number of citations.[65]
    b. The share of Highly-Cited Publications (HCP).
    c. Citation Distribution Index (CDI).

The indicators above were used in different ways, following a comparative approach (benchmarking the UK against other ESA member countries) and an exploratory approach focused on the UK itself. For instance, while citations and publication volume were used to compare the UK to other countries, breaking down the citations by research themes was used to explore the UK's research.

Regarding **counting methods**, both full and fractional counting were applied selectively. Full counting and fractional counting are defined as follows:

- Full counting assigns a score of '1' to every author listed on a publication.
- Fractional counting assigns a fractional score to each author on a publication. For instance, on a publication with four authors, each author will be given a score of '0.25'.

Both are undertaken on different levels of analysis, reflecting different goals and assumptions. **Country-level counting** will assign a full or fractional count to every country with authors on the paper. For example, using a paper published by one French author and four Georgian authors from different institutions, full counting will assign a score of '1' to each country, and fractional counting will assign a score of '0.5' to each. However, counting on the level of authors or institutions will give them respective scores of '0.2' and '0.8'.

[64] Khojasteh et al. (2023).

[65] OpenAlex Support (2025).

Full counting is occasionally used to understand the overall visibility of a country or institution in the scientific literature (i.e. presence in the authorships of publications). In contrast, fractional counting provides an understanding of the relative contribution to a publication. The choice of counting methods can significantly affect how credit for publications is attributed. For instance, an institution might appear in a large number of publications, and full counting will give that institution credit for each of them despite only having a marginal contribution in terms of authorships. Fractional counting can help with this, although it will tend to inflate the value of single versus multi-authored publications. Additionally, fractional counting enables normalized citation indicators like FWCI since it will only count each publication as '1' regardless of its number of authors.[66] Given the different implications of these differing counting methods, both are used in this study, and the counting method is specified for each analysis.

Other counting methods can be applied and should be acknowledged. First-author counting can be used to attribute credit for a publication to the first author only and, therefore, their institution and country. We considered this approach for this study but abandoned it due to concerns about the inconsistency of the assignment of author positions among scientists.[67] Last author counting can be used analogously for last authors. In their evaluation of French biomedical research, SIRIS Academic used a version of last-author counting that applied full counting to all of the last-author's institutions and institution groups.[68] Doing so aimed to address the specificities of the French research ecosystem and researchers' tendency to report multiple affiliations and joined affiliations, where a university hospital with a distinct identity is formally included in an affiliation with the university within which it formally sits.

Regarding meta-data, some efforts were made to correct and complete missing or inaccurate meta-data in OpenAlex. To handle inconsistencies in the spelling of institution names, dictionaries of institutions were used to harmonise these into single versions. Doing so aimed to provide a more accurate account of the respective contributions of different institutions.

The decision was also made to rely on OpenAlex's recently implemented topic classification. Classifications in bibliographic databases often rely on rather rigid classifications of papers by topic, which, as SIRIS points out, may miss the nuances of modern interdisciplinary research.[69] OpenAlex's topic classification is based on a methodology developed by the Centre for Science and Technology Studies (CWTS) at the University of Leiden, which classifies papers based on co-authorship networks.[70] Scientometrics commonly uses this approach, assuming that groups of papers that frequently cite each other indicate a research field or community.[71] One advantage is that it inductively derives topics from publications rather than based on a deductive classification of academic disciplines, leaving room for interdisciplinary research fields and for the boundaries between scientific disciplines to shift over time.

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[66] Perianes-Rodriguez et al. (2016).

[67] Drivas (2024).

[68] SIRIS Academic (2023, 9 & 29).

[69] SIRIS Academic (2023, 10).

[70] Van Eck & Waltman (2024).

[71] Leng & Leng (2021).

G.4. Limitations

Several limitations should be acknowledged when using OpenAlex to identify ESA-funded research. First, each database has trade-offs regarding its representativeness of global scientific output, which can be diverse and difficult to record fully. While having numerous advantages over alternatives (as mentioned in E.2), OpenAlex faces a range of limitations. There are acknowledged issues with the meta-data of OpenAlex, including author affiliations. These result from OpenAlex being the successor of Microsoft Academic Graph (MAG) and prioritising completeness over curation (contra, for instance, the highly curated Scopus and WoS).

Likewise, the French government has provided funding for OpenAlex to improve the completeness of French scientific works, and some French research institutions, such as Sorbonne University, have ended their subscriptions to WoS.[72] Note, however, that this also presents a potential bias in the database and the position of the Centre national de la recherche scientifique (CNRS) as the most prolific institution in OpenAlex as of 14 November 2024 (with 2,615,000 works, compared with the next most prolific institutions, the Chinese Academy of Sciences, totalling 1,311,000, and the US Department of Energy, totally 1,239,000) may reflect OpenAlex's coverage of the CNRS works rather than genuinely greater scientific productivity. Since France is the second-highest contributing ESA member (accounting for more than 1/5th of all its contributions), it might be expected to lead among ESA-funded publications. However, the potential bias towards French publications in OpenAlex's coverage should still be understood as a limitation when evaluating its scientific output relative to other ESA countries.

Second, using funding acknowledgements as a method for associating research and a research funder is limited because this is self-reported data. There may be papers where ESA funding is incorrectly or not attributed. While there have been efforts to ensure the completeness of this data, such as the use of additional acknowledgements from Scopus and WoS described in E.2., it still provides a substantial limitation.

Alongside these limitations, it should be acknowledged that the UK Space Agency often funds research with the hope it will later be funded by ESA, which is an impact of UK participation in ESA not captured by looking at research directly funded by ESA. Therefore, there is a wider benefit from ESA involvement that ESA funding acknowledgements will not reflect, so it is important to note that UK Space Agency national funding and ESA funding are highly interlinked. We believe future research on benefits from ESA funding should examine this relationship.

[72] French Ministry of Higher Education and Research (2024); Sorbonne University (2023).

Annex H. Econometric analyses

H.1. Staggered Difference-in-Differences

To establish the causal impact of ESA funding on UK firms, we employed a staggered difference-in-differences (SDiD) approach. This approach is described in detail below.

H.1.1. Data

The following table provides an overview of the data used in this analysis, including longitudinal data on outcomes of interest from Office for National Statistics (ONS) sources. The ONS datasets described below provide annual data on the outcomes of interest for ESA contractors at a firm level. Firm-level data was compiled by linking the Companies House Reference number to the Interdepartmental Business Register (IDBR), which serves as the sampling frame for all ONS business surveys, including those identified below. The ONS datasets were accessed via the ONS Secure Research Service.

Table 26: Datasets used in the SDiD analysis

Dataset	Description and role in study
ESA contract data	The SDiD analyses utilised all available electronic historical data on ESA contracts awarded to UK firms. Additional historical contract data exists in ESA archives, but only in hardcopy, not digital form, so it could not be used. This data provided information on who awarded the contract, when it was awarded, its total value and its programme/activity area. For most ESA programme domains, the dataset covers the period 2012–2024. However, a longer time series was available for the HRE programme domain, covering the period 2000–2024. We incorporated this data to increase sample size and to capture longer-term effects. However, it is important to note that this earlier data represents only a subset of ESA contracts awarded during that period, and the sample size for these earlier years is relatively small and specific to this domain. As a result, impact estimates from 14 years onwards are based on a smaller and less representative sample and should be interpreted cautiously. Negative values in the contract dataset were removed during the data-cleaning process. These values represent subcontracts awarded to entities in other countries and are included by ESA to track geographic return. However, for this analysis (which focuses on the overall effect of ESA contracts on economic outcomes for UK firms), these subcontracts represent inefficiencies in converting financial resources from ESA contracts into firm-level economic benefits and, therefore, were not deducted from contract totals. Only ESA contract data up to 2022 was used for the analyses, as the Annual Business Survey (ABS) and BERD data needed for the SDiD analyses were only available up to this year. While the BSD is available up to 2023, the dataset was restricted to 2022 for consistency.

Business Expenditure on Research and Development Survey (ONS)	The BERD is an annual survey undertaken by the ONS comprising a panel of known R&D performers and a random probability survey of other firms to capture information on their expenditure on R&D activities and related measures. This was used to construct a longitudinal panel dataset describing the evolution of R&D activity amongst UK firms receiving ESA contracts. The BERD survey is delivered using random probability sampling. Consequently, the incomplete population coverage is assumed not to introduce systematic non-response or attrition bias.
Business Structure Database (ONS)	The BSD is an annual snapshot of the Interdepartmental Business Register, providing measures of employment and turnover for all firms registered for Value Added Tax (VAT) and Pay-as-you-earn (PAYE) and covers 99% of economic activity in the UK. The underlying data is drawn from administrative data (VAT and PAYE returns to His Majesty's Revenue and Customs (HMRC) and the ONS' regular surveys (the Business Register Employment Survey and the Annual Business Survey). The data (particularly observations of turnover) is associated with reporting lags, and in some cases, turnover measures may be two years out of date.
Annual Business Survey (ONS)	The ABS is an annual mandatory survey of large firms (with 250 employees or more) and a sample survey of small and medium-sized firms. The ONS uses the survey to generate estimates of total output (GVA) in the economy and other macroeconomic aggregates. However, the micro-data can be used to provide observations on GVA, capital investment and GVA per worker.

Source: ESA contract data, Business Expenditure on Research and Development Survey (ONS 2024b), Business Structure Database (ERC 2025), Annual Business Survey (ONS 2024c).

H.1.2. Counterfactual selection

To understand the additional effect of the programme, a counterfactual scenario needed to be developed describing what would have happened to successful ESA contractors had they not been awarded a contract. As contracts were allocated non-randomly, counterfactual selection must address potential selection bias issues, minimising systematic differences between data points in the treatment and counterfactual groups as far as possible.

In the case of ESA contracts, selection bias is potentially introduced at two stages:

- **Self-selection:** Applicants 'self-select' into the treatment by bidding for ESA funding. Applicants can be assumed to be systematically different from non-applicants in ways that would influence comparisons between the two groups. For example, non-applicants may not have the same technical capabilities as those applying for funding, representing unobserved characteristics of the applicant. Other factors that represent this issue include technology under development, anticipated profit levels, and managerial qualities. In this example, comparing successful ESA contractors to non-applicants risks an overestimation of effects.
- **Selection process:** Applicants are judged by ESA on their technical feasibility, scientific merit, value for money and ability to deliver. If these judgements are made successfully, successful entities would be expected to outperform unsuccessful applicants without funding, resulting in an overestimation of effects.

Identifying a control group in the context of ESA contractors is challenging. The space sector is highly specialised, and comparable firms are limited. In the absence of this data, we sought to build a counterfactual scenario using the Pipeline Design described below.

The Pipeline Design involves using businesses successful in securing a contract with ESA in later years as a counterfactual for businesses awarded a contract by ESA in earlier years, under the assumption that the effects of ESA contracts, if any, should be visible amongst the latter group first. The benefit of this approach is that businesses awarded contracts can be assumed to share similar unobserved characteristics, motivating their interest in securing a contract with ESA and determining their success.

This approach provides an unbiased estimate of the impacts if there are no systematic differences between businesses that secured contracts at different time points. However, results will be biased if there is a link between the timing of contract awards and the outcomes of interest, e.g. if there was a tendency to award contracts to businesses with greater growth potential in earlier years, then this would lead to an overstatement of the impacts associated with the awarding of ESA contracts.

H.1.3. Econometric approach

To investigate the direct impact of ESA contracts on UK companies, we implemented a SDiD approach. This involves the application of the extension of differences in different models to multi-period data, as proposed by Callaway and Sant'Anna (2020).[73] Including the application of the standard (two-period) difference-in-difference estimator for each cohort of firms and every post-treatment period (with the group of untreated firms – made up of yet-to-be-treated firms – forming the control group for these analyses). The estimated effect of the programme is established by taking a weighted average of these treatment effects.[74] The group-specific treatment effects can be averaged to present an overall treatment effect. The expression for the group-specific treatment effects is:

$$ATT(g,t) = E\left[\left(\frac{G_g}{E[G_g]} - \frac{\frac{p_g(X)C}{1-p_g(X)}}{E\left[\frac{p_g(X)C}{1-p_g(X)}\right]}\right) Y_t - Y_{g-1}\right]$$

Where the weights, p, are propensity scores, G is a binary variable equal to one for firms first treated in year g, and C is a binary variable equal to one for firms in the potential counterfactual group, which had not yet received a contract at time t. The equation above gives the treatment effect at time t for the group of firms receiving contracts at time g. It is computed by comparing changes in outcomes for the group of firms in receipt of a contract at time g between periods g-1 and time t to that of a control group of firms not yet treated by time t (C).

This approach follows the SDiD estimator proposed by Callaway and Sant'Anna (2020), which is specifically designed for settings where units (in this case, firms) are treated at different points in time. Rather than relying on a single control group of never-treated units or assuming homogeneous treatment timing, this method constructs comparisons that are specific to each treatment cohort and outcome period. In other words, for each group of firms treated in a given year, the estimator compares their post-treatment outcomes to the outcomes of firms that are still untreated at that time, ensuring that the control group is plausibly comparable. The estimated average treatment effect for each cohort and time period (ATT(g, t)) is then aggregated across cohorts to generate an overall average treatment effect. This approach improves

[73] Callaway & Sant'Anna (2020).

[74] Callaway & Sant'Anna (2020).

the robustness of causal inference by accounting for treatment heterogeneity over time and avoiding biases associated with more traditional two-way fixed effects estimators when treatment timing varies.

Our chosen DiD estimator for staggered treatment effects was implemented in STATA using the user-written command 'csdid'. Given the potential drawbacks of the two-way fixed effects models, these results are considered the most robust.

The validity of findings partly depends on a parallel trends assumption - that firms awarded contracts would have followed a similar trajectory in the absence of the programme to the counterfactual scenario. This cannot be fully tested, but support for this assumption can be obtained by implementing an 'event study' that tests whether firms receiving funding followed similar trends before receiving funding. The results of these tests are presented in Section H.1.4 below.

Control variables for all firm-level regressions included region, an indicator for whether the immediate owner was a foreign-owned company (dummy variable equal to one if a foreign entity owned the company) and broad industrial sector (UK SIC at the Section level).

H.1.4. Pipeline model validity and parallel trends

The pipeline approach outlined above will produce unbiased findings if there are no systematic differences between firms awarded funding at different points in time. This section provides an analysis of the observed characteristics of firms supported in different years to explore the validity of this assumption.

Our event study analysis confirmed that this assumption holds for all outcome variables except GVA, where we detect weak evidence of a pre-treatment difference in trends. Specifically, the average annual pre-treatment effect for GVA is statistically significant at the 95% confidence level ($p = 0.049$), although the confidence interval marginally includes zero (95% confidence interval: -0.001 to 0.019). While this suggests that the estimated treatment effects for GVA should be interpreted with greater caution, we note that the effects for this outcome remain directionally consistent with those observed for turnover and productivity, for which the parallel trends assumption is not rejected. It is also worth noting that the magnitude of the pre-treatment difference is relatively small, corresponding to a 0.9% annual uplift in GVA per £1 million in contract value.

The table below presents the results of these tests, showing the average annual pre-treatment effect – the average difference in outcomes in the pre-treatment period between those funded earlier and firms funded later. Assuming the parallel trends are true, this coefficient should not be statistically different from zero.

Table 27: Average annual pre-treatment effect for SDiD outcomes of interest

	Coefficient	p-value	95% CI lower bound	95% CI upper bound
Turnover	0.0150	0.280	-0.034	0.064
GVA	0.009**	0.049	-0.001	0.019
Employment	0.009	0.335	-0.033	0.052
R&D employment	0.010	0.379	-0.053	0.073
Turnover per worker	0.006	0.275	-0.012	0.024
GVA per worker	0.002	0.373	-0.011	0.0156

Source: Ipsos UK analysis. ***, **, and * indicate that the estimated coefficient is significant at the 99%, 95%, and 90% confidence levels, respectively.

H.1.5. Results

This section presents the full regression output from the SDiD analyses. The tables below include estimates of the average treatment effects by year (prefixed with Tp).

Table 28: Effect of £1m in ESA contract value on contractor firm turnover

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average annual treatment effect	0.082	0.011	7.646	0.000	0.061	0.103
Tp0	0.015	0.012	1.290	0.099	-0.007	0.038
Tp1	0.014	0.013	1.104	0.135	-0.010	0.038
Tp2	0.050	0.013	3.727	0.000	0.024	0.076
Tp3	0.063	0.014	4.385	0.000	0.035	0.091
Tp4	0.078	0.015	5.084	0.000	0.049	0.108
Tp5	0.075	0.016	4.558	0.000	0.043	0.107
Tp6	0.069	0.018	3.943	0.000	0.036	0.103
Tp7	0.071	0.019	3.744	0.000	0.034	0.107
Tp8	0.071	0.020	3.534	0.000	0.033	0.110
Tp9	0.078	0.021	3.731	0.000	0.038	0.118
Tp10	0.091	0.022	4.165	0.000	0.049	0.133
Tp11	0.095	0.023	4.181	0.000	0.051	0.138
Tp12	0.100	0.024	4.233	0.000	0.055	0.145
Tp13	0.102	0.025	4.140	0.000	0.054	0.149
Tp14	0.118	0.026	4.621	0.000	0.069	0.167
Tp15	0.114	0.027	4.279	0.000	0.063	0.164
Tp16	0.103	0.028	3.635	0.000	0.049	0.158
Tp17	0.096	0.030	3.150	0.001	0.037	0.154
Tp18	0.097	0.033	2.994	0.001	0.035	0.160
Tp19	0.107	0.035	3.072	0.001	0.040	0.174
Tp20	0.116	0.037	3.126	0.001	0.045	0.188

Source: Ipsos UK analysis.

Table 29: Effect of £1m in ESA contract value on contractor firm GVA

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average annual treatment effect	0.067	0.023	2.850	0.002	0.022	0.112
Tp0	0.013	0.010	1.290	0.099	-0.006	0.033

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp1	0.013	0.011	1.103	0.135	-0.009	0.035
Tp2	0.053	0.013	4.106	0.000	0.028	0.077
Tp3	0.069	0.014	4.835	0.000	0.042	0.097
Tp4	0.085	0.016	5.306	0.000	0.054	0.116
Tp5	0.067	0.018	3.711	0.000	0.032	0.101
Tp6	0.072	0.020	3.584	0.000	0.034	0.111
Tp7	0.068	0.023	3.032	0.001	0.025	0.112
Tp8	0.085	0.025	3.354	0.000	0.036	0.133
Tp9	0.067	0.028	2.377	0.009	0.013	0.122
Tp10	0.079	0.032	2.492	0.006	0.018	0.140
Tp11	0.106	0.036	2.991	0.001	0.038	0.174
Tp12	0.092	0.040	2.310	0.010	0.015	0.168

Source: Ipsos UK analysis.

Table 30: Effect of £1m in ESA contract value on contractor firm employment

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average annual treatment effect	0.033	0.013	2.565	0.005	0.008	0.057
Tp0	0.013	0.014	0.916	0.180	-0.014	0.040
Tp1	0.050	0.015	3.307	0.000	0.021	0.078
Tp2	0.058	0.016	3.639	0.000	0.028	0.089
Tp3	0.073	0.017	4.258	0.000	0.040	0.106
Tp4	0.073	0.018	3.966	0.000	0.038	0.108
Tp5	0.069	0.020	3.534	0.000	0.032	0.107
Tp6	0.068	0.021	3.258	0.001	0.028	0.109
Tp7	0.059	0.022	2.639	0.004	0.016	0.103
Tp8	0.047	0.024	1.969	0.024	0.001	0.094
Tp9	0.035	0.025	1.391	0.082	-0.013	0.083
Tp10	0.030	0.026	1.143	0.127	-0.020	0.080
Tp11	0.026	0.027	0.946	0.172	-0.026	0.078
Tp12	0.022	0.028	0.764	0.222	-0.033	0.076
Tp13	0.017	0.029	0.586	0.279	-0.039	0.073
Tp14	0.012	0.030	0.406	0.342	-0.046	0.071
Tp15	0.009	0.032	0.287	0.387	-0.052	0.070
Tp16	0.008	0.034	0.222	0.412	-0.058	0.073
Tp17	0.007	0.036	0.187	0.426	-0.063	0.076
Tp18	0.005	0.039	0.129	0.449	-0.070	0.079
Tp19	0.003	0.042	0.084	0.466	-0.076	0.083
Tp20	0.003	0.044	0.067	0.473	-0.082	0.088

Source: Ipsos UK analysis.

Table 31: Effect of £1m in ESA contract value on contractor firm R&D employment

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average annual treatment effect	0.061	0.012	5.180	0.000	0.038	0.083
Tp0	0.046	0.009	5.364	0.000	0.029	0.062
Tp1	0.088	0.009	9.323	0.000	0.070	0.106
Tp2	0.110	0.011	10.463	0.000	0.090	0.130
Tp3	0.128	0.012	11.007	0.000	0.106	0.151

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp4	0.156	0.013	12.030	0.000	0.131	0.181
Tp5	0.172	0.014	11.976	0.001	0.145	0.200
Tp6	0.121	0.016	7.553	0.002	0.090	0.151
Tp7	0.108	0.018	6.124	0.004	0.074	0.143
Tp8	0.087	0.020	4.414	0.005	0.049	0.125
Tp9	0.078	0.022	3.579	0.007	0.036	0.120
Tp10	0.051	0.024	2.096	0.017	0.004	0.097
Tp11	0.041	0.027	1.510	0.048	-0.011	0.092
Tp12	0.024	0.030	0.816	0.154	-0.033	0.082
Tp13	0.010	0.033	0.294	0.192	-0.054	0.073
Tp14	0.009	0.037	0.252	0.203	-0.061	0.080
Tp15	0.010	0.041	0.238	0.245	-0.069	0.088
Tp16	0.010	0.045	0.217	0.310	-0.077	0.097
Tp17	0.008	0.050	0.164	0.362	-0.088	0.105
Tp18	0.008	0.056	0.137	0.415	-0.100	0.115
Tp19	0.006	0.062	0.090	0.431	-0.113	0.125
Tp20	0.003	0.069	0.044	0.522	-0.129	0.135

Source: Ipsos UK analysis.

Table 32: Effect of £1m in ESA contract value on contractor firm turnover per worker

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average annual treatment effect	0.049	0.010	4.920	0.000	0.030	0.069
Tp0	0.002	0.012	0.196	0.422	-0.020	0.025
Tp1	-0.036	0.013	-2.845	0.998	-0.060	-0.012
Tp2	-0.008	0.013	-0.617	0.731	-0.034	0.018
Tp3	-0.010	0.014	-0.699	0.758	-0.038	0.018
Tp4	0.005	0.015	0.349	0.364	-0.024	0.035
Tp5	0.006	0.016	0.339	0.367	-0.026	0.037
Tp6	0.001	0.018	0.054	0.479	-0.033	0.035
Tp7	0.011	0.019	0.593	0.277	-0.025	0.047
Tp8	0.024	0.020	1.183	0.118	-0.015	0.063
Tp9	0.043	0.021	2.070	0.019	0.003	0.084
Tp10	0.061	0.022	2.801	0.003	0.019	0.103
Tp11	0.069	0.023	3.052	0.001	0.026	0.113
Tp12	0.078	0.024	3.321	0.000	0.033	0.124
Tp13	0.084	0.025	3.440	0.000	0.037	0.131
Tp14	0.106	0.026	4.136	0.000	0.057	0.155
Tp15	0.104	0.027	3.936	0.000	0.053	0.155
Tp16	0.096	0.028	3.371	0.000	0.041	0.150
Tp17	0.089	0.030	2.926	0.002	0.031	0.147
Tp18	0.092	0.033	2.840	0.002	0.030	0.155
Tp19	0.103	0.035	2.971	0.001	0.037	0.170
Tp20	0.113	0.037	3.046	0.001	0.042	0.185

Source: Ipsos UK analysis.

Table 33: Effect of £1m in ESA contract value on contractor firm GVA per worker

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average annual treatment effect	0.039	0.010	3.922	0.000	0.020	0.059
Tp0	0.003	0.016	0.162	0.436	-0.029	0.034
Tp1	0.025	0.015	1.696	0.045	-0.003	0.053
Tp2	0.028	0.015	1.793	0.037	-0.002	0.057
Tp3	0.030	0.016	1.878	0.030	-0.001	0.061
Tp4	0.028	0.017	1.673	0.047	-0.004	0.061
Tp5	0.039	0.018	2.175	0.015	0.005	0.073
Tp6	0.045	0.019	2.423	0.008	0.009	0.081
Tp7	0.052	0.020	2.654	0.004	0.014	0.090
Tp8	0.046	0.021	2.225	0.013	0.006	0.086
Tp9	0.050	0.022	2.286	0.011	0.008	0.091
Tp10	0.059	0.023	2.612	0.005	0.016	0.103
Tp11	0.056	0.024	2.325	0.010	0.010	0.102
Tp12	0.050	0.025	1.978	0.024	0.001	0.098

Source: Ipsos UK analysis.

Table 34: Effect of £1m in ESA contract value on contractor firm R&D expenditure

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average annual treatment effect	0.066	0.018	3.613	0.000	0.031	0.102
Tp0	0.058	0.008	7.647	0.000	0.043	0.072
Tp1	0.094	0.008	11.237	0.000	0.078	0.110
Tp2	0.117	0.009	12.563	0.000	0.099	0.134
Tp3	0.150	0.010	14.561	0.000	0.130	0.170
Tp4	0.201	0.011	17.613	0.000	0.179	0.223
Tp5	0.197	0.013	15.549	0.000	0.173	0.222
Tp6	0.142	0.014	10.060	0.000	0.115	0.169
Tp7	0.123	0.016	7.854	0.000	0.093	0.153
Tp8	0.084	0.017	4.823	0.000	0.050	0.117
Tp9	0.065	0.019	3.381	0.000	0.028	0.102
Tp10	0.034	0.021	1.581	0.057	-0.007	0.075
Tp11	0.035	0.024	1.461	0.072	-0.011	0.080
Tp12	0.029	0.026	1.086	0.139	-0.022	0.079
Tp13	0.014	0.029	0.490	0.312	-0.042	0.071
Tp14	0.009	0.032	0.291	0.386	-0.053	0.072
Tp15	0.011	0.036	0.297	0.383	-0.059	0.080
Tp16	0.010	0.040	0.245	0.403	-0.067	0.087
Tp17	0.006	0.044	0.129	0.449	-0.080	0.091
Tp18	0.008	0.049	0.170	0.433	-0.086	0.103
Tp19	0.004	0.055	0.074	0.471	-0.101	0.109
Tp20	0.003	0.061	0.055	0.478	-0.113	0.120

Source: Ipsos UK analysis.

As a robustness check, we re-estimated the models using an alternative specification of the treatment variable: a binary indicator equal to 0 prior to a firm receiving any ESA contracts and equal to 1 from the period of the first contract award onwards. The results from this specification were broadly consistent with those obtained in the main analysis, which employed a cumulative treatment variable. However, this alternative approach does not account for firms receiving multiple contracts, which is a relatively common occurrence in the dataset. This specification therefore does not adequately capture variation in treatment intensity, and the corresponding estimates are not reported here. Nonetheless, the similarity of the findings across these specifications strengthens confidence in the robustness of the primary results to alternative definitions of treatment.

H.1.6. Results by ESA domain[75]

We disaggregated the results of the SDiD analyses by ESA programme domain to assess the extent to which the economic impacts of ESA contracts differ across programme areas. We examined the effects of ESA funding on economic growth, employment, productivity, and private R&D investment for each of five ESA domains:

- Telecommunications and Integrated Applications
- Earth Observation
- Mandatory Programme and Activities
- Human and Robotic Exploration
- Other Programmes and Activities.

Due to limited sample sizes in the available dataset, we could not conduct robust econometric analysis for the remaining two ESA domains: Space Safety and Space Transportation.

The parallel trends assumption was tested using event study analyses for all five domains analysed. In each case, the average annual pre-treatment effect coefficients were statistically indistinguishable from zero at the 5% significance level ($p<0.05$), suggesting that the parallel trends assumption holds and supporting the validity of a causal interpretation of the estimated treatment effects.

Our analysis identifies statistically significant impacts across a range of outcome variables for three ESA programme domains: **Telecommunications**, **EO**, and **HRE**. In contrast, we do not observe statistically significant impacts across the outcome measures considered for the Mandatory Programme and Activities or Other Programmes and Activities domains. The full regression output from these domain-level analyses is presented in the tables below. These tables include estimates of the average treatment effects by year (prefixed with Tp). These results should be interpreted with caution due to two key limitations:

- **Sample size constraints:** Disaggregating the dataset by domain necessarily reduces the number of observations available for each analysis, particularly in domains with fewer ESA contract recipients or shorter available time series. This reduction in statistical power increases the standard errors around estimated treatment effects, making it more difficult to detect statistically significant effects even where substantive impacts may be present. This is particularly relevant for the Other Programmes and Activities domain, where the sample size was smaller and estimates were

[75] The use of 'domain' here refers to the thematic programme areas as outlined in the UK Space Agency 2022-2025 Corporate Plan.

consequently more uncertain.

- **Heterogeneity within domains:** Some ESA domains include a diverse set of programme activities that differ in their objectives and technological focus. This is particularly salient in the Mandatory Programme and Activities domain and the Other Programmes and Activities domain. Initiatives within these domains may have significant economic impacts which may be diluted by when aggregated with less commercially relevant programmes in the same domain. Thus, aggregated results at the domain level may obscure underlying variation in programme-level performance. Further disaggregation (for example, to the level of specific programmes) was not feasible within the scope of this analysis due to sample size constraints and data limitations. However, we acknowledge that the statistically insignificant results observed for some domains do not preclude the possibility of significant impacts at a more granular level. Future research may benefit from more disaggregated programme-level analysis, where permitted by greater sample sizes and improved data granularity.

Table 35: Effect of £1m in ESA contract value on contractor firm economic performance: Telecommunications domain

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Turnover						
Average annual treatment effect	0.068	0.013	5.323	0.000	0.043	0.092
Tp0	0.012	0.008	1.583	0.057	-0.003	0.026
Tp1	0.024	0.008	2.829	0.002	0.008	0.040
Tp2	0.055	0.009	5.914	0.000	0.037	0.073
Tp3	0.069	0.010	6.733	0.000	0.050	0.089
Tp4	0.067	0.011	5.846	0.000	0.045	0.089
Tp5	0.069	0.013	5.412	0.000	0.044	0.093
Tp6	0.053	0.014	3.792	0.000	0.026	0.080
Tp7	0.057	0.016	3.632	0.000	0.027	0.087
Tp8	0.054	0.017	3.117	0.001	0.021	0.087
Tp9	0.059	0.019	3.061	0.001	0.022	0.096
Tp10	0.067	0.021	3.123	0.001	0.026	0.108
Tp11	0.091	0.024	3.819	0.000	0.045	0.136
Tp12	0.079	0.026	2.994	0.001	0.028	0.130
Tp13	0.080	0.029	2.738	0.003	0.024	0.136
Tp14	0.093	0.032	2.878	0.002	0.031	0.156
Tp15	0.083	0.036	2.307	0.011	0.014	0.152
Tp16	0.095	0.040	2.362	0.009	0.018	0.171
Tp17	0.073	0.044	1.646	0.050	-0.012	0.158
Tp18	0.074	0.049	1.507	0.066	-0.020	0.169
Tp19	0.084	0.055	1.539	0.062	-0.021	0.189
Tp20	0.089	0.061	1.463	0.072	-0.028	0.205
GVA						
Average annual treatment effect	0.071	0.023	3.007	0.001	0.025	0.116

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp0	0.012	0.010	1.164	0.122	-0.008	0.032
Tp1	0.013	0.012	1.089	0.138	-0.010	0.035
Tp2	0.085	0.013	6.476	0.000	0.060	0.110
Tp3	0.070	0.015	4.800	0.000	0.042	0.099
Tp4	0.111	0.016	6.775	0.000	0.080	0.143
Tp5	0.107	0.018	5.800	0.000	0.071	0.142
Tp6	0.062	0.021	3.006	0.001	0.022	0.102
Tp7	0.067	0.023	2.920	0.002	0.023	0.112
Tp8	0.054	0.026	2.106	0.018	0.005	0.104
Tp9	0.074	0.029	2.557	0.005	0.018	0.130
Tp10	0.089	0.032	2.752	0.003	0.027	0.152
Tp11	0.067	0.036	1.842	0.033	-0.003	0.137
Tp12	0.105	0.041	2.577	0.005	0.027	0.183
Employment						
Average annual treatment effect	0.028	0.013	2.198	0.014	0.004	0.053
Tp0	0.010	0.008	1.267	0.103	-0.005	0.024
Tp1	0.039	0.008	4.713	0.000	0.023	0.055
Tp2	0.063	0.009	6.835	0.000	0.046	0.081
Tp3	0.075	0.010	7.304	0.000	0.055	0.095
Tp4	0.079	0.011	6.922	0.000	0.057	0.101
Tp5	0.060	0.013	4.693	0.000	0.035	0.084
Tp6	0.051	0.014	3.615	0.000	0.024	0.078
Tp7	0.044	0.016	2.823	0.002	0.014	0.074
Tp8	0.035	0.017	2.030	0.021	0.002	0.069
Tp9	0.026	0.019	1.344	0.089	-0.011	0.063
Tp10	0.020	0.021	0.955	0.170	-0.021	0.061
Tp11	0.022	0.024	0.926	0.177	-0.024	0.068
Tp12	0.016	0.026	0.607	0.272	-0.035	0.067
Tp13	0.013	0.029	0.436	0.331	-0.043	0.069
Tp14	0.009	0.032	0.283	0.388	-0.053	0.072
Tp15	0.006	0.036	0.173	0.431	-0.063	0.075
Tp16	0.006	0.040	0.161	0.436	-0.070	0.083
Tp17	0.005	0.044	0.114	0.455	-0.080	0.090
Tp18	0.004	0.049	0.075	0.470	-0.091	0.098
Tp19	0.003	0.055	0.047	0.481	-0.102	0.108
Tp20	0.002	0.061	0.037	0.485	-0.114	0.119
R&D employment						
Average annual treatment effect	0.027	0.012	2.305	0.011	0.005	0.049
Tp0	0.018	0.009	2.092	0.000	0.001	0.034
Tp1	0.045	0.009	4.699	0.000	0.026	0.063
Tp2	0.044	0.011	4.175	0.000	0.024	0.064
Tp3	0.069	0.012	5.944	0.000	0.047	0.092
Tp4	0.089	0.013	6.857	0.000	0.064	0.114

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp5	0.077	0.014	5.389	0.001	0.050	0.105
Tp6	0.047	0.016	2.946	0.002	0.016	0.078
Tp7	0.042	0.018	2.388	0.004	0.008	0.076
Tp8	0.034	0.020	1.721	0.005	-0.004	0.072
Tp9	0.030	0.022	1.396	0.007	-0.011	0.072
Tp10	0.018	0.024	0.754	0.017	-0.028	0.065
Tp11	0.018	0.027	0.680	0.048	-0.033	0.070
Tp12	0.010	0.030	0.318	0.154	-0.048	0.067
Tp13	0.004	0.033	0.115	0.192	-0.060	0.067
Tp14	0.004	0.037	0.098	0.203	-0.067	0.074
Tp15	0.004	0.041	0.086	0.245	-0.075	0.082
Tp16	0.004	0.045	0.098	0.310	-0.083	0.091
Tp17	0.003	0.050	0.064	0.362	-0.093	0.100
Tp18	0.003	0.056	0.054	0.415	-0.104	0.110
Tp19	0.002	0.062	0.035	0.431	-0.117	0.121
Tp20	0.001	0.069	0.017	0.522	-0.131	0.133
GVA per worker						
Average annual treatment effect	0.058	0.010	5.754	0.000	0.038	0.077
Tp0	0.004	0.016	0.219	0.436	-0.028	0.035
Tp1	0.032	0.015	2.189	0.045	0.004	0.060
Tp2	0.077	0.015	5.026	0.037	0.048	0.107
Tp3	0.053	0.016	3.303	0.030	0.022	0.085
Tp4	0.048	0.017	2.839	0.047	0.016	0.081
Tp5	0.071	0.018	3.964	0.015	0.036	0.105
Tp6	0.067	0.019	3.579	0.008	0.031	0.103
Tp7	0.066	0.020	3.339	0.004	0.028	0.103
Tp8	0.055	0.021	2.677	0.013	0.016	0.095
Tp9	0.063	0.022	2.900	0.011	0.021	0.105
Tp10	0.078	0.023	3.429	0.005	0.034	0.122
Tp11	0.066	0.024	2.747	0.010	0.020	0.112
Tp12	0.069	0.025	2.746	0.024	0.021	0.117
R&D expenditure						
Average annual treatment effect	0.058	0.018	3.151	0.001	0.023	0.093
Tp0	0.052	0.008	6.959	0.000	0.038	0.067
Tp1	0.132	0.008	15.731	0.000	0.115	0.148
Tp2	0.122	0.009	13.129	0.000	0.104	0.140
Tp3	0.176	0.010	17.036	0.000	0.156	0.195
Tp4	0.140	0.011	12.285	0.000	0.119	0.162
Tp5	0.148	0.013	11.662	0.000	0.124	0.172
Tp6	0.120	0.014	8.501	0.000	0.093	0.147
Tp7	0.080	0.016	5.105	0.000	0.050	0.110
Tp8	0.060	0.017	3.449	0.000	0.027	0.093
Tp9	0.051	0.019	2.637	0.004	0.014	0.088

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp10	0.026	0.021	1.233	0.109	-0.015	0.067
Tp11	0.031	0.024	1.315	0.094	-0.014	0.077
Tp12	0.022	0.026	0.847	0.199	-0.028	0.073
Tp13	0.011	0.029	0.382	0.351	-0.045	0.067
Tp14	0.008	0.032	0.246	0.403	-0.054	0.070
Tp15	0.008	0.036	0.214	0.415	-0.062	0.077
Tp16	0.010	0.040	0.239	0.405	-0.067	0.086
Tp17	0.004	0.044	0.101	0.460	-0.081	0.090
Tp18	0.008	0.049	0.165	0.434	-0.086	0.103
Tp19	0.004	0.055	0.067	0.473	-0.101	0.109
Tp20	0.002	0.061	0.039	0.484	-0.114	0.119

Source: Ipsos UK analysis.

Table 36: Effect of £1m in ESA contract value on contractor firm economic performance: EO domain

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Turnover						
Average annual treatment effect	0.049	0.013	3.831	0.000	0.024	0.073
Tp0	0.009	0.008	1.218	0.112	-0.005	0.024
Tp1	0.008	0.008	1.010	0.156	-0.008	0.025
Tp2	0.029	0.009	3.113	0.001	0.011	0.047
Tp3	0.039	0.010	3.741	0.000	0.019	0.058
Tp4	0.035	0.011	3.077	0.001	0.013	0.057
Tp5	0.046	0.013	3.608	0.000	0.021	0.070
Tp6	0.041	0.014	2.917	0.002	0.014	0.068
Tp7	0.044	0.016	2.794	0.003	0.014	0.074
Tp8	0.042	0.017	2.398	0.008	0.008	0.075
Tp9	0.045	0.019	2.355	0.009	0.008	0.082
Tp10	0.056	0.021	2.602	0.005	0.015	0.097
Tp11	0.060	0.024	2.546	0.005	0.015	0.106
Tp12	0.061	0.026	2.303	0.011	0.010	0.111
Tp13	0.062	0.029	2.106	0.018	0.005	0.118
Tp14	0.072	0.032	2.214	0.013	0.010	0.134
Tp15	0.069	0.036	1.923	0.027	0.000	0.139
Tp16	0.063	0.040	1.575	0.058	-0.014	0.140
Tp17	0.056	0.044	1.266	0.103	-0.029	0.141
Tp18	0.057	0.049	1.159	0.123	-0.038	0.152
Tp19	0.065	0.055	1.184	0.118	-0.040	0.170
Tp20	0.068	0.061	1.125	0.130	-0.048	0.185
GVA						
Average annual treatment effect	0.046	0.023	1.970	0.024	0.001	0.091
Tp0	0.009	0.010	0.832	0.203	-0.011	0.029

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp1	0.010	0.012	0.838	0.201	-0.013	0.032
Tp2	0.041	0.013	3.131	0.001	0.016	0.066
Tp3	0.037	0.015	2.526	0.006	0.009	0.065
Tp4	0.062	0.016	3.764	0.000	0.030	0.093
Tp5	0.056	0.018	3.053	0.001	0.021	0.092
Tp6	0.041	0.021	2.004	0.023	0.002	0.081
Tp7	0.052	0.023	2.246	0.012	0.008	0.096
Tp8	0.042	0.026	1.620	0.053	-0.008	0.092
Tp9	0.057	0.029	1.967	0.025	0.001	0.113
Tp10	0.069	0.032	2.117	0.017	0.006	0.131
Tp11	0.056	0.036	1.535	0.062	-0.014	0.126
Tp12	0.070	0.041	1.718	0.043	-0.008	0.148
Employment						
Average annual treatment effect	0.019	0.013	1.467	0.071	-0.006	0.043
Tp0	0.007	0.008	0.975	0.165	-0.007	0.022
Tp1	0.028	0.008	3.392	0.000	0.012	0.044
Tp2	0.033	0.009	3.597	0.000	0.016	0.051
Tp3	0.042	0.010	4.058	0.000	0.022	0.062
Tp4	0.042	0.011	3.643	0.000	0.020	0.064
Tp5	0.040	0.013	3.129	0.001	0.015	0.064
Tp6	0.039	0.014	2.781	0.003	0.012	0.066
Tp7	0.034	0.016	2.172	0.015	0.004	0.064
Tp8	0.027	0.017	1.561	0.059	-0.006	0.060
Tp9	0.020	0.019	1.034	0.151	-0.017	0.057
Tp10	0.017	0.021	0.795	0.213	-0.024	0.058
Tp11	0.015	0.024	0.617	0.269	-0.031	0.060
Tp12	0.012	0.026	0.467	0.320	-0.038	0.063
Tp13	0.010	0.029	0.336	0.369	-0.046	0.066
Tp14	0.007	0.032	0.218	0.414	-0.055	0.069
Tp15	0.005	0.036	0.144	0.443	-0.064	0.074
Tp16	0.004	0.040	0.107	0.457	-0.073	0.081
Tp17	0.004	0.044	0.087	0.465	-0.081	0.089
Tp18	0.003	0.049	0.058	0.477	-0.092	0.097
Tp19	0.002	0.055	0.036	0.485	-0.103	0.107
Tp20	0.002	0.061	0.028	0.489	-0.115	0.118
R&D employment						
Average annual treatment effect	0.018	0.012	1.554	0.060	-0.004	0.041
Tp0	0.014	0.009	1.609	0.000	-0.003	0.030
Tp1	0.026	0.009	2.797	0.000	0.008	0.045
Tp2	0.033	0.011	3.139	0.000	0.013	0.053
Tp3	0.039	0.012	3.302	0.000	0.016	0.061
Tp4	0.047	0.013	3.609	0.000	0.022	0.072
Tp5	0.052	0.014	3.593	0.001	0.024	0.079

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp6	0.036	0.016	2.266	0.002	0.006	0.067
Tp7	0.033	0.018	1.837	0.004	-0.001	0.067
Tp8	0.026	0.020	1.324	0.005	-0.012	0.064
Tp9	0.023	0.022	1.074	0.007	-0.018	0.065
Tp10	0.015	0.024	0.629	0.017	-0.031	0.062
Tp11	0.012	0.027	0.453	0.048	-0.039	0.064
Tp12	0.007	0.030	0.245	0.154	-0.050	0.065
Tp13	0.003	0.033	0.088	0.192	-0.061	0.067
Tp14	0.003	0.037	0.076	0.203	-0.068	0.073
Tp15	0.003	0.041	0.071	0.245	-0.075	0.081
Tp16	0.003	0.045	0.065	0.310	-0.084	0.090
Tp17	0.002	0.050	0.049	0.362	-0.094	0.099
Tp18	0.002	0.056	0.041	0.415	-0.105	0.110
Tp19	0.002	0.062	0.027	0.431	-0.117	0.121
Tp20	0.001	0.069	0.013	0.522	-0.131	0.133
GVA per worker						
Average annual treatment effect	0.038	0.010	3.794	0.000	0.019	0.057
Tp0	0.003	0.016	0.156	0.436	-0.029	0.034
Tp1	0.025	0.015	1.684	0.045	-0.003	0.053
Tp2	0.028	0.015	1.795	0.037	-0.002	0.057
Tp3	0.028	0.016	1.738	0.030	-0.003	0.059
Tp4	0.027	0.017	1.577	0.047	-0.006	0.059
Tp5	0.037	0.018	2.086	0.015	0.003	0.071
Tp6	0.045	0.019	2.386	0.008	0.009	0.081
Tp7	0.051	0.020	2.569	0.004	0.013	0.088
Tp8	0.043	0.021	2.059	0.013	0.003	0.082
Tp9	0.048	0.022	2.231	0.011	0.007	0.090
Tp10	0.060	0.023	2.638	0.005	0.016	0.104
Tp11	0.055	0.024	2.289	0.010	0.009	0.101
Tp12	0.046	0.025	1.831	0.024	-0.002	0.094
R&D expenditure						
Average annual treatment effect	0.038	0.018	2.072	0.019	0.003	0.073
Tp0	0.040	0.008	5.353	0.000	0.026	0.055
Tp1	0.047	0.008	5.618	0.000	0.031	0.063
Tp2	0.064	0.009	6.910	0.000	0.046	0.082
Tp3	0.098	0.010	9.465	0.000	0.078	0.117
Tp4	0.111	0.011	9.687	0.000	0.089	0.133
Tp5	0.099	0.013	7.774	0.000	0.074	0.123
Tp6	0.092	0.014	6.539	0.000	0.065	0.119
Tp7	0.061	0.016	3.927	0.000	0.031	0.091
Tp8	0.046	0.017	2.653	0.004	0.013	0.079
Tp9	0.039	0.019	2.028	0.021	0.002	0.076
Tp10	0.022	0.021	1.028	0.152	-0.019	0.063

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp11	0.021	0.024	0.876	0.190	-0.025	0.066
Tp12	0.017	0.026	0.651	0.257	-0.033	0.068
Tp13	0.009	0.029	0.294	0.384	-0.048	0.065
Tp14	0.006	0.032	0.189	0.425	-0.056	0.068
Tp15	0.006	0.036	0.178	0.429	-0.063	0.076
Tp16	0.006	0.040	0.160	0.437	-0.070	0.083
Tp17	0.003	0.044	0.078	0.469	-0.082	0.089
Tp18	0.006	0.049	0.127	0.449	-0.088	0.101
Tp19	0.003	0.055	0.052	0.479	-0.102	0.108
Tp20	0.002	0.061	0.030	0.488	-0.115	0.118

Source: Ipsos UK analysis.

Table 37: Effect of £1m in ESA contract value on contractor firms' economic performance: Human and Robotic Exploration domain

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Turnover						
Average annual treatment effect	0.029	0.013	3.640	0.000	0.017	0.051
Tp0	0.005	0.008	1.157	0.115	-0.009	0.020
Tp1	0.005	0.009	0.960	0.161	-0.011	0.021
Tp2	0.017	0.010	2.957	0.001	-0.001	0.035
Tp3	0.023	0.011	3.554	0.000	0.003	0.043
Tp4	0.021	0.012	2.923	0.001	-0.001	0.043
Tp5	0.027	0.013	3.428	0.000	0.003	0.051
Tp6	0.024	0.015	2.771	0.002	-0.003	0.051
Tp7	0.026	0.016	2.654	0.003	-0.004	0.056
Tp8	0.025	0.018	2.278	0.008	-0.009	0.058
Tp9	0.027	0.020	2.237	0.010	-0.010	0.064
Tp10	0.033	0.022	2.472	0.005	-0.008	0.074
Tp11	0.036	0.024	2.419	0.006	-0.010	0.081
Tp12	0.036	0.027	2.188	0.011	-0.015	0.086
Tp13	0.036	0.030	2.001	0.018	-0.020	0.093
Tp14	0.042	0.033	2.103	0.014	-0.020	0.105
Tp15	0.041	0.037	1.827	0.028	-0.028	0.110
Tp16	0.037	0.041	1.496	0.059	-0.040	0.114
Tp17	0.033	0.046	1.203	0.106	-0.052	0.118
Tp18	0.034	0.051	1.101	0.127	-0.061	0.128
Tp19	0.038	0.056	1.125	0.122	-0.067	0.143
Tp20	0.040	0.063	1.069	0.134	-0.076	0.157
GVA						
Average annual treatment effect	0.030	0.024	2.029	0.025	0.001	0.063
Tp0	0.003	0.011	0.857	0.209	-0.017	0.023
Tp1	0.003	0.012	0.863	0.207	-0.020	0.025

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp2	0.012	0.013	3.225	0.001	-0.013	0.037
Tp3	0.011	0.015	2.602	0.006	-0.017	0.039
Tp4	0.019	0.017	3.877	0.000	-0.013	0.050
Tp5	0.017	0.019	3.144	0.001	-0.018	0.052
Tp6	0.012	0.021	2.064	0.023	-0.027	0.052
Tp7	0.016	0.024	2.313	0.013	-0.029	0.060
Tp8	0.013	0.027	1.669	0.054	-0.037	0.062
Tp9	0.017	0.030	2.026	0.025	-0.039	0.073
Tp10	0.021	0.033	2.180	0.018	-0.042	0.083
Tp11	0.017	0.037	1.581	0.064	-0.053	0.086
Tp12	0.021	0.042	1.769	0.044	-0.057	0.099
Employment						
Average annual treatment effect	0.013	0.013	1.394	0.073	-0.004	0.030
Tp0	0.005	0.008	0.975	0.165	-0.009	0.019
Tp1	0.019	0.008	3.392	0.000	0.003	0.035
Tp2	0.023	0.009	3.597	0.000	0.005	0.041
Tp3	0.028	0.010	4.058	0.000	0.009	0.048
Tp4	0.028	0.011	3.643	0.000	0.006	0.050
Tp5	0.027	0.013	3.129	0.001	0.003	0.051
Tp6	0.027	0.014	2.781	0.003	0.000	0.054
Tp7	0.023	0.016	2.172	0.015	-0.007	0.053
Tp8	0.018	0.017	1.561	0.059	-0.015	0.052
Tp9	0.014	0.019	1.034	0.151	-0.023	0.051
Tp10	0.012	0.021	0.795	0.213	-0.029	0.053
Tp11	0.010	0.024	0.617	0.269	-0.036	0.056
Tp12	0.008	0.026	0.467	0.320	-0.042	0.059
Tp13	0.007	0.029	0.336	0.369	-0.049	0.063
Tp14	0.008	0.032	0.218	0.414	-0.055	0.070
Tp15	0.004	0.036	0.144	0.443	-0.066	0.073
Tp16	0.003	0.040	0.107	0.457	-0.074	0.080
Tp17	0.003	0.044	0.087	0.465	-0.083	0.088
Tp18	0.006	0.049	0.058	0.477	-0.089	0.101
Tp19	0.001	0.055	0.036	0.485	-0.104	0.106
Tp20	0.001	0.061	0.028	0.489	-0.115	0.118
R&D employment						
Average annual treatment effect	0.008	0.011	1.585	0.060	-0.004	0.041
Tp0	0.017	0.008	1.641	0.000	0.001	0.033
Tp1	0.018	0.009	2.853	0.362	0.000	0.036
Tp2	0.021	0.010	3.202	0.002	0.001	0.041
Tp3	0.026	0.011	3.368	0.009	0.004	0.049
Tp4	0.024	0.012	3.681	0.183	-0.001	0.049
Tp5	0.017	0.013	3.665	0.136	-0.011	0.044
Tp6	0.007	0.015	2.311	0.193	-0.024	0.038

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp7	0.004	0.016	1.874	0.117	-0.030	0.038
Tp8	-0.002	0.018	1.351	0.224	-0.039	0.036
Tp9	0.001	0.020	1.095	0.383	-0.041	0.043
Tp10	0.001	0.022	0.641	0.234	-0.046	0.047
Tp11	0.013	0.025	0.462	0.048	-0.037	0.066
Tp12	0.007	0.027	0.250	0.154	-0.050	0.064
Tp13	0.003	0.030	0.090	0.192	-0.061	0.066
Tp14	0.003	0.034	0.077	0.203	-0.068	0.073
Tp15	0.003	0.038	0.073	0.245	-0.076	0.081
Tp16	0.003	0.042	0.066	0.310	-0.085	0.089
Tp17	0.002	0.046	0.050	0.362	-0.095	0.098
Tp18	0.002	0.051	0.042	0.415	-0.105	0.110
Tp19	0.002	0.057	0.028	0.431	-0.117	0.121
Tp20	0.001	0.069	0.013	0.522	-0.131	0.133
GVA per worker						
Average annual treatment effect	0.030	0.010	3.908	0.000	0.013	0.057
Tp0	0.002	0.017	0.161	0.449	-0.019	0.022
Tp1	0.020	0.015	1.734	0.046	-0.003	0.042
Tp2	0.022	0.016	1.849	0.038	-0.003	0.047
Tp3	0.023	0.017	1.791	0.031	-0.006	0.051
Tp4	0.021	0.018	1.625	0.049	-0.010	0.053
Tp5	0.030	0.018	2.149	0.015	-0.006	0.065
Tp6	0.036	0.019	2.458	0.008	-0.004	0.075
Tp7	0.040	0.020	2.646	0.004	-0.004	0.085
Tp8	0.034	0.021	2.121	0.013	-0.016	0.084
Tp9	0.039	0.022	2.298	0.011	-0.017	0.094
Tp10	0.048	0.023	2.717	0.005	-0.014	0.110
Tp11	0.044	0.025	2.358	0.010	-0.026	0.114
Tp12	0.037	0.026	1.885	0.025	-0.041	0.115
R&D expenditure						
Average annual treatment effect	0.026	0.019	1.968	0.020	0.002	0.051
Tp0	0.028	0.008	5.353	0.000	0.014	0.043
Tp1	0.033	0.008	5.618	0.000	0.017	0.049
Tp2	0.045	0.009	6.910	0.000	0.027	0.063
Tp3	0.068	0.010	9.465	0.000	0.048	0.088
Tp4	0.078	0.011	9.687	0.000	0.056	0.100
Tp5	0.069	0.013	7.774	0.000	0.045	0.093
Tp6	0.054	0.014	6.539	0.000	0.027	0.082
Tp7	0.043	0.016	3.927	0.000	0.013	0.073
Tp8	0.032	0.017	2.653	0.399	-0.001	0.066
Tp9	0.017	0.019	2.028	0.213	-0.020	0.054
Tp10	0.015	0.021	1.028	0.152	-0.026	0.056
Tp11	0.015	0.024	0.876	0.190	-0.031	0.060

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp12	0.012	0.026	0.651	0.257	-0.039	0.063
Tp13	0.006	0.029	0.294	0.384	-0.050	0.062
Tp14	0.004	0.032	0.189	0.425	-0.058	0.067
Tp15	0.004	0.036	0.178	0.429	-0.065	0.074
Tp16	0.004	0.040	0.160	0.437	-0.072	0.081
Tp17	0.002	0.044	0.078	0.469	-0.083	0.088
Tp18	0.004	0.049	0.127	0.449	-0.090	0.099
Tp19	0.002	0.055	0.052	0.479	-0.103	0.107
Tp20	0.001	0.061	0.030	0.488	-0.115	0.118

Source: Ipsos UK analysis.

Table 38: Effect of £1m in ESA contract value on contractor firms' economic performance: Mandatory Programme and Activities domain

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Turnover						
Average annual treatment effect	0.013	8.154	147.768	0.619	-0.044	0.069
Tp0	0.015	0.478	245.170	0.800	-0.001	0.031
Tp1	0.012	0.213	496.091	0.760	-0.006	0.030
Tp2	0.010	0.240	397.084	0.430	-0.010	0.030
Tp3	0.009	0.168	509.307	0.710	-0.013	0.031
Tp4	0.010	0.146	529.339	0.400	-0.015	0.034
Tp5	0.010	0.186	374.809	0.580	-0.018	0.038
Tp6	0.013	0.339	184.550	0.820	-0.018	0.043
Tp7	0.015	0.419	134.806	0.710	-0.019	0.049
Tp8	0.010	0.581	87.530	0.500	-0.028	0.048
Tp9	0.014	0.717	63.937	0.650	-0.028	0.056
Tp10	0.014	1.326	31.136	0.430	-0.033	0.060
Tp11	0.017	1.471	25.270	0.620	-0.035	0.069
Tp12	0.014	3.141	10.665	0.780	-0.043	0.071
Tp13	0.017	8.716	3.462	0.400	-0.047	0.081
Tp14	0.009	10.184	2.670	0.640	-0.061	0.080
Tp15	0.011	11.663	2.100	0.530	-0.067	0.090
Tp16	0.012	10.254	2.152	0.470	-0.075	0.099
Tp17	0.014	15.634	1.271	0.750	-0.082	0.111
Tp18	0.014	18.660	0.960	0.560	-0.093	0.122
Tp19	0.014	28.374	0.569	0.780	-0.105	0.133
Tp20	0.011	58.324	0.249	0.670	-0.131	0.133
GVA						
Average annual treatment effect	0.012	0.407	184.176	0.588	-0.031	0.055
Tp0	0.009	0.859	111.493	0.460	-0.011	0.029
Tp1	0.012	0.918	93.120	0.580	-0.010	0.035
Tp2	0.008	0.154	494.305	0.580	-0.017	0.034

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp3	0.011	0.208	327.119	0.740	-0.017	0.039
Tp4	0.017	0.148	412.253	0.710	-0.015	0.049
Tp5	0.015	0.172	315.138	0.480	-0.020	0.051
Tp6	0.013	0.333	145.827	0.420	-0.027	0.052
Tp7	0.009	0.343	126.451	0.750	-0.035	0.054
Tp8	0.014	0.475	81.451	0.760	-0.036	0.063
Tp9	0.011	0.391	88.271	0.550	-0.045	0.066
Tp10	0.011	0.363	84.841	0.430	-0.051	0.074
Tp11	0.009	0.543	50.695	0.480	-0.061	0.079
Tp12	0.015	0.388	63.326	0.710	-0.063	0.093
Employment						
Average annual treatment effect	0.013	8.154	147.768	0.620	-0.044	0.069
Tp0	0.012	0.478	245.170	0.590	-0.004	0.028
Tp1	0.010	0.213	496.091	0.460	-0.008	0.028
Tp2	0.009	0.240	397.084	0.520	-0.011	0.029
Tp3	0.009	0.168	509.307	0.830	-0.013	0.032
Tp4	0.016	0.146	529.339	0.650	-0.009	0.041
Tp5	0.016	0.186	374.809	0.740	-0.011	0.044
Tp6	0.010	0.339	184.550	0.800	-0.020	0.041
Tp7	0.013	0.419	134.806	0.500	-0.022	0.047
Tp8	0.016	0.581	87.530	0.540	-0.022	0.053
Tp9	0.015	0.717	63.937	0.550	-0.027	0.057
Tp10	0.017	1.326	31.136	0.400	-0.030	0.063
Tp11	0.009	1.471	25.270	0.620	-0.043	0.061
Tp12	0.016	3.141	10.665	0.810	-0.041	0.074
Tp13	0.015	8.716	3.462	0.530	-0.049	0.078
Tp14	0.013	10.184	2.670	0.830	-0.058	0.083
Tp15	0.010	11.663	2.100	0.470	-0.069	0.088
Tp16	0.011	10.254	2.152	0.490	-0.076	0.098
Tp17	0.015	15.634	1.271	0.750	-0.082	0.111
Tp18	0.017	18.660	0.960	0.810	-0.091	0.124
Tp19	0.017	28.374	0.569	0.450	-0.102	0.136
Tp20	0.010	58.324	0.249	0.690	-0.131	0.133
R&D employment						
Average annual treatment effect	0.012	8.154	147.768	0.626	-0.045	0.068
Tp0	0.010	0.478	245.170	0.470	-0.007	0.026
Tp1	0.011	0.213	496.091	0.570	-0.007	0.030
Tp2	0.013	0.240	397.084	0.790	-0.008	0.033
Tp3	0.013	0.168	509.307	0.450	-0.009	0.036
Tp4	0.016	0.146	529.339	0.560	-0.009	0.041
Tp5	0.014	0.186	374.809	0.700	-0.014	0.042
Tp6	0.010	0.339	184.550	0.740	-0.021	0.041
Tp7	0.013	0.419	134.806	0.830	-0.021	0.047

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp8	0.012	0.581	87.530	0.770	-0.025	0.050
Tp9	0.017	0.717	63.937	0.780	-0.025	0.059
Tp10	0.014	1.326	31.136	0.430	-0.033	0.060
Tp11	0.013	1.471	25.270	0.750	-0.039	0.065
Tp12	0.013	3.141	10.665	0.620	-0.045	0.070
Tp13	0.013	8.716	3.462	0.630	-0.051	0.076
Tp14	0.013	10.184	2.670	0.490	-0.058	0.083
Tp15	0.010	11.663	2.100	0.720	-0.068	0.089
Tp16	0.011	10.254	2.152	0.810	-0.076	0.098
Tp17	0.011	15.634	1.271	0.450	-0.085	0.108
Tp18	0.012	18.660	0.960	0.470	-0.095	0.119
Tp19	0.008	28.374	0.569	0.660	-0.111	0.127
Tp20	0.015	58.324	0.249	0.450	-0.131	0.133
GVA per worker						
Average annual treatment effect	0.013	0.650	160.042	0.617	-0.024	0.050
Tp0	0.013	4.568	13.272	0.410	-0.019	0.044
Tp1	0.009	0.457	149.104	0.440	-0.019	0.038
Tp2	0.013	0.199	326.071	0.670	-0.016	0.043
Tp3	0.011	0.303	204.065	0.840	-0.020	0.042
Tp4	0.015	0.352	167.048	0.850	-0.018	0.047
Tp5	0.011	0.252	222.150	0.580	-0.024	0.045
Tp6	0.016	0.279	191.017	0.700	-0.020	0.052
Tp7	0.017	0.299	169.729	0.620	-0.021	0.055
Tp8	0.014	0.374	129.585	0.580	-0.026	0.053
Tp9	0.015	0.345	133.715	0.710	-0.027	0.056
Tp10	0.012	0.292	150.559	0.480	-0.032	0.055
Tp11	0.010	0.364	114.875	0.540	-0.036	0.056
Tp12	0.009	0.364	109.358	0.600	-0.040	0.057
R&D expenditure						
Average annual treatment effect	0.012	8.154	147.768	0.652	-0.045	0.067
Tp0	0.008	0.478	245.170	0.690	-0.008	0.024
Tp1	0.013	0.213	496.091	0.820	-0.005	0.031
Tp2	0.009	0.240	397.084	0.840	-0.011	0.029
Tp3	0.015	0.168	509.307	0.710	-0.007	0.037
Tp4	0.014	0.146	529.339	0.400	-0.011	0.038
Tp5	0.009	0.186	374.809	0.430	-0.019	0.037
Tp6	0.015	0.339	184.550	0.460	-0.015	0.046
Tp7	0.009	0.419	134.806	0.560	-0.026	0.043
Tp8	0.014	0.581	87.530	0.750	-0.024	0.051
Tp9	0.012	0.717	63.937	0.760	-0.030	0.054
Tp10	0.011	1.326	31.136	0.750	-0.036	0.057
Tp11	0.011	1.471	25.270	0.490	-0.040	0.063
Tp12	0.014	3.141	10.665	0.810	-0.043	0.072

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp13	0.011	8.716	3.462	0.750	-0.053	0.074
Tp14	0.017	10.184	2.670	0.730	-0.054	0.087
Tp15	0.009	11.663	2.100	0.780	-0.070	0.087
Tp16	0.008	10.254	2.152	0.410	-0.079	0.095
Tp17	0.012	15.634	1.271	0.580	-0.084	0.109
Tp18	0.012	18.660	0.960	0.580	-0.096	0.119
Tp19	0.008	28.374	0.569	0.550	-0.111	0.127
Tp20	0.012	58.324	0.249	0.840	-0.131	0.133

Source: Ipsos UK analysis.

Table 39: Effect of £1m in ESA contract value on contractor firms' economic performance: Other Programmes and Activities domain

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Turnover						
Average annual treatment effect	0.013	0.378	212.480	0.677	-0.038	0.062
Tp0	0.016	0.632	210.197	0.700	0.001	0.030
Tp1	0.009	0.354	338.290	0.850	-0.007	0.025
Tp2	0.015	0.169	637.191	0.490	-0.003	0.033
Tp3	0.015	0.149	653.525	0.720	-0.005	0.034
Tp4	0.012	0.171	511.230	0.820	-0.010	0.034
Tp5	0.010	0.185	426.370	0.810	-0.014	0.035
Tp6	0.016	0.264	269.111	0.850	-0.011	0.043
Tp7	0.013	0.275	232.209	0.840	-0.017	0.043
Tp8	0.010	0.321	179.550	0.650	-0.023	0.044
Tp9	0.011	0.327	158.855	0.600	-0.026	0.048
Tp10	0.017	0.320	145.979	0.680	-0.024	0.058
Tp11	0.011	0.262	160.857	0.400	-0.034	0.057
Tp12	0.015	0.334	113.593	0.400	-0.036	0.066
Tp13	0.012	0.365	93.588	0.590	-0.044	0.068
Tp14	0.009	0.347	88.625	0.800	-0.054	0.071
Tp15	0.012	0.433	64.010	0.600	-0.058	0.081
Tp16	0.011	0.423	59.048	0.590	-0.066	0.088
Tp17	0.010	0.607	37.067	0.700	-0.075	0.095
Tp18	0.013	0.664	30.569	0.850	-0.081	0.108
Tp19	0.011	0.650	28.130	0.760	-0.094	0.116
Tp20	0.016	0.684	24.088	0.520	-0.116	0.118
GVA						
Average annual treatment effect	0.012	0.407	184.176	0.624	-0.031	0.055
Tp0	0.012	0.859	111.493	0.660	-0.008	0.032
Tp1	0.013	0.918	93.120	0.440	-0.009	0.036
Tp2	0.015	0.154	494.305	0.440	-0.010	0.040
Tp3	0.010	0.208	327.119	0.780	-0.019	0.038

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp4	0.016	0.148	412.253	0.640	-0.016	0.047
Tp5	0.010	0.172	315.138	0.400	-0.025	0.046
Tp6	0.009	0.333	145.827	0.760	-0.031	0.048
Tp7	0.010	0.343	126.451	0.580	-0.035	0.054
Tp8	0.013	0.475	81.451	0.740	-0.036	0.063
Tp9	0.015	0.391	88.271	0.490	-0.041	0.071
Tp10	0.008	0.363	84.841	0.780	-0.054	0.071
Tp11	0.009	0.543	50.695	0.800	-0.061	0.079
Tp12	0.014	0.388	63.326	0.600	-0.064	0.092
Employment						
Average annual treatment effect	0.012	4.554	186.691	0.645	-0.038	0.062
Tp0	0.016	0.789	168.193	0.590	0.002	0.031
Tp1	0.010	0.212	563.671	0.750	-0.006	0.026
Tp2	0.010	0.146	736.364	0.630	-0.007	0.028
Tp3	0.012	0.137	708.894	0.680	-0.008	0.032
Tp4	0.014	0.144	605.271	0.730	-0.008	0.036
Tp5	0.011	0.213	369.725	0.560	-0.014	0.035
Tp6	0.013	0.277	256.534	0.800	-0.014	0.040
Tp7	0.012	0.354	180.514	0.410	-0.018	0.042
Tp8	0.011	0.493	116.925	0.750	-0.022	0.045
Tp9	0.008	0.744	69.751	0.540	-0.029	0.045
Tp10	0.013	1.048	44.627	0.570	-0.028	0.054
Tp11	0.017	1.080	38.982	0.590	-0.029	0.062
Tp12	0.016	1.647	23.033	0.740	-0.034	0.067
Tp13	0.011	2.291	14.918	0.810	-0.046	0.067
Tp14	0.013	3.528	8.730	0.490	-0.049	0.075
Tp15	0.009	5.772	4.807	0.540	-0.060	0.079
Tp16	0.016	6.205	4.028	0.790	-0.061	0.093
Tp17	0.012	8.801	2.559	0.820	-0.074	0.097
Tp18	0.011	13.291	1.526	0.510	-0.083	0.106
Tp19	0.012	21.075	0.867	0.700	-0.093	0.117
Tp20	0.014	27.393	0.601	0.540	-0.116	0.118
R&D employment						
Average annual treatment effect	0.012	8.154	147.768	0.669	-0.045	0.068
Tp0	0.014	0.478	245.170	0.560	-0.003	0.030
Tp1	0.008	0.213	496.091	0.700	-0.010	0.027
Tp2	0.015	0.240	397.084	0.850	-0.005	0.035
Tp3	0.012	0.168	509.307	0.750	-0.011	0.034
Tp4	0.010	0.146	529.339	0.850	-0.015	0.034
Tp5	0.014	0.186	374.809	0.480	-0.014	0.042
Tp6	0.010	0.339	184.550	0.850	-0.020	0.041
Tp7	0.016	0.419	134.806	0.680	-0.018	0.050
Tp8	0.010	0.581	87.530	0.780	-0.028	0.048

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp9	0.013	0.717	63.937	0.670	-0.029	0.055
Tp10	0.013	1.326	31.136	0.610	-0.034	0.060
Tp11	0.011	1.471	25.270	0.760	-0.041	0.062
Tp12	0.012	3.141	10.665	0.500	-0.045	0.070
Tp13	0.008	8.716	3.462	0.410	-0.055	0.072
Tp14	0.016	10.184	2.670	0.470	-0.055	0.087
Tp15	0.014	11.663	2.100	0.800	-0.064	0.093
Tp16	0.008	10.254	2.152	0.740	-0.079	0.095
Tp17	0.011	15.634	1.271	0.750	-0.086	0.108
Tp18	0.009	18.660	0.960	0.760	-0.099	0.116
Tp19	0.012	28.374	0.569	0.570	-0.107	0.131
Tp20	0.017	58.324	0.249	0.510	-0.131	0.133
GVA per worker						
Average annual treatment effect	0.013	0.650	160.042	0.684	-0.024	0.050
Tp0	0.009	4.568	13.272	0.840	-0.023	0.040
Tp1	0.017	0.457	149.104	0.620	-0.011	0.045
Tp2	0.017	0.199	326.071	0.660	-0.013	0.046
Tp3	0.013	0.303	204.065	0.830	-0.018	0.044
Tp4	0.012	0.352	167.048	0.470	-0.020	0.045
Tp5	0.015	0.252	222.150	0.520	-0.019	0.049
Tp6	0.016	0.279	191.017	0.720	-0.020	0.052
Tp7	0.009	0.299	169.729	0.580	-0.029	0.046
Tp8	0.017	0.374	129.585	0.810	-0.023	0.057
Tp9	0.013	0.345	133.715	0.830	-0.028	0.055
Tp10	0.013	0.292	150.559	0.690	-0.031	0.056
Tp11	0.009	0.364	114.875	0.700	-0.037	0.055
Tp12	0.010	0.364	109.358	0.620	-0.038	0.059
R&D expenditure						
Average annual treatment effect	0.013	3.625	443.633	0.655	-0.038	0.062
Tp0	0.014	0.144	923.730	0.800	-0.001	0.028
Tp1	0.016	0.064	1,881.273	0.590	0.000	0.032
Tp2	0.015	0.076	1,414.476	0.840	-0.003	0.033
Tp3	0.010	0.059	1,653.564	0.500	-0.010	0.029
Tp4	0.010	0.081	1,074.193	0.690	-0.012	0.032
Tp5	0.014	0.086	918.668	0.730	-0.010	0.038
Tp6	0.017	0.118	603.314	0.570	-0.010	0.044
Tp7	0.015	0.196	326.389	0.810	-0.015	0.045
Tp8	0.009	0.290	198.651	0.650	-0.024	0.042
Tp9	0.016	0.379	136.834	0.840	-0.021	0.053
Tp10	0.008	0.811	57.657	0.690	-0.033	0.049
Tp11	0.013	0.761	55.369	0.620	-0.032	0.059
Tp12	0.017	1.181	32.135	0.400	-0.034	0.067
Tp13	0.010	2.617	13.064	0.610	-0.046	0.066

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Tp14	0.009	4.068	7.571	0.790	-0.053	0.071
Tp15	0.008	4.680	5.928	0.600	-0.061	0.077
Tp16	0.010	4.178	5.982	0.510	-0.066	0.087
Tp17	0.013	9.910	2.272	0.460	-0.073	0.098
Tp18	0.017	6.045	3.356	0.770	-0.078	0.111
Tp19	0.009	14.850	1.231	0.440	-0.096	0.114
Tp20	0.015	25.532	0.645	0.850	-0.116	0.118

Source: Ipsos UK analysis.

H.2. Spatial effects

A series of analyses were completed exploring the spatial impacts of UK Space Agency contracts at the local level. This was achieved by redefining the unit of analysis as the Output Areas located within a predefined distance from firms receiving contracts. The analysis is predicated on the assumptions that the strength of the effects of the contracts on economic activity within an area will depend on the number of firms located nearby receiving a contract (i.e. a dose-response relationship) and that the strength of these effects will vary by distance (a distance-decay relationship).

This exercise required mapping firm locations and drawing a boundary around each firm up to 20km within which economic activity could be observed, accomplished using postcodes provided by the UK Space Agency and mapped in QGIS.

We used the following approach to examine the following local impacts of UK Space Agency activity:

- **Local firms' productivity:** The ABS holds longitudinal data on GVA and was used to explore the extent of any local agglomeration effects by examining how far there is evidence of a positive effect on the productivity of firms located in proximate areas.
- **Local employment:** The BSD offers longitudinal data on employment at an Output Area level, which can be used to explore the extent of any local displacement or multiplier effects. In this case, if the estimated employment effects within a certain distance are smaller than the estimated direct effects of contracts, this would provide prima facie evidence of local (net) displacement effects (with the reverse holding if the estimated local effect is positive).
- **Clustering effects:** The BSD also allows for the analysis of how far UK Space Agency contracts have supported clustering effects, in which firms concentrate around those receiving contracts to benefit from local agglomerations. This was explored by defining an outcome as the number of local firms operating near the firm receiving the contract.
- **Unemployment claimants**: DWP data on out-of-work claimants was used to determine how far any local spillover effects are visible in the number of people returning to work.

For this analysis, estimates of the impact of the contracts will be biased if recipients tend to be located within existing clusters of innovative firms. As areas without nearby recipients would otherwise form the effective comparison group for the analysis, this approach could overstate the effects of contracts, as existing clusters could be expected to grow more rapidly regardless of public intervention. This issue was mitigated by limiting the focus to only those areas near firms receiving contracts (defined as within 10km).

The estimating equation for the spatial analysis is as follows:

$$y_{it} = \alpha + \left(\beta^1 T_{it}^{0-1km} + \beta^2 T_{it}^{1-5km} + \beta^3 T_{it}^{5-10km} + \beta^4 T_{it}^{10-20km}\right) + \rho \cdot X_{it} \cdot t + \alpha^i + \alpha^t + u_{it}$$

This distance-decay model explains outcomes in area i in period t as a function of the cumulative number of contracts awarded to firms located at greater distances from area i (T_{it}^{j}).

Here, the parameter β^1 captures the direct effect of the contracts in the areas in which firms are located. These can be compared directly with estimates of the firm-level impacts of the contracts to draw inferences on the net local impacts of UK Space Agency funding (e.g. if the area-level effect on employment is smaller than the firm-level effect, this would imply that UK Space Agency-supported firms have expanded by drawing resources away from other local firms).

The parameters β^2, β^3 and β^4 capture the effects of contracts awarded to firms located at distances of 1–5km, 5–10km and 10–20km, respectively. Positive coefficients indicate positive spillover effects, e.g. if contracts have encouraged agglomeration of economic activity. Negative coefficients would signal that UK Space Agency contracts have crowded out or displaced economic activity in nearby areas.

These results are not directly comparable to those of the firms themselves, given the differences in the methods used (staggered difference-in-difference versus the two-way fixed effects type model). This is because the staggered difference-in-difference approach does not currently account for more than one treatment variable and would, therefore, limit analysis to just one spatial area at a time.

We found that **UK Space Agency contracts had a positive net economic impact on local economic growth and productivity**. The impacts included:

- **Increased activity within the Output Area (OA) of the firm:** Each contract led to an approximate 5.1% increase in the number of jobs within the OA where the recipient firm was located, a 6.3% increase in the turnover of firms based in the area and a 3.4% increase in turnover per worker. These impacts are broadly comparable to those observed amongst those applying for funding, suggesting that displacement or crowding-out effects at the local level were negligible.

- **GVA impacts:** Within the OA where the recipient firm was located, contracts are estimated to have led to a 4.7 and 2.8% increase in local GVA and GVA per worker, respectively.

- **Clustering**: The results show that the contracts awarded positively affected the number of firms located in areas proximate to those awarded contracts. These effects were largest in areas 1–10km from the firms' receiving contracts (4.3% in areas 1–5km away and 2.5% in areas 5–10km away). This indicates that UK Space Agency contracts produced clustering effects at the local level, with no evidence of net displacement effects within 10km.

- **Increased activity within proximate areas**: There were also positive economic impacts at distances 1–10km from those awarded contracts. Larger effects were observed for employment and turnover at distances 1–5km compared to areas 5–10km away, and there was no evidence of net displacement or crowding-out effects locally. Impacts on GVA and GVA per worker were only identified in areas 1–5km away where effects were present outside the OA of the recipient firm. These areas saw an estimated increase in GVA and GVA per worker of 0.5% and 0.3%, respectively.

- **Impacts on unemployment:** No statistically significant impacts were found on unemployment in the analysis of claimant counts, suggesting that the increases observed in firm and local employment came from workers moving between firms. This is perhaps expected given the specialised nature of many of the jobs in the sector.

A robustness check of the analysis was also conducted using the same models and data with an alternative specification of the firm locations. Specifically, for one large corporation, the firm locations used in the models were limited to the two company sites in which the majority of the firm's space-related activity takes place. This alternative specification did not find different estimates of effects on the outcomes of interest.

These findings indicate that UK Space Agency funding has produced positive spillover effects for local economies. Given the evidence on firm relocations, it is assumed that some of this effect has come from attracting higher-value activities to the area and increasing output for existing firms. Notably, there will likely be corresponding negative effects on some local economies from which activities were relocated.

The full results of the econometric analysis are presented in Table below.

Table 40: Estimated indirect effects of UK Space Agency contracts – comparisons between Output Areas within 20km of firms awarded contracts

Outcome	Coefficient	T-stat	P value
Employment			
In OA	0.051***	3.716	0.002
Within 1km	0.006	0.972	0.240
1–5km	0.005**	1.669	0.063
5–10km	0.001*	1.142	0.174
10–20km	0.000	0.453	0.261
Turnover			
In OA	0.063***	4.144	0.001
Within 1km	0.009	1.420	0.110
1–5km	0.007**	1.948	0.040
5–10km	0.003	2.825	0.102
10–20km	-0.000	0.274	0.316
Turnover per worker			
In OA	0.034*	1.027	0.094
Within 1km	0.002	0.594	0.283
1–5km	0.003	0.548	0.298
5–10km	0.001	0.700	0.250

Outcome	Coefficient	T-stat	P value
10–20km	-0.001	0.588	0.292
Number of firms			
In OA	0.008	1.193	0.118
Within 1km	0.007	1.464	0.187
1–5km	0.043*	1.660	0.064
5–10km	0.025*	2.894	0.079
10–20km	0.002	1.201	0.175
GVA			
In OA	0.047***	2.974	0.001
Within 1km	0.005	0.577	0.298
1–5km	0.005*	1.052	0.085
5–10km	0.002	0.857	0.201
10–20km	0.000	0.653	0.384
GVA per worker			
In OA	0.028**	1.809	0.021
Within 1km	0.000	0.522	0.194
1–5km	0.003*	1.426	0.090
5–10km	0.001	0.393	0.251
10–20km	0.001	0.574	0.248
Claimants			
In OA	-0.004	1.038	0.264
Within 1km	-0.000	0.587	0.195
1–5km	-0.001	1.103	0.395
5–10km	-0.002	0.987	0.208
10–20km	0.000	0.572	0.213

Source: Ipsos UK analysis. ***, **, and * indicate that the estimated coefficient was significant at the 99%, 95% and 90% confidence levels, respectively. All models were estimated to have fixed effects and unobserved time-specific shocks.

Annex I. Economic evaluation approach

I.1. Deflators and discounting

In line with the HM Treasury Green Book, the costs and benefits of social value should be estimated in 'real' base-year prices, i.e. removing the effects of general inflation. Both costs and benefits have been deflated to 2023 prices using GDP Deflators at Market Prices derived from the National Accounts and published quarterly by the ONS.

Discounting both costs and benefits is required to compare costs and benefits occurring over different periods. Discounting social value is based on time preference – people generally prefer to receive goods and services now rather than later. As suggested by the HM Treasury Green Book, a 3.5% discount rate is applied to all years following the first year of costs in 2000.

I.2. Return on public investment

The analysis of the return on public investment follows HM Treasury Green Book guidance and builds on the SDiD econometric results presented in Section H.1. The objective of this analysis is to estimate the NPV and BCR of ESA investments, drawing on robust empirical evidence of the economic impacts generated by ESA contracts awarded to UK firms.

I.2.1. Benefits

The benefits quantified in this analysis are derived from the estimated additional GVA per worker attributable to ESA contract funding, as identified through the staggered SDiD analysis detailed in Section H.1. Consistent with HM Treasury Green Book guidance, the valuation focuses exclusively on productivity-related benefits, specifically, the statistically significant direct effects on GVA per worker observed at the $p < 0.05$ level. Other economic impacts estimated through the SDiD analysis are excluded from the benefit calculation to avoid double counting and to ensure alignment with Green Book principles. Productivity-based measures such as GVA per worker are preferred because they are less likely to reflect displacement effects and are more likely to capture genuine net economic benefits.[76]

[76] Displacement effects occur when gains in one area come at the expense of losses elsewhere in the economy (e.g. a contract boosts one firm's output but reduces demand for competitors). GVA per worker is less sensitive to these issues than gross output measures such as turnover because they reflect improvements in output per unit of labour, rather than gross increases in activity. In the case of ESA contracts, the focus on innovation and high-tech capability

To estimate the total benefits, we applied the observed firm-level treatment effects to the full contract recipient population over an eight-year assumed benefit period. This time window reflects the period when the estimated effect on GVA per worker is statistically significant at the $p < 0.05$ level. Specifically, the effect becomes statistically significant from the fifth year following the contract award, and the dataset permits a maximum of 13 years of post-treatment observation, yielding an effective eight-year window during which statistically robust benefits can be identified. We applied the annual treatment effects to contractors' baseline GVA per worker, number of employees[77] and the total ESA contract value for each award year.[78] We calculated both variables using a winsorised mean to mitigate the influence of outliers and ensure that these outliers do not distort the aggregate benefit estimates.

Applying year-specific treatment effects allows for a more precise aggregation of benefits compared to application of the average annual treatment effect across all years, as the former captures heterogeneity in the magnitude and statistical significance of impacts across post-treatment years. In the SDiD specification, treatment effects are estimated separately for each post-treatment year. Importantly, some of these year-specific estimates do not reach conventional levels of statistical significance ($p < 0.05$), even when the average annual treatment effect across all post-treatment years is statistically significant. Isolating and applying only statistically significant annual effects for the aggregation of benefits therefore leads to a more precise estimate. This represents best practice in economic evaluation when year-specific effects are available and statistically robust. A winsorised mean is a statistical measure that reduces the impact of outliers by capping extreme values within a dataset, which typically involves replacing extreme values with the nearest non-outlier value rather than excluding these values from the analysis. The standard approach to estimating economic benefits using the SDiD results discussed earlier in this report is to calculate an average GVA per worker uplift attributable in statistical terms to ESA contracts and scale this up using a 90% trimmed mean of baseline firm employment and GVA figures. This approach is appropriate when the distribution of firms by employment and GVA is not highly skewed. However, in the case of ESA contracts, the firm distribution is highly skewed: one large corporation accounts for approximately 47% of the total contract value awarded to UK companies. In this context, applying a trimmed mean (which excludes the top and bottom 10% of firms based on size) would understate the benefits of public investment. Conversely, using an unadjusted mean would overstate the benefits due to the outsized influence of the dominant firm, which would skew the data. We employed a winsorised mean to baseline employment and GVA per worker data to address this. National statistical agencies (including the ONS) commonly use this statistical measure to improve the

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development further supports the use of productivity-based metrics as these investments are intended to enhance firms' efficiency and long-term competitiveness rather than simply increase output volume.

[77] Baseline values for GVA per worker and employment were calculated using firm-level records accessed through the ONS Secure Research Service. For each firm in the sample, we obtained the relevant indicators for the firm's baseline year, defined as the year before they received the ESA contract under study (t-1). This year varies across the sample depending on the timing of contract receipt. We then calculated the winsorised mean across the sample to derive baseline values. For those firms with multiple contracts, the baseline year was defined as t-1 for the first contract.

[78] Total benefit in year A = Weighted annual treatment effect $_A$ × baseline GVA per worker × baseline number of employees × total ESA contract value awarded in year A.

quality of business survey statistics.[79] It accounts for the influence of the large corporation in question without allowing its considerable size to skew the results disproportionately.

For this analysis, the employment and GVA values associated with the largest outlier firm and firms with the minimum non-zero value were winsorised by imputing the nearest non-outlier value within the dataset. As a robustness check, we calculated an alternative baseline employment mean in which we imputed the employment value for the outlier firm with data on headcount at the firm's primary UK sites focused on space-related activity. The resulting mean was larger than the winsorised mean by 26%. The trimmed mean was approximately four times smaller than the winsorised mean, while the unadjusted mean was nearly three times larger. These results reassure us that using the winsorised mean is appropriate for this context. Importantly, we have conducted an analysis to test for statistically significant differences in the estimated treatment effect of ESA contracts on small versus large firms and found no such differences.

We applied the estimated annual treatment effect to contractors' winsorised baseline GVA per worker and employment figures to generate total nominal benefit estimates. We then adjusted these nominal benefits using the deflators and discounting approach described in Section I.1.

We additionally conducted a sensitivity analysis to assess the robustness of the benefit estimates to statistical uncertainty in the treatment effect by re-estimating total benefits using the lower and upper bounds of the 95% confidence interval around the treatment effect for GVA per worker. The lower-bound estimate provides a conservative scenario, reflecting the minimum plausible benefit level consistent with the observed data and confidence level. Conversely, the upper-bound estimate reflects an optimistic scenario, assuming the treatment effect is at the upper end of the confidence interval. The results are presented in Table 41below.

Table 41: Sensitivity analysis of the benefits of ESA contract funding

Assumption	Estimated coefficient	Benefits (net present value)	BCR
95% CI lower bound	0.020	£4.922 billion	1.33
95% CI upper bound	0.059	£50.683 billion	13.65

Source: Ipsos UK analysis.

I.2.2. Costs

The cost of the UK Space Agency's investment in ESA programmes over the period under analysis is based exclusively on direct public sector contributions. As these costs are to be used for estimating a public BCR (rather than a broader social BCR), the cost base reflects only expenditure by the public sector, excluding any private R&D expenditure that may have been leveraged due to programme participation. We deflated and discounted all cost estimates per the methodology set out in Section I.1, which aligns with HM Treasury Green Book guidance.

Direct costs: The principal cost component is the UK Space Agency's financial contributions to ESA. For the 2013–2022 period, these contributions are drawn directly from ESA's financial reporting obligations.

[79] See, for example, Martinoz et al (2015); Office for National Statistics (2024).

These figures correspond to the investments for which direct economic benefits to UK-based ESA contractors have been calculated in the benefit analysis.

Between 2000 and 2012, comprehensive records of the UK Space Agency's contributions to ESA were unavailable. As a result, we modelled a cost estimate for this period using ESA contract data. Specifically, we uplifted the value of contracts awarded to UK firms during this period by an overhead adjustment factor to approximate the UK Space Agency's financial contribution. This adjustment factor (16.9%) was calculated as the average percentage difference between ESA contract values and the UK Space Agency's contributions between 2013 and 2022 period. This was applied uniformly across the earlier contract values to approximate the corresponding programme costs.

Programme overheads: Besides direct financial contributions to ESA, the UK Space Agency incurs internal programme management and administrative overheads associated with delivering and overseeing ESA-related activities. No complete administrative dataset was available for these costs over the full appraisal period. Therefore, an estimate was constructed to reflect staff costs and associated non-staff overheads.

The UK Space Agency provided an estimate of the number of full-time equivalent (FTE) staff involved in ESA-related work by civil service grade. These FTE estimates were mapped to salary bands using ONS Civil Service Statistics (2007–2022) data. For the 2012–2022 period, grade-specific salary data was available for the UK Space Agency. Without agency-specific data, we applied median civil service grade-specific salary data for the preceding period (2007–2011). For earlier years (2000–2007), where no civil service salary data were available, we deflated the 2007 salary estimates using ONS annual growth rate in wages and salaries data.

To account for variation in administrative activity intensity over the period, we applied an adjustment factor to the 2000–2008 period, reflecting a clear discontinuity in ESA-related expenditure between the appraisal period's earlier and later years. The volume of ESA-related activity was materially lower prior to 2009 due to lower levels of UK investment in ESA programmes and limitations in the underlying contract dataset used to estimate programme benefits. Specifically, the available contract data for 2000–2008 represents only a partial subset of total contracts, as earlier records are not fully digitised (and therefore not accessible). The period 2009–2022 (characterised by higher levels of ESA engagement) was used as the baseline (index = 1), with salary estimates for 2000–2008 scaled proportionally downward based on the relative value of ESA-related activity during those years.

Estimated salary costs were then adjusted to reflect total labour costs, applying a non-wage uplift using the ONS Index of Labour Costs per Hour for the public administration sector. As these data were only available for 2011–2022, we imputed values for earlier years using the closest available year rather than the average to reflect the secular downward trend in the wage cost share over time.

Finally, an uplift was applied to estimate total overheads beyond labour costs. This was based on an analysis of UK Space Agency Financial Statements for 2018/2019 through 2022/2023 (published in UK Space Agency Annual Reports). Net operating expenditure, excluding subscriptions, grants and other programme funding, was used to calculate the average staff cost share of total operating expenditure. The inverse of this share was used to estimate an uplift factor for total overheads. The five-year average of this ratio was applied to the staff cost estimates to generate a full estimate of the UK Space Agency's programme overheads over the appraisal period.

I.3. Return on investment

I.3.1. Benefits

The approach to estimating benefits to calculate the return on investment follows the same methodology used for estimating the return on public investment, which is set out section I.2.1 above. Specifically, this is based on estimates of additional GVA per worker attributable to ESA contract funding which are modelled using SDiD econometric analysis. To calculate the aggregate economic benefit, we applied the observed treatment effects from the SDiD analysis to the full contract recipient population over an eight-year assumed benefit period. This time window reflects the period when the estimated effect on GVA per worker is statistically significant at the $p < 0.05$ level. For further detail, please refer to section I.2.1 above.

I.3.2. Costs

The net social cost of the programme is largely comprised of the net increases in investment induced in terms of (a) R&D expenditures and (b) follow-on capital investment. These costs were estimated based on the SDiD findings to provide an estimate of the lifetime social cost of the programme:

- **Value of additional R&D spending:** Estimates of the average effects on R&D spending were aggregated across the full contract recipient population over a ten-year assumed cost period. This time window reflects the period when the estimated effect on R&D expenditure is statistically significant at the $p < 0.05$ level.
- **Value of additional capital investment:** Estimates of the average effects of the programme on capital investment across the full contract recipient population over a five-year assumed cost period. This time window reflects the period when the estimated effect on capital expenditure is statistically significant at the $p < 0.05$ level.
- **Administrative costs:** Both ESA and the UK Space Agency incur internal programme management and administrative overheads associated with delivering and overseeing ESA-related activities. Because no complete administrative dataset was available for these costs over the full appraisal period, an estimate was calculated based on the return on public investment analysis. Specifically, for ESA, a 16.9% overhead was calculated from the total value of UK financial contributions to ESA over the period (for further detail, see section I.2.1 above). For the UK Space Agency, the administrative cost estimate used in the return on public investment analysis was applied here, as detailed in section I.2.1 above.

I.3.3. Results

R&D expenditure

The results of the SDiD analysis indicate that £1m of ESA contract funding led to an average annual increase of 6.6% in R&D expenditure among beneficiary firms over the time period of the analysis. This uplift is observed from the year of ESA contract receipt and remains statistically significant at the $p < 0.05$ level for a ten-year period, after which the effect is no longer statistically significant. The detailed SDiD findings are provided in Section 2.2.4 of the main evaluation report and section H.1.5 of this technical annex.

When applied to the entire population of contract recipients and over the assumed cost duration of ten years, we estimated the total aggregate R&D expenditure uplift associated with the programme at £3.458bn in constant 2023 prices.[80] The approach to applying the observed treatment effects to the full contract recipient population is the same as that used for the programme benefits, as described in section I.2.1 above.

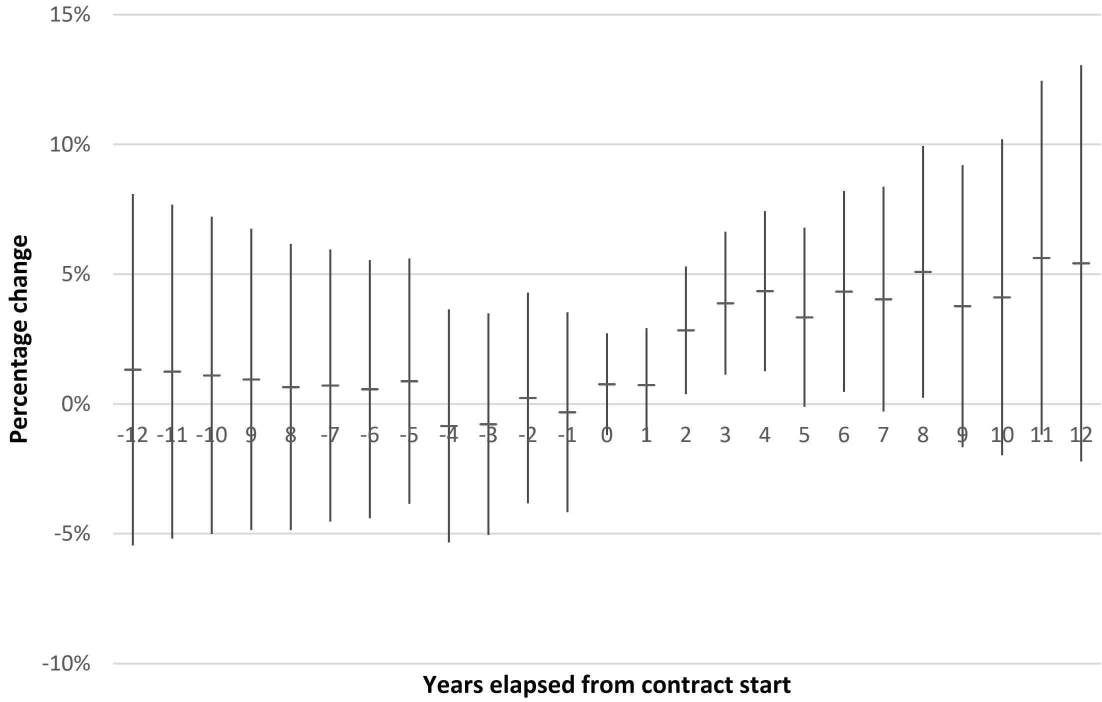
Capital expenditure

The results of the SDiD analysis indicate that £1m of ESA contract funding led to an average annual increase of 3.7% in capital expenditure among beneficiary firms over the time period of the analysis. This uplift is observed to be statistically significant (at the $p < 0.05$ level) from the second to the fourth year following the award of an ESA contract, becomes non-significant thereafter, and is again statistically significant in the sixth- and ninth-years post-award. Further detail is provided in Figure 4 and Table 42 below.

The error bars in Figure 4 represent 95% confidence intervals, illustrating the range within which we can be 95% confident that the true impact likely sits. Table 42 presents the full regression output from the SDiD analysis, including estimates of the average treatment effects by year (prefixed with Tp).

[80] We conducted a sensitivity analysis to account for the statistical uncertainty in the estimated treatment effect. This involved recalculating the aggregate economic impact using the lower and upper bounds of the 95% confidence interval for the estimated R&D expenditure effect. The lower bound estimate of R&D expenditure was £2.798bn (based on the 3.1% lower bound effect size), while the upper bound estimate was £4.119bn (based on the 10.2% upper bound effect size).

Figure 4: Effects of ESA contracts on capital expenditure among UK beneficiary companies



Source: Ipsos UK analysis

Table 42: Effect of £1m in ESA contract value on contractor firm capital expenditure

	Coefficient	Std. error	z	p-value	95% CI lower bound	95% CI upper bound
Average treatment effect	0.037	0.023	2.388	0.032	0.022	0.112
Tp0	0.008	0.010	1.290	0.099	-0.012	0.027
Tp1	0.007	0.011	1.103	0.135	-0.015	0.029
Tp2	0.028	0.013	4.106	0.003	0.004	0.053
Tp3	0.039	0.014	4.835	0.000	0.011	0.066
Tp4	0.043	0.016	5.306	0.000	0.013	0.074
Tp5	0.033	0.018	3.711	0.103	-0.001	0.068
Tp6	0.043	0.020	3.584	0.017	0.005	0.082
Tp7	0.040	0.023	3.032	0.215	-0.003	0.084
Tp8	0.051	0.025	3.354	0.098	0.002	0.099
Tp9	0.038	0.028	2.377	0.009	-0.017	0.092
Tp10	0.041	0.032	2.492	0.635	-0.020	0.102
Tp11	0.056	0.036	2.991	0.139	-0.012	0.124
Tp12	0.054	0.040	2.310	0.105	-0.022	0.131

Source: Ipsos UK analysis

The analysis will produce unbiased findings if there are no systematic differences between firms awarded funding at different points in time. Our event study analysis confirmed that this assumption (i.e. the parallel trends assumption) holds for the outcome variable. Table 43 below presents the results of this analysis, showing the average pre-treatment effect, the average difference in outcomes in the pre-treatment period between those funded earlier and firms funded later. If the parallel trends assumption is valid, this coefficient should not be statistically different from zero ($p < 0.05$).

Table 43: Average SDiD pre-treatment effect for effect of ESA contract value on capital expenditure

	Coefficient	p-value	95% CI lower bound	95% CI upper bound
Average pre-treatment effect	0.005	0.104	-0.001	0.019

Source: Ipsos UK analysis

When applied to the entire population of contract recipients and over the assumed cost duration of five years, we estimated the total aggregate capital expenditure uplift associated with the programme at £197m in constant 2023 prices.[81] The approach to applying the observed treatment effects to the full contract recipient population is the same as that used for the programme benefits, as described in section I.2.1 above.

Administrative costs

The combined administrative costs incurred by ESA and the UK Space Agency over the appraisal period are estimated at £676m in constant 2023 prices, after applying appropriate deflators and discounting in line with HM Treasury Green Book guidance. This estimate reflects the net present value of programme management and overhead costs associated with the delivery and oversight of UK-funded ESA activities, using the methodology outlined in section I.3.2 above and consistent with the approach taken in the return on public investment analysis.

Total costs

The total estimated cost of the programme from a social perspective - incorporating R&D expenditure, capital investment and administrative costs - is £4.331bn in constant 2023 prices, after deflating and discounting in line with HMT Green Book guidance. This compares to a total public cost of £3.714 billion based on the administrative data used in the return on public investment analysis. The higher social cost reflects the inclusion of private sector investment and indicates a degree of crowding-in, whereby public funding has stimulated additional investment by contract recipient firms.

Benefit-cost ratio

We estimate the BCR for the UK Space Agency's contributions to ESA at 6.42.[82]

I.4. Monetisation of wider socio-economic benefits

The methods used to estimate, in monetary terms, wider socio-economic benefits represent novel methods that aim to estimate the benefits of ESA missions to the UK and wider. Although these methods are consistent with the HM Treasury Green Book, they are not commonplace in cost-benefit analysis. Therefore, we do not include these estimates within the main cost-benefit analysis. Instead, they provide a flavour of the potential additional benefits while pushing forward the methodologies that could be expanded on in future evaluations, including the Value of Information (VoI) approach and an estimate of the benefits from space debris removal (focusing on the increased running and replacement costs for satellite owners).

[81] We conducted a sensitivity analysis to account for the statistical uncertainty in the estimated treatment effect. This involved recalculating the aggregate economic impact using the lower and upper bounds of the 95% confidence interval for the estimated capital expenditure effect. The lower bound estimate of programme benefits was £19m (based on the 2.2% lower bound effect size), while the upper bound estimate was £374m (based on the 11.2% upper bound effect size).

[82] Sensitivity analysis based on the 95% confidence interval of the estimated economic impact indicates a lower bound BCR of 1.41 and an upper bound BCR of 9.81.

I.4.1. Value of Information

The Value of Information (VoI) approach provides an opportunity to quantify and monetise socio-economic benefits specific to missions based on their improvement in decision-making.

The examples included are not exhaustive but provide a flavour of the types of benefits that could, in theory, be derived from ESA missions. However, the findings should be interpreted cautiously since this is a novel, assumptions-based approach. The VoI approach implicitly assumes that a percentage improvement in the accuracy of available information directly links to the percentage change in socioeconomic value. In practice, it is very difficult to know the extent to which this assumption is likely to be correct, given that forecasting is likely to include a range of evidence besides that provided by ESA missions, and it is even harder to know whether decision-makers will act on those forecasts even if correct. We have therefore provided an assessment of the strength of the causal link (how likely is it that information from the mission will be used in decision-making in the context of the example) and the underlying assumptions (the strength of assumptions that the change in accuracy will lead to the magnitude of socioeconomic benefits suggested). Due to the uncertainties described, the estimated value included below is therefore not included in the core benefit-cost ratio and instead intended to provide a sense of the additional value that could be created through ESA investment. Calculations and assumptions used to estimate the benefits are included in the methodological annex. In keeping with the uncertainty-aware approach, each example includes an assessment of the strength of the causal link between ESA and the outcomes and an assessment of the underlying assumptions.

This methodology acknowledges that while some benefits can be directly observed and measured using large datasets, others may be indirect or intangible and thus require a more exploratory approach to valuation. The methodology stems from a desire to better articulate the value derived from investments, particularly in areas where traditional evaluation methods fall short. The VOI approach also offers an opportunity to capture global impacts, for example supporting prediction of weather events, which are also included in this section.

The VoI approach is not based on existing data but instead relies on interviews and desk research to identify previous, current and future uses of outputs from ESA-funded missions.

The identified examples include:

- Improved confidence in assessing air travel risks following natural events
- Impact of better decision making on hurricane response
- Improved solar power forecasting reducing inefficiency costs
- Improved climate change prediction bringing forward decision-making
- Improved identification of degraded peatland for restoration.

Therefore, the estimates provided through the approach can be used to better understand the magnitude of benefits that could come from ESA missions. Given the limitations of this approach, we have included a two-point comparative rating on the strength of assumptions:

- The causal impact of missions: Certainty over the impact of mission outputs to improving the specific socio-economic impacts identified.
- The underlying assumptions: The attribution of the expected impact from mission outputs' in improving the specific socio-economic impacts identified.

Prioritisation of use cases has focussed on the potential value that can be robustly estimated while remaining proportionate to the assessment scale. This results in a selective deep dive into specific ESA programs that promise significant informational value, guided by historical data and current engagement with the UK Space Agency.

In contrast to earlier assessments that may have employed point estimates or proprietary models, the updated VoI methodology emphasises transparency, reproducibility and a more accurate articulation of uncertainty. It ensures that all data used is accessible and that any primary data collection methods can be replicated in future assessments. The examples and respective calculations used to derive the estimated benefits are included below.

Improved prediction of floods contributing to reducing economic costs

Causal link: Medium-strong (the link between Aeolus-2 and improved weather prediction is well documented; however, evidence of improvement is less evident for the UK than in other areas worldwide).

Underlying Assumptions: Medium-low (decision-making on floods is likely to incorporate a range of datasets, and it is, therefore, hard to say to what extent data provided by Aeolus-2 will improve decision-making).

Background

Aeolus-2 is expected to reduce errors in wind speed measurements and improve resolution compared to its predecessor.[83] More accurate weather predictions allow for earlier flood warnings, giving authorities and residents more time to prepare and mitigate potential damage. While the most significant impacts are seen in the tropics and polar regions, there are still improvements in European forecasts.

For example, weather forecasts in the Northern Hemisphere's middle latitudes are improving, with predictions of air pressure at 5km altitude, a key factor in temperature and wind patterns, now 0.5–1% more accurate up to four days out.[84] Higher resolution data from Aeolus-2 could lead to more localised flood predictions, allowing for targeted preparedness measures. Earlier and more accurate warnings allow for better flood prevention measures, potentially reducing the overall damage caused by flooding. More precise predictions enable authorities to allocate resources more efficiently, focusing on the highest-risk areas.

Estimation of value in monetary terms

The UK experienced major floods in 2007, 2013/2014 and 2015/2016. According to estimates from DEFRA and the Environment Agency, the cost of flooding in these years equated to:

- £3.2bn in 2007 (£5.01bn in 2024 prices)[85]
- £1.3bn in 2013/2014 (£1.77bn in 2024)[86]

[83] Airbus (2025).
[84] Rennie et al. (2022).
[85] Environment Agency & Defra (2021).
[86] Environment Agency & Defra (2016).

- £1.6bn in 2015/2016 (£2.17bn in 2024).[87]

More precise predictions enable authorities to allocate resources more efficiently, focusing on the highest-risk areas. We assume a 0.5-1% improvement directly translates to cost reduction. Taking an average of the cost of floods in 2007, 2013/2014, and 2015/16 is £2.98bn in 2024 prices. Applying a 0.5%-1% reduction in costs from better prediction suggests a saving of £14.9–29.8m for a heavy flood year.

Improved confidence in assessing air travel risks following natural events

Causal link: Medium-strong link (the link between Aeolus-2 and wind prediction is well documented. However, evidence of improvement is less evident for Northern Europe than other areas worldwide).

Underlying Assumptions: Medium-low (there are likely to be several factors influencing decisions as to when to allow flights following a natural event. Therefore, it is hard to say how much Aeolus-2 data would improve confidence.

Background

Aeolus-2 has the potential to significantly improve decision-making in aviation safety during high-risk natural events by enhancing wind prediction and modelling. An example of this is the improvement in volcanic ash dispersion modelling. The accuracy of volcanic ash early warning systems depends on precise meteorological inputs. Aeolus-2's advanced lidar technology could provide higher-resolution wind measurements, enabling more accurate forecasts of ash plume pathways.[88] Studies have shown that assimilating Aeolus wind data into Numerical Weather Prediction (NWP) models significantly improves volcanic ash simulations, as evidenced during the Etna eruption in 2021.

Estimation of value in monetary terms

The eruption of Iceland's Eyjafjallajökull volcano is a recent example of an event during which 80% of European flights were cancelled, causing a net impact on the UK GDP of an estimated £466m (2010 prices).[89] Research shows that a similar volcanic event which could ground flights in Northern Europe should be expected around once every 44 years.[90]
Studies have shown that assimilating Aeolus wind data into NWP models significantly improves volcanic ash simulations, as evidenced during the Etna eruption in 2021.[91]

Research by NASA estimates that accurate wind prediction would have allowed 12% of cancelled scheduled flights to run on time, significantly reducing revenue losses due to unnecessary delays. We take a more conservative assumption that data improvements of 0.52% directly translate into improved volcanic–ash simulations.

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[87] Environment Agency (2018).

[88] For evidence that assimilating Aeolus wind data into NWP models significantly improves volcanic ash simulations, as seen during the Etna eruption in 2021, see Amiridis et al. (2023).

[89] Research Excellent Framework (2014).

[90] For evidence showing the expected frequency of volcanic eruptions that could ground flights in Northern Europe, see: Watson et al. (2017).

[91] NASA (2023).

Converting the costs of delays of £466m into current prices yields a value of £682m. Our assessment shows that for a similar event, improvements from Aeolus-2 could have between £3–14m in GDP savings from better confidence to fly aircraft on time during natural events such as an ash cloud.

Improved solar power forecasting

Causal link: Low (TRUTHS is not designed to influence solar forecasting, and therefore, the extent to which TRUTHS data will be used in this context is unknown, although its qualities suggest data could be informative for solar forecasting).

Underlying Assumptions: Low (given the uncertainty around using TRUTH to inform decision-making in this context, the underlying assumptions are low confidence).

Background

Better solar forecasts can help run the energy system more efficiently, ultimately leading to lower consumer bills. TRUTHS will make continuous measurements of the Earth's incoming solar radiation and outgoing reflected radiation in the solar reflective domain up to ten times more accurately than current satellites [92]

While TRUTHS itself do not directly forecast solar energy output, its hyperspectral imaging spectrometer and Cryogenic Solar Absolute Radiometer (CSAR) will provide high-resolution data that could be integrated into forecasting models. Reliable solar irradiance data is a critical input for forecasting solar power generation. This allows grid operators to anticipate fluctuations in solar energy supply and balance the grid effectively, reducing the need for conventional power plants and improving grid stability.

Estimation of value in monetary terms

TRUTHS will improve the accuracy of Spectrally Resolved Solar Irradiance (SRSI) to 0.3%. In 2012, the SORCE (Solar Radiation and Climate Experiment) aimed for a SRSI of 0.5% accuracy,[93] suggesting an improvement of 40%.

Evidence from the US suggests that the mis-forecast of solar energy costs around US$1.5 /MWh[94] (2021 prices). This can be converted to £1.40 per MwH (US$1.5 in 2021 prices converted to GBP 2024 prices). Assuming that the costs of mis-forecasting and accuracy of predictions are the same in the UK as in the US, this is a potential cost of £19.6m a year based on estimated energy consumption in the UK of 14 TwH in 2024.[95]

Assuming a 40% improvement (relatively conservative compared to the 10x improvement), we estimate that TRUTHS could reduce solar balancing costs by £8m a year.

Limitations

The differences between the US and UK energy systems mean that applying the estimated cost of mis-forecasting solar energy from the US to the UK creates uncertainty. In particular, we identify that:

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[92] For evidence of 10x improvement to TRUTHS above existing satellites, see NPL (2025).
[93] eoPortal (2012).
[94] Wang et al. (2022).
[95] Department for Energy Security & Net Zero (2025).

- The UK has a unified electricity market managed by National Grid ESO, unlike the US's multiple regional markets with independent system operators, which might have different market dynamics and pricing mechanisms.
- The UK's heavier reliance on wind energy and the US's on solar energy impacts how their systems manage forecast errors differently.
- Differences in grid connectivity, capacity and regulation between the UK and US will likely affect the cost of managing imbalances.

Climate change prediction

Causal link: Strong (a key objective of the TRUTHS mission is influencing policy and decision-making concerning climate change).

Underlying Assumptions: Low (there is very significant uncertainty surrounding the potential behavioural response of future decision-makers).

Background

The TRUTHS mission will improve EO data accuracy, which will, in turn, cut the time required for climate scientists to determine changes to the Earth's temperature. The mission provides 'benchmark' measurements with uncertainties small enough that future change can be detected from a background of natural variability in as short a time as possible.

Estimation of value in monetary terms

Weatherhead et al. provide a formula that models the time taken to detect trends, focusing on environmental data.[96] For global mean temperature, where natural variability (σ_N) is relatively low and trends (ω) are moderate (e.g., ~0.02°C/year), the study suggested that detecting significant trends requires about 19 years of continuous data:

$$n_* \approx \frac{3.3\sigma_n}{\mid \omega \mid (1-\varphi)}^{2/3}$$

- Where: n∗: number of years needed to detect the trend
- σN: Standard deviation of the noise
- ω: Magnitude of the trend per year
- ϕ: Lag-1 autocorrelation of the noise.

Climate data noise comprises natural variability and measurement inaccuracies. Natural variability typically dominates the noise in long-term global temperature data, while measurement inaccuracies contribute a smaller portion. We therefore assume that noise from measurement inaccuracies accounts for 10% of the

[96] Weatherhead et al (1988).

variation. Therefore, a 40% improvement in accuracy from TRUTHS would improve the identification of global trends by around one year or 5%.

Being able to predict trends in global temperatures faster offers several benefits in the fight against climate change:

- Faster validation of climate models: Early detection of trends allows quicker confirmation of whether climate models accurately reflect reality. This helps refine these models, leading to more accurate predictions and a better understanding of how the climate system responds to human activities.
- More effective policy interventions: With faster trend identification, policymakers can make more informed and timely decisions regarding climate change mitigation and adaptation strategies. This allows for quicker adjustments and implementation of policies, leading to more effective climate action.
- Accelerated technology development: Knowing the accurate trajectory of climate change sooner encourages faster development and adoption of new technologies to reduce emissions and adapt to climate impacts. This acceleration is crucial for achieving global climate goals.
- Improved disaster preparedness: Early warning systems for extreme weather events, such as hurricanes, droughts, and floods, benefit significantly from faster trend prediction. This allows for better preparedness, potentially saving lives and reducing economic losses.
- Enhanced public awareness: Evidence of accelerating climate trends, backed by reliable data, can be a powerful tool for raising public awareness and mobilizing action. This increased awareness can drive individual and collective efforts to reduce emissions and support climate-friendly policies.

Therefore, condensing the range of potential benefits set out above into one monetary estimate is extremely challenging. Estimates from the early adaptation investments deliver an estimated benefit-cost ratio range between 2:1 and 10:1, with UK spending this decade estimated at between £4.2–25bn per year[97]. Based on the above estimates, we take a conservative assumption of £4.2bn spending per year on adaption that achieves a 2:1 benefits-cost ratio. Based on this, spending over the next decade will create a benefit of £8.4bn for the UK. We have already seen that TRUTHS is expected to enable decisions around 5% earlier, potentially creating a range of benefits. Applying a 5% improved benefit to the estimated benefit-cost ratio would improve benefits to £8.82bn a year, equating to a £0.42bn per year of spending.

Therefore, our assessment suggests that, **with better data from TRUTHS, trends in global temperature could be identified around one year earlier, which could lead to a saving of around £0.42bn per year based on estimates of future investment in climate change adaption**.

Peatland restoration

Causal link: Strong (satellite data is already well used in peatland evaluation).

Underlying assumptions: Medium-low (it is difficult to know whether identification of peatlands in need of restoration will lead to restoration).

[97] Watkiss, P (2022)

Background

Sentinel 2 regularly monitors various aspects and features of the Earth. By funding ESA, the UK secures access to Sentinel-2 data, which monitors various aspects and features of the earth regularly. High-resolution imagery can help monitor peatland conditions – key ecosystems for climate regulation, water supply, flood prevention and biodiversity. Where peatlands are not effectively identified and protected, they release carbon, contributing to rather than mitigating climate change.

Sentinel-2's high spatial resolution (10m for key spectral bands) and frequent revisit times (five days for both Sentinel-2A and 2B) make it particularly effective for monitoring peatland conditions over large areas. This is especially useful for detecting changes in vegetation and bare peat and creating time-series analyses to track condition changes over time. Compared to alternatives like MODIS or Landsat, Sentinel data provides finer spatial details, crucial for smaller or fragmented peatlands.

Estimation of value in monetary terms

According to the ONS Natural Capital Accounts, there are around 640,000 hectares of peatland in near natural conditions, whereby peatland can hold carbon, storing approximately 1,800 kt CO_2 a year. However, damaged peatlands have become a significant net source of greenhouse gases and represent a risk to global climate, emitting over 20 million tonnes of carbon dioxide equivalents (CO_2e) each year. Preventing further damage and restoring healthy ecosystem function can, therefore, play an important role in climate regulation within the UK. Sentinel-2 imagery has been used to create fine-scale maps of bare peat, a key indicator of degraded peatland. These maps have been scaled up using regression modelling to predict bare peat across larger regions, helping identify areas in poor condition that require restoration interventions. This approach has facilitated targeted restoration efforts by providing cost-effective and large-scale monitoring capabilities.

A study using Sentinel-1 SAR backscatter data from 2023 in Scotland achieved a root mean square error (RMSE) of 2.1 cm for water table depth (WTD) predictions in peatlands. In comparison, multiple linear regression models without Sentinel data achieved a lower accuracy of RMSE = 4.5 cm. This highlights the improved precision of Sentinel-1 data for monitoring WTD in peatlands and an improvement in accuracy of 53%.

In 2018, 80% of 3 million tonnes of peatland in the UK was classed as 'poor condition'.[98] The UK Peatland Programme has seen slow progress, with around 255,000 hectares of peatland restoration between 2018 and 2024. A 53% improvement in peatland restoration would result in an additional 135,000 hectares of peatland restored per year. We make a conservative assumption that the effect will be half as strong, resulting in 67,500 hectares of peatland restored per year. Potential abatement from peatland restoration can provide up to 9 tonnes of CO_2 equivalent (CO_2e) per hectare per year.[99] Our assessment estimates that **through better identification of peatlands using Sentinel-2 data, there could be a reduction in carbon emissions of 1.2m tonnes per year, equivalent to over £40m per year**.

Impact of better decision making on hurricane response

[98] International Union for Conservation of Nature (IUCN) UK Peatland Programme (2021).
[99] Artz et al. (2013).

Causal link: Strong (the link between Aeolus-2 and improved weather prediction is well documented, especially in the US).

Underlying assumptions: Medium-low (decision-making on hurricane response is likely to incorporate a range of datasets, and it is, therefore, hard to say to what extent data provided by Aeolus-2 will improve decision-making.)

Background

Hurricanes are among the costliest natural disasters in the world, with a significant portion of their impact linked to the accuracy of their forecasts. Better prediction of cyclones helps to improve preparation and reduce negative impacts.

Aeolus-2 provides horizontal line-of-sight wind measurements, which are particularly valuable for improving forecasts in the upper and lower stratosphere. These wind profiles help refine the characterisation of steering winds and wind shear, both critical for predicting hurricane tracks and intensities.

Estimation of value in monetary terms

The average cost of 18 major cyclones in the US is US$5.5bn in 2022 prices (£5.01bn in 2025 prices), with an average error in wind speed of 30%.[100] We assume that an improvement of 0.5–2% means that wind speed predictions would improve to 29.4–29.8%. **Our assessment estimates that the value Aeolus-2 data provides in allowing for better prediction and preparedness for hurricanes is around £30m per major hurricane**. Although this is not a benefit directly related to the UK, it shows the potential benefits the UK can contribute internationally through ESA.

1.4.2. Space debris

The socioeconomic benefits of the space safety portfolio extend beyond space weather. Space debris also represents a significant challenge and a potential cost for future space operations.

An avoided-cost method has been employed to estimate the potential benefits of mitigating risks from space debris. Based on NASA research, the method developed assesses the economic implications of orbital debris and the benefits of debris remediation.[101] This approach quantifies the probability of UK satellites needing to employ warnings and manoeuvres to avoid space debris and estimate the collision probability. The cost of manoeuvres and warnings is based on employee time and fuel costs, while the cost of collision is based on the private cost to replace satellites. Therefore, the method is a partial estimate, and the results do not include significant cost savings, namely:

- Socio-economic costs from the loss of mission functionality, e.g. on navigation services or defence. These will likely be significant.
- The need for additional ongoing monitoring due to the increasing amount of space debris.

Probability of warnings, manoeuvres and collisions

[100] Molina & Rudick (2022).
[101] Locke et al. (2024).

The probability of warning, manoeuvres and collisions are based upon the existing forecasts of space debris under varying assumptions of post-mission disposal (PMD). To estimate the number of encounters (warnings and manoeuvres) and collisions, we used the Number of Encounters Assessment Tool (NEAT) developed by COMSPOC. NEAT uses a probability-based algorithm to assess the long-term encounter rate between all pairs of satellites. Therefore, the NEAT tool enables estimates for all satellites of interest (in this case, UK satellites) of the expected number of encounters based on the total amount of space debris.

The costs of manoeuvres, warnings and collisions are estimated based on existing evidence. As mentioned before, these monetary estimates are likely to be an underestimate of the true impact of reducing space debris as the unit costs do not factor in the potential impacts of losing functioning satellites, which could impact communications or data capture, causing potential loss of revenue or cause safety issues, or which are critical for national security. Therefore, the method provides a highly conservative estimate of the costs associated with warnings, manoeuvres and collisions of UK satellites. The table below includes estimates from NASA's research, converted to GBP at 2024 prices.

Table 44: Cost of warnings, manoeuvres and collisions for UK satellites (in £, at 2024 prices)

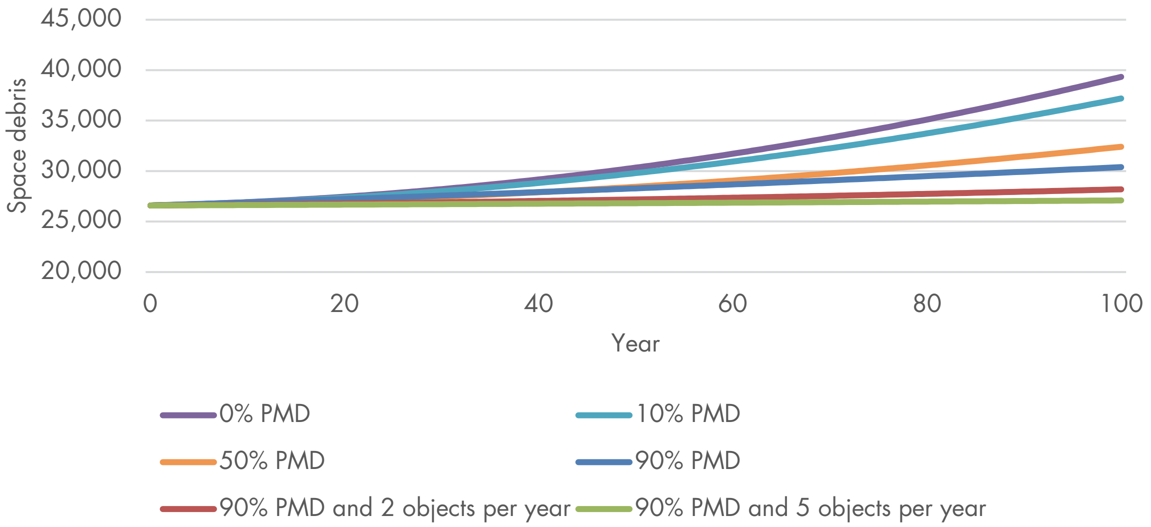
Satellite type	**Number of satellites**	**Warning cost**	**Manoeuvre cost**	**Collision cost**
Government / Military	13	£126	£632	£674,138,400
Commercial (>200kg)	40	£2.50	£548	£916,663,800
Commercial (<200kg)	603	0	0	£2,466,360

Source: Ipsos' own calculations using data provided by COMSPOC's Number of Encounters Assessment Tool.

By applying estimates from LEGEND forecasts to current estimates of space debris,[102] we can estimate the expected quantity of space debris based on both post-mission disposal rates (PMD) and the removal of large space debris.

[102] LEGEND, which stands for Low-Earth-Orbit-to-Geosynchronous-Orbit Environment Debris model, is a model NASA developed to simulate the past and future orbital debris environment in near-Earth space. It covers an altitude ranging from 200–40,000 km, encompassing LEO, MEO, GEO and beyond. The model considers various factors like satellite launches, explosions, collisions, and decay to project how the debris environment might change over time. It provides information on debris characteristics such as size distribution, spatial density, velocity distribution and flux, which helps in understanding the risks associated with orbital debris and developing mitigation strategies.

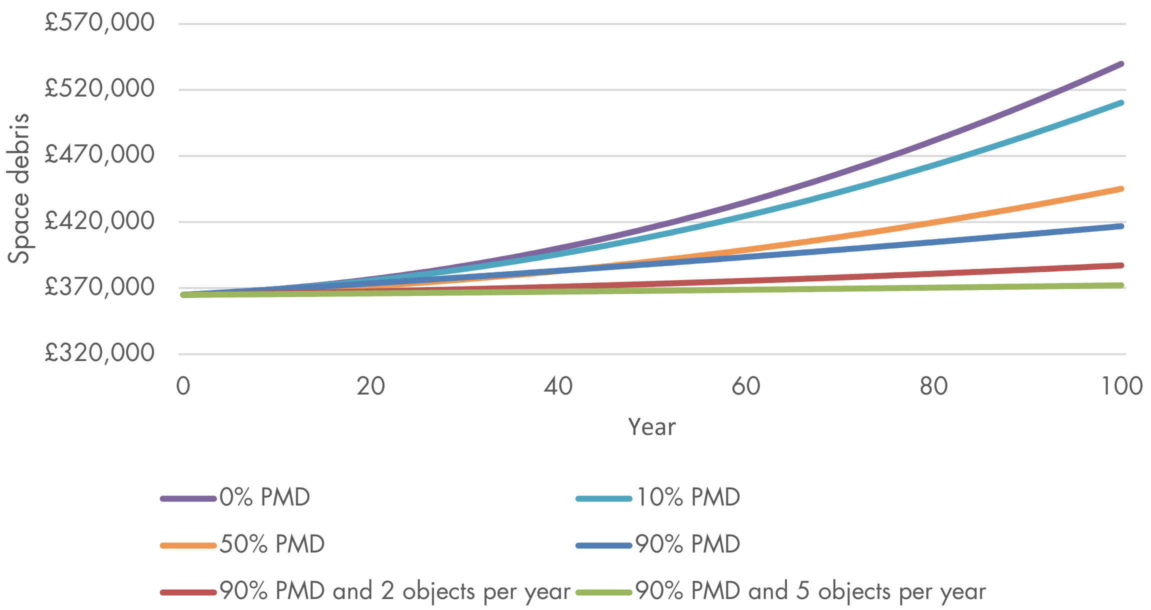
Figure 5: Forecasted quantity of space debris by Post Mission Disposal (PMD) scenario



Source: Ipsos' own calculations using data provided by COMSPOC's Number of Encounters Assessment Tool. RAND Europe Analysis.

The estimates show that the impact on space debris is incremental at first but however, overtime the benefits of space debris removal begin to scale up more noticeably against a 0% PMD scenario. This acceleration is further enhanced by the prevention of potential cascading collisions, which can have exponential negative effects if not addressed. As a result, a long-term perspective is essential when assessing the benefits of debris remediation. Below sets out the forecasted costs to the UK of space debris under the different scenarios of PMD and large object removal.

Figure 6: Forecasted annual costs of space debris to the UK by scenario



Source: Ipsos' own calculations using data provided by COMSPOC's Number of Encounters Assessment Tool. RAND Europe Analysis.

The above estimates identify that in the short term there are very limited direct benefits from space debris removal; however, when comparing a 0% PMD to 90% PMD with an additional five large objects removed per year the annual benefit after 100 years of removal could be in excess of £160,000 a year. This represents a difference in the probability of collision of a UK satellite from 0.69% to 0.47% per year. At a 90% PMD with 5 large objects removed a year this broadly represents a stasis in the quantity of space debris.

Limitations

The modelling of interactions between space debris and the impact on the UK is extremely complex. The model used is simplistic and aims to provide an indication of the magnitude of benefits. The main limitations of the approach are listed below:

- The orbits of satellites and debris are modelled in a highly simplified way.
- The modelling does not consider debris smaller than 1 cm in diameter. However, a strike from debris smaller has the potential to disable a spacecraft.
- Probabilities of collision for non-trackable debris are not included
- The model does not account for future changes in the cost of replacing satellites
- Forecasted increases in space debris are taken from LEGEND forecasts from 2010 and applied to updated estimates of space debris form 2023. An updated forecast would therefore provide more certainty on the expected change in space debris under difference scenarios of debris removal.
- The model does not include costs to UK from losing non-UK satellites.
- The cost estimates do not include additional costs from monitoring space debris or the socio-economic impacts of losing (more is explained on the potential value missed below)

Impacts on PNT

As shown above the estimates taking purely the private costs of replacing satellites are relatively small compared to the potential costs of space debris removal. However, the public impacts of collisions are likely to be large. One potential impact from losing satellite connectivity is on PNT. If one satellite is severely damaged by a high energy collision, then the resulting debris field could lead to a chain reaction of collisions with other spacecraft that occupy similar orbits. This could lead to GNSS outages if such an event were to occur within the orbital plane of a GNSS constellation. According to estimates by London Economics[103] the economic cost of losing PNT for 24 hours could be in excess of £1,400m. It is difficult to say the probability of such an event occurring which therefore makes it difficult to include these estimates in the probability modelling however it is clear that these costs would outweigh the private costs of satellite replacement.

[103] London Economics (2022)

Annex J. Expert reviews

J.1. James Webb Space Telescope

J.1.1. Context and reviewer instructions

Context and purpose

This evaluation is designed to assess the impact, delivery, and value for money of the UK's investments in ESA. It aims to offer a comprehensive understanding of how the UK's ESA investments enhance the UK's overall space R&D capabilities and sector growth. The evaluation covers all investment areas (e.g. space safety) and a selection of programmes/missions) under those (e.g. Vigil).

The evaluation team has worked closely with the UK Space Agency to determine which specific investments will be evaluated and the 'intensity' of those assessments. **CLIMATE SPACE/CCI (EO), JWST (Science), Solar Orbiter (science), Vigil (space safety) and NAVISP** have been chosen as programmes to be evaluated at a high intensity. This means that we will spend more resources conducting document review, interviews, scientometrics and economic analyses on them.

The five programmes above will also undergo **expert review**. This additional layer of analysis by you, our external experts, will provide a level of peer review and technical assessment of our findings. We will incorporate your assessments into our main synthesis report and retain your raw assessments as annexes for the client. We will be approaching Bonnie and Amanda on a separate project to conduct reviews for JWST and Solar Orbiter missions under ESA's Space Science programme.

Instructions

Overall approach

Your review will focus on the big-ticket investments. The suggested allocation is as follows:

- NavISP - Navigation Innovation Support Programme[104] – Peter
- VIGIL[105] – Bonnie and Peter
- CLIMATE SPACE/CCI[106] – Amanda and Peter

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[104] UK Government (2022a).
[105] UK Space Agency (2024a).
[106] ESA Climate Office (2025b).

- JWST[107] – Bonnie, Krista and Amanda
- Solar Orbiter[108] – Bonnie, Krista and Amanda.

Your task will be to review the information in this document about the investment and complete your assessment (in Section 3) against a set of criteria, as well as an overall summary 'verdict'.

This document is split into the following sections:

- **Section 1: Context and reviewer instructions** – background on this assignment and details on what your task is.
- **Section 2: Investment briefing** – basic summary and facts of the investment and our initial findings against the assessment criteria.
- **Section 3: Reviewer assessment** – a set of boxes to fill in against the assessment criteria with graded scoring and a summary 'verdict' – this is what you complete.
- **Appendix** – additional information and sources on the investment for further reading as needed, e.g. journal articles and external assessments.

The assessment criteria are as follows:

- **Technological significance and novelty of the UK element**
- **Significance and additionality of the UK contribution to the overall mission**
- **Potential socio-economic impact/implications of the UK element**
- **National capability and reputational contribution**.

Each of the above criteria will be scored. This is purely for moderation purposes and will not be reported in the evaluation. The rubric is as follows:

- **3 - Clear positive benefits derived from UK involvement** – close to universal agreement of sources and clear evidence of the specific UK element providing benefits
- **2 - Moderately positive benefits derived from UK involvement** – sparse but strong examples of evidence of the benefit of UK involvement and impact
- **1 - Mixed evidence of benefits derived from UK involvement** – very sparse evidence that may be conflicting or contradictory
- **0 - None / negative evidence of benefits derived from UK involvement**

The step-by-step approach to this task is:

1. The RAND Europe team provide this document per investment via email, indicating a suggested timeline for review and team comments.

[107] UK Space Agency (2024b).
[108] UK Space Agency (2023).

2. Experts review the information and provide initial reviews and scores against the assessment criteria. We ask that you 'moderate' by conducting your initial assessments and then meeting to discuss your results before sending those to the evaluation team.
3. Experts send the completed reviews to the evaluation team by the agreed deadline.
4. The evaluation team check these reviews and send them back to the experts with any clarifying questions and comments, with a requested return deadline.
5. Experts respond/act on those comments and finalise their reviews to send back to the team.
6. The experts and evaluation team have a brief meeting to discuss the emerging findings.
7. The analysis is incorporated into our client reports.

J.1.2. Investment briefing

Investment: Science Programme (JWST)

Investment into ESA Science Programme (colours indicate low/med/high bands)

Cumulative spending to the end of 2022 (€m)	2023 Budget (€m)	Projected Commitment (2024–2028) (€m)	Projected commitments (2029 onwards) (€m)	UK CM22 Investment (£m/€m)	% of total MS amounts at CM22
11,253.5	891.1	491.8	99.0	410.1/474.5	15%

UK National Investment in JWST Instrumentation (MIRI)

Pre-launch			Post-launch			
Cumulative spending to FY 19/20 (£)	FY 20/21 (£)	FY 21/22 (£)	FY 22/23 (£)	FY 23/24 (£)	FY 24/25 (£)	FY 25/26 (£)
£13,817,000	£97,900	£64,000	£244,660	£117,500	£90,000	£30,000

Summary description of the investment

The James Webb Space Telescope (JWST) is an international collaboration between NASA, ESA and the Canadian Space Agency (CSA) to advance our understanding of the early Universe, stellar evolution and exoplanetary science. ESA contributed the Ariane 5 launch vehicle, operational support and key scientific components, including the Mid-Infrared Instrument (MIRI), which was led by the UK. MIRI's ability to observe in the mid-infrared spectrum is crucial for penetrating cosmic dust, capturing light from the earliest galaxies, and enabling detailed studies of exoplanet atmospheres. It is one of JWST's key instruments, forming the foundation for many of its key scientific objectives.

The UK's involvement was supported through two complementary funding streams. The UK's mandatory financial contributions to ESA's Science Programme supported shared mission costs, including the Ariane 5 launch vehicle, mission operations, and scientific instrumentation across all member states. This funding ensured UK participation in JWST and access to telescope data. Additionally, targeted national investments through the UK Space Agency and associated research councils (i.e. the STFC) provided additional funding specifically for MIRI. These investments allowed the UK to lead the design, development and testing of this critical instrument, showcasing its technological leadership and securing a key role within the consortium. This dual funding model enabled the UK to balance the benefits of collective European collaboration with targeted national investments that ensured leadership in key aspects of the mission. This approach is particularly important in an ESA programme area where the UK are not able to target investments towards specific missions at the Council at Ministerial level meetings.

Justification for evaluating this investment

- **UK influence:** The UK was the lead European contributor to the development of MIRI, assuming a key role in its design, engineering, and calibration. This leadership, supported by significant national funding beyond ESA mandatory contributions, highlights the UK's commitment to maintaining strategic influence in international space science collaborations. MIRI's success directly reflects the UK's technological and scientific expertise.
- **Programme overlap:** JWST complements other UK-supported ESA missions, such as Gaia, which maps the Milky Way's stars, and Ariel, which focuses on exoplanet atmospheres. Together, these missions provide a comprehensive understanding of stellar and planetary evolution, amplifying the scientific value of the UK's ESA investments. JWST's observations also benefit collaborations with ground-based telescopes and missions like PLATO.
- **Benefits lead time:** Since becoming operational in 2022, JWST has produced immediate and high-impact results, including observing early galaxy formation and breakthroughs in characterising exoplanet atmospheres. These immediate scientific benefits are complemented by the long-term value of MIRI's capabilities, ensuring sustained returns on UK investments.
- **Socioeconomic benefits:** UK investments in MIRI have supported the creation of high-tech jobs in areas such as cryogenics, optics, and data analysis. Collaboration between institutions like RAL Space and the UK Astronomy Technology Centre has boosted the UK's industrial and academic capabilities. This expertise positions the UK to lead future missions and creates commercial opportunities for spin-off technologies.
- **Policy alignment:** JWST aligns with the UK's National Space Strategy, advancing core objectives such as fostering scientific excellence, enhancing international collaboration, and driving innovation in space science and technology. The mission's emphasis on groundbreaking discoveries supports the UK's ambition to remain at the forefront of global space exploration.
- **Value for money (VfM):** Assessing the VfM of this dual investment model is essential to determine whether the UK's contributions to JWST have achieved meaningful returns. This evaluation should analyse the scientific, economic, and strategic impacts of combining ESA Science Programme's funding with national investments in MIRI. Such an assessment would consider MIRI's transformative scientific contributions, the economic benefits from technology spin-offs and job creation, and the strategic enhancement of the UK's influence in international space science.

This mission warrants detailed M&E to assess the scale and complexity of UK contributions. Evaluating the national funding for MIRI may be more straightforward, as it directly supported instrumentation development, enabling clear attribution to outcomes such as technological advancements and scientific impact. In contrast, evaluating the impact of the UK's investments in ESA is more challenging due to the fixed nature of these investments and their broader focus on industrial spending across ESA member states rather than the development of instrumentation. Nonetheless, the high budget mandatory investment requires accountability and transparency. M&E should aim to capture the immediate outcomes from JWST's operational phase while also tracking the long-term scientific, economic, and reputational impacts, particularly MIRI's role in advancing mid-infrared astronomy.

Key areas of UK involvement/technologies
List the three most significant contributions / use cases from the UK to the programme/mission
Development of the Mid-Infrared Instrument (MIRI): MIRI is one of four major scientific instruments aboard JWST, complementing the Near-Infrared Camera (NIRCam), Near-Infrared Spectrograph (NIRSpec), and Fine Guidance Sensor/NIRISS. NIRCam, developed by the United States, serves as JWST's primary imager for studying early galaxies and stellar populations in the near-infrared. NIRSpec, provided by ESA with German contributions, facilitates large-scale galaxy and star surveys by simultaneously observing up to 100 objects. The Canadian-built FGS/NIRISS ensures precision pointing and supports exoplanet studies. The UK played a leading role in MIRI's development,[109] spearheading its design, integration, and calibration to deliver one of JWST's most operationally advanced instruments. MIRI detects faint infrared (IR) light invisible to the human eye, enabling it to see through dense cosmic dust clouds to observe distant galaxies, star-forming regions, and exoplanets. Unlike visible light, IR penetrates dust, allowing MIRI to view previously hidden parts of the universe. Serving as both a camera and spectrograph, it captures mid-to-long infrared radiation, allowing scientists to examine the chemical compositions of gas clouds, stellar nurseries, and planetary atmospheres. Led by the UK Astronomy Technology Centre (UKATC) at Glasgow University,[110] MIRI is the only instrument on JWST dedicated to imaging the universe in the mid-infrared spectrum.
Thermal Engineering and Optical Technology: Whilst three of the instruments on the JWST operate at temperatures between 34 and 39 kelvins, MIRI relies on a sophisticated cryocooler system to maintain its detectors at temperatures below 7 Kelvin (-266°C) to achieve the sensitivity required for mid-infrared observations. Whilst the cryocooler was developed by NASA's Jet Propulsion Laboratory (JPL), RAL Space played a key role in the overall thermal engineering for MIRI, ensuring efficient integration of the cryocooler and managing the thermal stability of the instrument. This included designing thermal interfaces, conducting extensive testing, and addressing challenges such as heat dissipation in the extreme

[109] UK Space Agency (2024b).
[110] UKATC (2025).

environment of space. This work was critical for optimising MIRI's performance and ensuring reliable operation over the lifespan of the mission. Furthermore, the UKATC led the optical system design for MIRI, packaging and scientific performance verification both on the ground and during commissioning. It also developed the MIRI simulator tool and algorithms for the data pipeline, ensuring accurate and efficient data analysis. Furthermore, the UKATC designed and built the Spectrometer Pre-Optics (SPO), the first stage of the spectrometer, which houses the image slicer that splits incoming light into sections for analysis. This system allows scientists to examine the chemical composition of gas clouds, stars and planetary atmospheres. The SPO was integrated into MIRI and tested by RAL Space.
UK Scientific and Industrial Collaboration and Leadership: UK scientists (led by Prof. Gillian Wright at UKATC) defined MIRI's scientific objectives and ensured its successful calibration under extreme cryogenic conditions. Other UK institutions played significant roles in MIRI's development: RAL Space handled thermal engineering, instrument assembly, integration, and testing; Airbus UK (which acquired Astrium, who originally filled this role) provided consortium project management, product assurance coordination and system engineering leadership; the University of Leicester contributed mechanical engineering and ground support equipment, and the University of Cardiff developed elements of the calibration unit. This coordinated effort demonstrates the strength of the UK's academic and industrial partnerships, combining innovative research and engineering expertise to deliver one of JWST's most operationally complex and critical instruments.

Key outcomes
List the three most significant outcomes resulting from the UK's involvement in the programme/mission
Scientific Impact: MIRI has made significant contributions to multiple domains in astronomy. In 2023, MIRI's capabilities contributed to 110 peer-reviewed papers, representing 30% of all JWST-related publications, reflecting MIRIs role in advancing our understanding of the Universe. MIRI's unparalleled sensitivity has illuminated the early Universe, detecting high-redshift galaxies and studying cosmic reionization and galaxy evolution (Banzatti et al., 2024). Its spectroscopic tools have been instrumental in characterising the atmospheric compositions of exoplanets, including water and methane, advancing our knowledge of planetary systems (Schinnerer & Leroy, 2024). Additionally, MIRI has been critical for understanding disk chemistry and dynamics in protoplanetary systems, revealing the conditions conducive to planet formation (Temmink et al., 2024). Studies of polycyclic aromatic hydrocarbons (PAHs) and AGN feedback mechanisms using MIRI have deepened our understanding of interstellar and circumnuclear molecular processes (Zhang et al., 2024b). This success is further reflected in Cycle 1 of the JWST General Observer programme. This programme brought together over 2,200 unique investigators from 41 countries, including 43 US states and territories, 19 ESA member states, and 4 Canadian provinces. There were more successful UK-led proposals than any other non-US country,[111] highlighting that UK-led scientific impact has not just

[111] UK Space Agency (2024b).

derived from the initial development of MIRI but also from the subsequent contributions of the UK scientific community by utilising JWST-generated data.
Enhancing the UK's reputation as a Science Superpower: The UK's contribution to JWST has significantly enhanced the UK's scientific reputation, delivering MIRI-involved significant contributions to academia and industry, showcasing the UK's expertise in advanced space technology and instrumentation. The JWST has already made groundbreaking discoveries, such as observing the earliest galaxies and studying the atmospheres of exoplanets. These discoveries have been made possible, in part, due to the MIRI instrument, highlighting the UK's role in advancing our understanding of the universe. The UK's involvement in the JWST has strengthened its position as a key player in international space research. Collaborating with NASA, the European Space Agency (ESA), and other global institutions has enhanced the UK's reputation for scientific cooperation. The UK's success with the JWST has positioned it well for future opportunities in space exploration. For example, the UK has been actively involved in ESA's Gaia mission, which aims to create the most accurate 3D map of the Milky Way. The UK Space Agency has leveraged its success and partnerships formed through JWST to expand its portfolio of space science missions through the Space Science and Exploration Bilateral Programme (SEBP). This programme seeks to collaborate with international partners such as NASA, the Canadian Space Agency, JAXA (Japan), and ISRO (India) on various space science missions.
Public Engagement and Education: The UK's involvement in JWST has significantly contributed to the success of education and outreach initiatives in the UK. The Science and Technology Facilities Council (STFC) and the UK Space Agency have led a national public engagement programme,[112] working with science centres, planetariums, and astronomical societies to promote the JWST mission. Dedicated outreach fellows,[113] like Dr. Emma Curtis-Lake and Dr. Olivia Jones, have been appointed to work with schools, scientific communities, and the general public, fostering a deeper understanding and excitement about the telescope. Educational collaborations have resulted in the development of programmes and resources for schools, aiming to inspire students and highlight the possibilities of STEM careers. Community groups have organised hands-on activities, including building models of the JWST, to engage people of all ages and backgrounds. Additionally, the UK JWST consortium maintains an active online presence through its website and social media platforms, providing updates, educational content, and opportunities for public interaction. Over 150,000 people, including more than 100,000 schoolchildren, have participated in projects and activities supported by the Webb UK campaign.[114] These activities have made the JWST mission accessible and exciting for a broad audience.

[112] Science & Technology Facilities Council (2021).
[113] UKRI (2021).
[114] UKRI (2025).

J.1.3. Reviewer assessment

Overall summary 'verdict' *(200 words max.)*
The UK's investment in the general ESA programme enables participation in JWST. If not augmented with UK funds for the MIRI, the public engagement and educational benefits cited above would still be realized, but few other benefits would have accrued. The UK's contribution to the JWST mission by developing the MIRI instrument is significant and highlights national expertise in advanced instrumentation and cryogenic engineering. By contributing a unique capability to the planet's premier space telescope, the UK stands to benefit both in terms of its scientific reputation and potentially in its technical capacity. The JWST mission's groundbreaking discoveries are expected to profoundly impact our understanding of the Universe, from the formation of galaxies and stars to the potential habitability of exoplanets. The UK's participation has not only enhanced its own capabilities in space science but has also contributed to the development of the global space science ecosystem. The technical spin-offs in cryogenics and optics that may result from the UK's involvement showcase the wider impact of its contributions. Overall, there may be evidence that the UK's role in the JWST mission has solidified its position as a leader in space science and technology, potentially setting the stage for even more ambitious projects in the future. Some areas of possible missed opportunity include, for example, further strengthening various areas such as international corporation, talent attraction and increased PR to reach a wider audience. Additionally, we believe more evidence is needed to support these assertions, likely through a network analysis.

Technological significance and novelty of UK element *(~300 words)*	
Questions: To what extent is the technology/approach/solution best in class (for that time)? Is it innovative or new in terms of science, engineering or application? How does it compare to other approaches/instruments? Has there been any significant progression in TRL, commercial and/or scientific understanding because of the UK contribution? **Scoring:**	
MIRI is the highest resolution and most sensitive mid-infrared instrument available to astronomers. It is incredibly difficult to do mid-infrared astronomy from the ground, so this is a niche capability. Therefore, it is not just the best in class; it is all by itself in this class. Potential additional benefits depend on exactly what testing capabilities were developed at the National Satellite Test Facility (or other facilities) to conduct instrument testing at extremely low temperatures (7 Kelvin) for MIRI. Additional evidence to support this and any spin-off capabilities are needed for the review (see missing info. section).	
Score:	3

Significance and additionality of UK contribution to the overall mission/investment *(~300 words)*	
Questions: Was the UK contribution(s) a major part of the mission/programme delivery compared to other non-UK elements? Was it a supporting or leading contribution in terms of science, engineering, and/or data use? What does the UK bring to ESA in this respect? What about the UK contribution appears to have been 'special' (e.g. specific expertise, facilities, pedigree)? **Scoring:**	
MIRI's mid-infrared imager and spectrometer are a significant addition to JWST but are not a major contribution compared to the non-UK elements. The JWST mission would still be a success even without MIRI, but the potential scientific advancements are increased by having the additional wavelength coverage it provides. The unique aspect of the UK contribution was the cryogenic engineering side since developing a mid-infrared instrument requires specific expertise and testing at incredibly low temperatures. Few institutions worldwide have this capability. The UK's participation was essential in making JWST truly an international collaboration and has strengthened its position as a key partner in ESA's space science endeavours.	
Score:	2

Potential socio-economic impact/implications of UK element *(~300 words)*
Questions: What benefits have already been achieved or might be expected because of UK contributions, e.g. in security, space weather preparedness, climate monitoring and crisis resilience? How significant are those benefits in the context of wider space R&D/practice efforts to tackle the same problems? Were/are there any missed opportunities to have even more impact? **Scoring:**
The UK's contributions to JWST focus on advancing the understanding of the Universe, e.g. the formation of galaxies and stars and the characterization of exoplanets. While direct benefits in the areas mentioned may not be immediately apparent, there are areas in which indirect benefits exist. Particularly, the necessary buildup of expertise and facilities in/for cryogenic engineering for mid-infrared instrumentation could enable future opportunities for instrumentation R&D for applications beyond astronomy (e.g., remote sensing). There may also be technological applications in other sectors, such as quantum computing, communications and navigation. If the technologies and capabilities for the cryogenics developed for MIRI are reasonably broadly applicable, this could represent a large opportunity for the UK. However, additional research needs to be done to determine how applicable these capabilities are beyond astronomy instrumentation. Additionally, if the UK can parlay its participation in JWST into increased enthusiasm for STEM careers, that could result in significant long-term benefits by fostering a skilled workforce to address challenges in security, climate change, and crisis management. There were several missed opportunities to increase the impact of the UK's involvement in MIRI/JWST:

1. Instrument Development: Greater involvement in developing other JWST instruments could have expanded the UK's expertise.
2. Public Engagement: Enhanced outreach, such as TV programs and public lectures, might have better showcased the UK's role.
3. Industry Collaboration: Stronger partnerships with companies specializing in cryogenics and optics could have driven broader technological advancements and spin-outs into non-space domains.
4. Interdisciplinary Research: Promoting collaborations between astronomers and other research areas, such as Earth science.
5. International Collaboration: Expanded engagement with non-core partners, such as Japan or Australia, might have fostered additional scientific cooperation and knowledge sharing.

Score:	**2.5**

National capability and reputational contribution *(~300 words)*

Questions: By contributing, what has the UK gained in terms of its own capability to participate in investments/missions like this? What reputational gains appear to have been made for the UK because of the individual contributions? This can be both scientific and political, as relevant. What is the general global scientific significance (the 'ends') to which the technologies contribute (the 'means')?

Scoring:

The UK's involvement in developing MIRI has allowed the UK to enhance its expertise in advanced space technologies (e.g. cryogenics). This expertise can be leveraged for future space missions and could also have applications in other scientific and industrial sectors. Politically and reputationally, the UK's significant contributions to the JWST mission have showcased the country's leadership in space science and technology on a global stage, enhancing its reputation as a reliable and capable partner in large-scale scientific endeavours. This can help attract investment and talent to the UK's space sector and strengthen international partnerships with key players such as NASA, ESA and the Canadian Space Agency. By participating in this groundbreaking mission, the UK has not only enhanced its own scientific capabilities but has also contributed to the advancement of human knowledge and our understanding of the Universe.

However, at least some of these benefits would be accessible to the UK simply by being an ESA member. For example, due to ESA's role in JWST, ESA member countries must be allocated at least 15% of the total observing time in a particular cycle of proposals. It may be difficult to determine which reputational benefits can be attributed to the UK's contributions to MIRI and what may be from their involvement with JWST in general or simply as ESA members.

Score:	**2.5**

Optional: Indicate any missing information / lack of evidence
Here are a few areas where additional information or focus could further strengthen the involvement of the UK in space missions both now and in the future: 1. Specific examples of technological spin-offs: • Providing specific examples of potential spin-off technologies and their applications would make the advantages of the mission even more concrete and convincing. 2. Quantitative data on investment and talent attraction: • Quantitative data, e.g. the amount of investment attracted or the number of skilled scientists and engineers recruited due to the UK's participation in the mission. 3. Details on strengthened international partnerships: • Providing specific examples of how partnerships have been strengthened and what future collaborations are now being considered based on the connections created by this mission. 4. Specific UK-led scientific objectives and projects: • Examples focused on specific UK-led scientific projects or objectives that will be pursued using JWST data and highlighting some of these projects and their potential impact would showcase the UK's scientific leadership more effectively. 5. Potential challenges and limitations: • Acknowledging any potential challenges, limitations, or trade-offs associated with the UK's involvement would provide a more balanced perspective and demonstrate a comprehensive understanding, including any lessons learnt for future missions. These points are not meant to detract from the amazing outcomes of this mission. These aspects would further strengthen the analysis and provide a more complete picture of the UK's gains from its contributions to the mission.

Source: RAND Europe Analysis.

J.2. Climate Change Initiative (CCI)

J.2.1. Investment briefing

Investment: Climate Space/CCI

Scale of investment (colours indicate low/med/high bands)

Cumulative spending to the end of 2022 (€m)	2023 Budget (€m)	Projected Commitment (2024–2028) (€m)	Projected commitments (2029 onwards) (€m)	UK CM22 Investment (£m/€m)	% of total MS amounts at CM22
38.0	7.0	17.6	6.2	15.1/17.5	20.3%

Summary description of the investment

Established in 2008, the Climate Change Initiative (CCI) is a science programme to develop global, decadal-long satellite-derived climate data records. [115] Leveraging the satellite data from ESA missions, Member States, and international partners, the CCI produces datasets for Essential Climate Variables (ECVs), which underpin climate modelling. These records will substantially contribute to the IPCC's climate assessments and support the information chain necessary for effective policy and decision-making.

CLIMATE-SPACE is a continuation and expansion of the CCI. The new programme was proposed for the 2023–2029 period. It will build on CCI's work and respond to new EO requirements to support the United National Framework Convention of Climate Change (UNFCCC) Paris Agreement. CLIMATE-SPACE aims to provide systematic space-based observations that support climate science and service development, fulfilling both national and European policy requirements and promoting commercial growth through resilient technologies and services.

Justification for evaluating this investment (agreed with client)

- **UK influence:** The UK is a lead investor in this programme; however, its total investment is relatively small.
- **Programme overlap:** There is a strong overlap with CCI and other climate-related EO activities. There is notable overlap with other EO activities and wider UK priorities concerning EO within ESA.
- **Benefits lead time:** Approximately 3–4 years to produce and release updated data records of an ECV, 2–3 years post-release to be picked up by climate modellers and used in their models, and another 2–5 years for these climate models to generate any policy and socioeconomic impact.
- **Policy alignment:** There is a strong alignment with some aspects of the UK National Space Strategy (NSS) and other UK priorities, particularly those related to climate change and net zero.
- **Socioeconomic benefits:** Wider socioeconomic and environmental benefits are expected.
- **VfM:** The EO programme area is of key interest for applying programme-specific VfM methodologies, particularly those around improved and timely decision-making due to improved access to data.

The programme will undergo medium-high M&E. As a programme leader, the UK likewise needs to lead on M&E. There is considerable interest in capturing the benefits related to climate change and net zero. More intensive M&E is expected to be feasible given that the programme has a reasonably long history.

[115] ESA Climate Office (2025c).

Key areas of UK involvement/technologies
List the three most significant contributions / use cases from the UK to the programme/mission
The UK has played a key role across CCI scientific activities. The majority of CCI activities are structured as projects corresponding to each ECV, with 27 ECV projects in total under CCI.[116] UK organisations have major roles in most ECV projects and act as the science lead/prime on six projects: Sea Surface Temperature, Ice Sheets – Antarctica, Ocean Colour, Water Vapour, Biomass and Land Surface Temperature. UK organisations develop algorithms in these projects to generate climate retrievals from satellite data. The UK has leading institutions for some ECV areas (e.g. PML, the University of Reading, the University of Leicester, etc.) and contributes strong scientific expertise and institutional capabilities to the development of algorithms to generate ECV records.
The UK plays an important role in convening ESA climate science data and user communities. The UK hosts ESA's Climate Office, which oversees ESA's climate-related activities, enhancing the UK's presence in climate research and the international forum of climate policy. The UK MET Office leads Climate Modelling User Group activities under CCI, [117] linking the climate modelling community with ECV records producers by holding engagement events and the annual Integration Meetings. These activities enabled connection with data users, increased uptake of ECV data in modelling, and ensured the relevance of CCI activities towards user needs and priorities.
The UK plays a major role in CCI data management and distribution. All data records produced through CCI are publicly available through an Open Data Portal.[118] UK organisations such as Telespazio and CEDA played major roles in designing, developing, and maintaining the Open Data Portal. The tasks include transforming the ECV datasets into a format commonly used by climate modellers (Obs4MIPs), managing the website and providing tools for users to use the datasets. This supports data accessibility for modellers and assists the uptake of CCI datasets.

Key outcomes
List the three most significant outcomes resulting from the UK's involvement in the programme/mission
Knowledge Generation from UK organisations CCI projects produce long-term (e.g. 30–40 years) high-resolution data records for ECVs. The extensive time span and quality of CCI data are unique to the datasets produced by other space agencies worldwide, significantly advancing the scientific understanding of climate change and climate modelling. CCI projects have produced over 2,000 publications in total, with an average FWCI (Field-Weighted Citation Impact) of 3.67.[119] UK organisations act as the lead in six of these projects and as subcontractors in many other projects. Our bibliometric study identified 651 publications (full counting) with one or more UK authors.[120] The volume of publications and citations has bolstered the reputation of individual UK-based researchers and enhanced the standing of UK organisations within the field as a whole.
Socioeconomic Benefits/Policy Impact There are some instances where the main CCI outputs, ECV datasets, have translated directly into socioeconomic impact. For example, the dataset made in CCI_ Cloud, a UK-led project, has been used by a UK company to decide the location of solar farms, generating economic and environmental benefits. The outputs from the Biomass project have been used by the Welsh government in the Living Wales project to inform carbon assessment and regional climate policy. [121] The CCI GHG Project,[122]

[116] ESA Climate Office (2025d).
[117] ESA Climate Office (2025e).
[118] ESA Climate Office (2025f).
[119] These figures are not finalised and may change prior to publication of the report.
[120] These figures are not finalised and may change prior to publication of the report.
[121] Living Wales (2025).
[122] Buchwitz et al. (2024).

for which the UK's contribution ended in 2022, produced data that underpinned the evidence for the Global Methane Pledge Initiative, which has been influential in global climate actions. CCI outputs also have an indirect influence through a pipeline of operational services. Algorithms developed in the CCI_Sea_Surface_Temperature project have been transferred to operational service providers such as EuMatSat to inform more accurate weather forecasting. [123] The algorithm also fed into Copernicus Climate Change Services to support policy decision-making until Brexit, and the project team expect to reengage with Copernicus Services soon in 2025. ECMWF (European Centre for Medium-Range Weather Forecasts) also uses CCI data in their re-analysis,[124] which uses historical climate data from CCI and the contemporary model to recreate past climate conditions with improved accuracy. Re-analysis accurately reconstructs past climate conditions, enabling scientists to study long-term trends and validate climate models.
Organisation Capability Increase • Talent retention: Several interviewees from academic institutions reported that while the CCI funding is not enough to hire a researcher full-time, it increases the funding available to their teams and other funding streams to help retain the talent and expertise within the UK. • New/strengthened partnerships: Interviewees reported that they have established new collaborations or strengthened relationships with European and other UK organisations by participating in CCI projects. The collaborations improved the quality of outputs via access to external expertise and established UK organisations' reputations. Some of these collaborations have continued to other ESA or UK-funded programmes. • Follow-on contracts: Operational service providers, such as EuMatSat and Copernicus Services, use CCI outputs for their own programmes and issue contracts independent of CCI. As a result, the UK participants in those CCI projects secured follow-on funding from the service providers to expand their work on CCI.

J.2.2. Reviewer assessment

Overall summary 'verdict' *(200 words max.)*
ESA CCI employs state-of-the-art satellite observation technology to monitor climate variables, such as sea level rise, greenhouse gas concentrations, and land surface temperature. Using long-term satellite data is crucial in understanding climate trends, making this approach one of the leading methodologies for climate monitoring. This initiative is/will be a rewarding investment for the UK with direct socio-economic benefits and intellectual capital returns at home and worldwide.

Technological significance and novelty of UK element *(~300 words)*
Questions: To what extent is the technology/approach/solution best in class (for that time)? Is it innovative or new in terms of science, engineering or application? How does it compare to other approaches/instruments? Has there been any significant progression in TRL, commercial and/or scientific understanding because of the UK's contribution? Scoring: 3
Best-in-Class Solutions ESA CCI has developed cutting-edge algorithms and processing techniques to generate high-quality, consistent, long-term climate data records from multiple satellite sensors. The initiative has fostered the development of novel methods for data harmonization, cross-calibration, and uncertainty characterization, ensuring the data's accuracy and reliability.

[123] ESA Climate Office (2025g).
[124] European Centre for Medium-Range Weather Forecasts (2025).

Innovative and new approaches

The CCI's integration of various satellite datasets into comprehensive climate datasets is innovative, particularly in:

- Data Fusion: Combining datasets from different satellite missions to create more accurate and consistent climate records.
- Long-Term Monitoring: Utilising historical data to provide context for current climate changes, which is essential for effective climate modelling.

The UK has been at the forefront of developing these innovative approaches, particularly in atmospheric composition, ocean colour and land cover monitoring.

Comparison to other approaches/instruments:

Compared to ground-based measurements or shorter-term satellite observations, the CCI's long-term satellite datasets offer:

- Global Coverage: Satellite observations can cover remote and inaccessible areas where ground data is sparse.
- Consistency: The standardized methodology for data processing enhances comparability across different datasets.

ESA CCI datasets are considered the benchmark for many ECVs, providing the most comprehensive, consistent, and accurate information available. The initiative leverages data from multiple satellite missions, including ESA, NASA, and other international partners, ensuring the best possible global coverage and temporal resolution. The CCI datasets are often used as reference data for validating/improving other satellite-based products and climate models.

Progression in Technology Readiness Level (TRL), commercial, and scientific understanding:

The UK's contribution to ESA CCI has significantly advanced the TRL of various climate monitoring technologies, moving them from research and development stages to operational use. The datasets generated by the initiative have become essential tools for climate research, policy-making, and commercial applications, such as climate risk assessment and adaptation planning. The scientific understanding of climate change has greatly benefited from ESA CCI, with UK scientists/UK-based scientists playing a key role in analysing and interpreting the data, leading to numerous high-impact publications and improved climate models.

Some specific examples of the UK's contribution to ESA CCI include:

- The development of the GlobTemperature dataset, which provides a consistent, long-term record of global land surface temperatures, is essential for understanding climate variability and change.
- The creation of the CCI Sea Surface Temperature (SST) dataset), which is widely used for climate monitoring, ocean forecasting, and understanding ocean-atmosphere interactions.
- The UK's leading role in the CCI Biomass project, aims to provide global maps of above-ground biomass, which is crucial for understanding the role of forests in the carbon cycle and climate change mitigation.

5 CCI projects with significant UK involvement include:

1. Atmospheric Composition:
    - CCI Greenhouse Gases (GHG).
    - UK Participants: the University of Leicester, the University of Edinburgh, STFC RAL
    - Aim: To provide long-term, consistent and accurate satellite-based datasets for carbon dioxide (CO2) and methane (CH4) concentrations in the atmosphere, essential for understanding the carbon cycle and climate change.
2. Ocean Colour:
    - CCI Ocean Colour.
    - UK Participants: Plymouth Marine Laboratory, the National Oceanography Centre, STFC RAL.

- Aim: To develop a consistent, long-term, and globally calibrated time series of ocean colour data to monitor marine ecosystem health, primary productivity, and the global carbon cycle.

3. Land Cover Monitoring:
    - CCI Land Cover.
    - UK Participants: University College London (UCL), Telespazio UK, STFC RAL
    - Aim: To provide a consistent and accurate global land cover classification, which is essential for understanding land surface processes, ecosystem dynamics and human land use patterns.
4. CCI Biomass:
    - UK Participants: the University of Edinburgh, the University of Leicester, STFC RAL
    - Aim: To provide global maps of above-ground biomass, which are crucial for understanding the role of forests in the carbon cycle and climate change mitigation.
5. CCI Sea Surface Temperature (SST):
    - UK Participants: the University of Reading, Met Office, STFC Rutherford Appleton Laboratory
    - Aim: To create a consistent, long-term, and globally calibrated record of sea surface temperatures for climate monitoring, ocean forecasting, and understanding of ocean-atmosphere interactions.

In conclusion, the UK's contribution to ESA CCI has been significant, driving innovation, advancing the state-of-the-art in climate monitoring technologies, and improving scientific understanding of climate change. The datasets and tools developed through this initiative are considered best-in-class and have substantially impacted climate research, policy-making and commercial applications. The socioeconomic benefits of CCI are multiple, clear, and documented. Advancements of the state-of-the-art (data analytics and applied data analysis as applied via CCI) and contributions by UK researchers resulting in enhanced UK reputation are documented. UK-based talent development is clear, and talent retention may be positive. However, there is no explicit/conclusive evidence for retention.

Score:	3

Significance and additionality of the UK contribution to the overall mission/investment *(~300 words)*
Questions: Was the UK contribution(s) a major part of the mission/programme delivery compared to other non-UK elements? Was it a supporting or leading contribution in terms of science, engineering, and/or data use? Were there other/better solutions? What about the UK contribution appears to have been 'special' (e.g. specific expertise, facilities, pedigree)? Scoring: 3

Was the UK contribution(s) a major part of the mission/programme delivery compared to other non-UK elements?

The UK's contributions to the European Space Agency (ESA) Climate Change Initiative (CCI) programme have been significant and, in many cases, have played a leading role in the mission and programme delivery, e.g.:

- Leading contribution in science, engineering and data use:
    - UK scientists and institutions have been at the forefront of developing innovative algorithms, processing techniques, and data harmonization methods for various ESA CCI projects, e.g. Greenhouse Gases (GHG), Ocean Colour and Land Cover projects.
    - The UK has provided critical expertise in data validation, uncertainty characterization, and quality assurance, ensuring the accuracy and reliability of the CCI datasets.
    - UK researchers have been heavily involved in analysing and interpreting the CCI data, leading to numerous high-impact publications and improved climate models.
- Unique expertise, facilities and pedigree:
    - The UK has an excellent reputation in Earth observation, climate science, and data processing, with world-renowned institutions, e.g. the University of Leicester, the University of Edinburgh and the STFC Rutherford Appleton Laboratory.

  - The UK's expertise in satellite instrument design, calibration, and validation has been crucial for the success of many ESA CCI projects, ensuring the quality and consistency of the data.
  - The UK hosts several key facilities and data centres, such as the Centre for Environmental Data Analysis (CEDA) and the Climate Data Store (CDS), which play a vital role in archiving, distributing, and promoting the use of CCI datasets.
- Comparison to other non-UK elements:
  - While ESA CCI is a collaborative effort involving many European countries, the UK's contribution has been particularly significant in terms of scientific expertise, technological innovation, and data exploitation.
  - In many cases, UK-led projects and datasets have become the benchmark for their respective essential climate variables (ECVs), demonstrating the high quality and impact of the UK's work.
  - It is essential to recognize that ESA CCI's success results from a collective effort.
- Alternative solutions:
  - ESA CCI represents the state-of-the-art in satellite-based climate monitoring, and the approaches and datasets developed through the initiative are generally considered the best available solutions for their respective ECVs.
  - While there may be alternative methods or datasets for specific applications, ESA CCI's comprehensive, consistent, and long-term approach to climate monitoring is widely regarded as the gold standard in the field.

In conclusion, the UK's contribution to ESA CCI programme has been substantial and, in many cases, has played a leading role in the mission and programme delivery. The UK's expertise, facilities, and pedigree in Earth observation, climate science, and data processing have been critical to the initiative's success, with many UK-led projects and datasets setting the benchmark for their respective areas. While ESA CCI is a collaborative effort involving many European countries, the UK's contribution has been particularly significant and impactful. The UK is among the leading investors in CCI; the UK led or was primary on 6 of 27 CCI-associated ECV projects, reflecting its major role. CCI climate data directly affected Copernicus (EU/ESA Earth observation programme), and there are specific post-Brexit re-engagement activities in Copernicus.

Score:	3

Potential socio-economic impact/implications of UK element *(~300 words)*
Questions: What benefits have already been achieved or might be expected because of UK contributions, e.g. in security, space weather preparedness, climate monitoring and crisis resilience? How significant are those benefits in the context of wider space R&D/practice efforts to tackle the same problems? Where/are there any missed opportunities to have even more impact? Scoring: 3

The UK's contributions to the European Space Agency (ESA) Climate Change Initiative (CCI) have led to numerous benefits in many domains, e.g. climate monitoring, crisis resilience, and policymaking.

Examples of Benefits

1. Climate monitoring and understanding:
   - ESA CCI datasets have significantly improved understanding of climate change/drivers/impacts on Earth systems, e.g. the atmosphere, oceans and land surface.
   - UK-led projects, such as the CCI Greenhouse Gases (GHG) and the CCI Sea Surface Temperature (SST), have provided critical insights into the carbon cycle, ocean-atmosphere interactions, and global temperature trends.
   - The scientific community has widely used these datasets, leading to numerous high-impact publications and improved climate models essential for climate change mitigation and adaptation strategies.
2. Crisis resilience and preparedness:

- ESA CCI datasets have been used to develop early warning systems and risk assessment tools for various climate-related hazards, such as floods, droughts and heatwaves. For example, the CCI Soil Moisture dataset has been used to monitor and predict agricultural droughts, enabling better preparedness and response to food security crises.
- The CCI Land Cover dataset has been used to assess the vulnerability of ecosystems and human settlements to climate change impacts, informing adaptation and resilience planning.

3. Policy-making and international collaboration:
   - ESA CCI datasets have been used to support evidence-based policymaking at national/international levels, enabling decisions on climate change mitigation, adaptation, and sustainable development.
   - The UK's contribution to ESA CCI has strengthened its position as a leader in climate science and Earth observation, fostering international collaboration and knowledge exchange.
   - ESA CCI has also contributed to implementing international agreements, e.g. the Paris Agreement and the Sustainable Development Goals (SDGs), by providing essential climate data and monitoring tools (to manage effectively, you need to measure it).

Wider context and potential missed opportunities:

- ESA CCI is one of the most comprehensive and ambitious climate monitoring programs worldwide, and the UK's contribution has been significant in this context.
- However, other international efforts, such as NASA's Earth Science Division and the Copernicus Climate Change Service (C3S), provide important climate data and services.
- While the UK's contribution to ESA CCI has been substantial, there may have been missed opportunities to:
  - Further integrate and harmonise these efforts with other international programs, potentially achieving more significant impact and efficiency.
  - Create/Strengthen a pathway for more UK companies/institutes/entities to become involved to add depth to UK national capability.
  - There may have been opportunities to further promote the use of ESA CCI datasets in domains beyond climate science, e.g. the private sector, for climate risk assessment and sustainable finance.
  - The UK has world-class institutions, but the same players are often involved repeatedly across many CCI projects. To build competition and depth to UK capability, capacity/capability-building programs could be considered to reduce barriers to entry and develop climate-related expertise and knowledge.

Through CCI, the UK MET Office leads the Climate Modelling User Group (CMUG), and the CMUG team's composition reflects strong UK leadership and participation. Expanding this cooperation with ESA will likely enhance and grow that advantage over time. The net UK benefits as Earth has passed the 1.5 degrees tipping point and climate impacts increase will likely range from socioeconomic well-being domestically and in the developing world, e.g. assisting with rising seas in Bangladesh.

Score:	3

National capability and reputational contribution *(~300 words)*
Questions: By contributing, what has the UK gained in terms of its own capability to participate in investments/missions like this? What reputational gains appear to have been made for the UK as a result of the individual contributions? This can be both scientific and political, as relevant. Scoring: 3

- Enhanced UK capabilities:
  - The UK has developed and strengthened its expertise in satellite data processing, algorithm development and climate data analysis.

- UK institutions, such as the University of Leicester, the University of Edinburgh, and the STFC Rutherford Appleton Laboratory, have become world leaders in their respective areas of climate monitoring and Earth observation.
- The UK has also enhanced its capacity to design, build, and operate satellite instruments and ground segments, which are critical for future climate monitoring missions and investments.

- Increased international collaboration and influence:
  - The UK's contribution has strengthened its position as a key player in international climate science and Earth observation initiatives.
  - UK scientists/UK-based scientists and institutions have been involved in numerous international collaborations and partnerships through ESA CCI, fostering knowledge exchange and advancing state-of-the-art climate monitoring.
  - The UK's leadership in ESA CCI has also increased its influence in shaping the future direction of climate monitoring and Earth observation programs, both within Europe and globally.
- Scientific reputational gains:
  - The UK's contribution to ESA CCI has led to significant reputational gains in the scientific community, with UK-led projects /datasets setting the benchmark for their respective areas of climate monitoring.
  - UK scientists have been involved in numerous high-impact publications and have been recognised for their contributions to advancing climate science and Earth observation.
  - The UK's expertise in ESA CCI has also attracted top talent/funding to UK institutions, further strengthening its position as a leader in climate science and Earth observation.
- Political reputational gains:
  - The UK's contribution to ESA CCI has demonstrated its commitment to tackling climate change and supporting international efforts to monitor and mitigate its impacts.
  - The UK's leadership in ESA CCI has enhanced its reputation as a responsible and proactive member of the international community, committed to evidence-based policy-making and sustainable development.
  - The UK's involvement in ESA CCI has also strengthened its position in international climate negotiations and forums, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

In conclusion, the UK's contribution to ESA CCI has led to significant gains in its own capability in climate monitoring and Earth observation investments and missions. It has developed and strengthened its expertise, capacity, and international collaboration. The UK has also achieved significant reputational gains in both scientific and political areas, and it is recognised as a leader in climate science and Earth observation.

Owning a recognised skillset in climate data analytics will likely provide returns to the UK across geoeconomic sectors and the space sector. The interest in re-joining Copernicus post-Brexit bodes well.

Score:	3

Source: RAND Europe Analysis.

J.3. Solar Orbiter

J.3.1. Investment briefing

Investment: Science Programme					
Scale of investment (colours indicate low/med/high bands)					
Cumulative spending to the end of 2022 (€m)	2023 Budget (€m)	Projected Commitment (2024–2028) (€m)	Projected commitments (2029 onwards) (€m)	UK CM22 Investment (£m/€m)	% of total MS amounts at CM22
11,253.5	891.1	491.8	99.0	410.1/474.5	15%

UK National Investment in Solar Orbiter Instrumentation					
Pre-Launch	Post-Launch				
Cumulative spending to FY 2019/2020 (£m)	FY 2020/2021 (£m)	FY 2021/2022 (£m)	FY 2022/2023 (£m)	FY 2023/2024 (£m)	FY 2024/2025 (£m)
19.636	0.887	0.876	1.471	1.475	1.477

Summary of the Description of the Investment

The Solar Orbiter is a collaborative mission between ESA and NASA,[125] designed to study the Sun's heliosphere, magnetic field, and its impact on the solar system. ESA provided the spacecraft platform and most scientific instruments, and NASA provided substantial contributions, including the Atlas V launch vehicle. Solar Orbiter carries ten scientific instruments, split into in situ and remote sensing categories. The UK led the development of three instruments and supported the development of one further instrument, demonstrating scientific and industrial leadership. The in-situ instruments include the Solar Wind Analyser (SWA), developed and led by the Mullard Space Science Laboratory (MSSL) in the UK. Imperial College London led the development of the Magnetometer (MAG). The Radio and Plasma Waves (RPW) instrument was led by France, and the Energetic Particle Detector (EPD) was led by Germany.

The remote sensing instruments include the Extreme Ultraviolet Imager (EUI), supported by MSSL in the UK, with Belgium as the lead. RAL Space led the Spectral Imaging of the Coronal Environment (SPICE) in the UK. Other remote sensing instruments include the Polarimetric and Helioseismic Imager (PHI), led by Germany; the X-ray Spectrometer Telescope (STIX), led by Switzerland; the METIS/COR (Coronagraph), led by Italy; and the SolOHI (Heliospheric Imager), led by the US.

The UK's involvement was supported by a combination of mandatory contributions to ESA's Science Programme and targeted national investments through the UK Space Agency and associated research councils. This dual funding approach enabled the UK to lead aspects of instrumentation development while ensuring participation in mission science and data access. UK institutions such as the Mullard Space Science Laboratory (MSSL), Imperial College London, RAL Space, and Airbus UK worked collaboratively to design, develop, test and assemble instruments and the probe, demonstrating the strength of the UK's

[125] UK Space Agency (2023).

academic and industrial partnerships. This investment aligns with the UK's NSS, supporting advancements in space weather forecasting, which protects national infrastructure, demonstrating scientific leadership in heliophysics.
Justification for evaluating this investment (agreed with client)
• **UK influence:** The UK led the development of four key instruments: SWA (MSSL), MAG (Imperial College London) and SPICE (RAL Space), and contributed to EUI. These contributions position the UK as a leading nation in heliophysics, cementing the UK's influence within the Solar Orbiter consortium and ESA's Science Programme. • **Programme overlap:** Solar Orbiter complements other ESA missions, such as Vigil (also led by the UK, by providing an understanding and mitigating the impacts of space weather on Earth's infrastructure. • **Benefits lead time:** Launched in February 2020, Solar Orbiter has already generated data, such as the closest-ever images of the Sun and data on solar wind's dynamics. These short-term benefits are complemented by the long-term value of the mission, including risk mitigation, • **Socioeconomic benefits:** The UK's investments in Solar Orbiter have supported job creation. Collaborations between institutions such as MSSL, RAL Space, and Imperial College London have enhanced UK industrial and academic capabilities. • **Policy alignment:** Solar Orbiter with the UK's National Space Strategy goals, supporting critical infrastructure protection through advancements in space weather prediction. The mission also strengthens international collaboration and enhances the UK's leadership in space science and technology. • **Value for money (VfM):** Solar Orbiter represents a high-value investment for the UK, combining strategic ESA contributions with targeted national funding. The UK is also the prime contractor for Solar Orbiter, resulting in significant industrial return. This mission warrants detailed monitoring and evaluation (M&E) due to the scale and complexity of the UK's contributions. The significant industrial return for this mission makes attribution to the direct investment straightforward through the geo-return mechanism. The national investments into SWA, MAG, SPICE, and EUI are more directly attributable to scientific impact. M&E should focus on the immediate scientific results of the mission as well as the long-term benefits of improved space weather forecasting and building expertise in associated technologies.

Key areas of UK involvement/technologies
List the three most significant contributions / use cases from the UK to the programme/mission
Solar Wind Analyser (SWA) & Extreme Ultraviolet Imager (EUI): The SWA is one of Solar Orbiter's key instruments, designed to measure the properties of solar wind plasma, including ion and electron densities, velocities and temperatures. This data is critical for understanding the origins of solar wind and its interaction with the heliosphere. The MSSL at UCL led the design, development, and integration of

SWA. The instrument has sensors to analyse charged solar wind particles, contributing to the scientific understanding of solar wind composition and dynamics.

As co-investigators, MSSL also supported the development of the EUI, which captures high-resolution images of the solar atmosphere, focusing on solar phenomena such as coronal mass ejections and solar flares. This support included designing the thermal interfaces, conducting performance testing and integrating the instruments with the spacecraft. The EUI complements SPICE and MAG, providing visual context for data generated by these instruments.

Spectral Imaging of the Coronal Environment (SPICE): SPICE was developed by **RAL Space**, advancing capabilities in extreme ultraviolet imaging. SPICE uses cutting-edge spectroscopic techniques to capture high-resolution data on the Sun's chromosphere and corona. The UK's leadership included the optical and thermal design, calibration, and testing of SPICE, ensuring its ability to operate reliably in the extreme environment near the Sun. SPICE provides critical data that builds our understanding of how the solar wind is generated, contributing to improved space weather models.

Magnetometer (MAG): The MAG is critical for measuring the magnetic fields in the solar wind and the interplanetary environment. Developed and led by **Imperial College London**, MAG provides data on magnetic reconnection processes, which are key to understanding energy transfer from the Sun to the heliosphere. The UK played a central role in designing and calibrating the magnetometer and ensuring its precision and reliability in harsh space conditions. MAG has already generated data on how magnetic fields shape the behaviour of the solar wind and its interaction with planetary environments, contributing to a better understanding of space weather and its effects on Earth.

Key outcomes
List the three most significant outcomes resulting from the UK's involvement in the programme/mission

1. **Enhanced Space Weather Forecasting:** Solar Orbiter data from UK-led instruments can improve models for predicting space weather,[126] which is essential for protecting satellite infrastructure, power grids, and aviation systems.
2. **Leadership and Capability Building in Heliophysics:** UK researchers have published high-impact findings based on Solar Orbiter data, enhancing the UK's reputation in solar physics and fostering new international collaborations. For example, findings from SPICE have provided detailed insights into the chemical composition of the solar atmosphere,[127] enabling improved models of solar wind generation. MAG data have offered groundbreaking measurements of magnetic reconnection processes,[128] critical to understanding solar storms and their effects on Earth. Similarly, SWA has generated data on the dynamics of solar wind particles, contributing to our broader understanding of heliospheric physics and the Sun's influence on the solar

[126] Laker et al. (2024).

[127] Brooks et al. (2022).

[128] Owen et al. (2021).

system.[129] This leadership and expertise have also enabled UK scientists and engineers to take on roles in other missions, particularly for MAG. The development of ESA's upcoming Vigil mission operationalises the magnetometer for 24/7 monitoring, providing fore- and now-casting capabilities for space weather. Additionally, NASA has purchased some of Vigil's instruments, further showcasing the international reliance on UK-developed technology and expertise.[130]

3. **Industrial and Technological Impact:** The mission has supported high-skilled jobs and advanced the UK's technological capabilities in space instrumentation, plasma physics, and thermal engineering. Airbus UK was awarded the prime contract for mission delivery, with a value of approximately £300m.[131] This achievement represents the only ESA science mission where the UK has secured the prime contracting role, highlighting the UK's industrial leadership. The contract not only supported jobs within Airbus and its supply chain but also showcased the UK's ability to deliver on large-scale, complex space missions. This ultimately led to Airbus having the capability to lead Vigil, a Space Safety and Security mission. Collaborations with institutions like MSSL and RAL Space also built academic capabilities, positioning the UK for future contributions to ESA and NASA missions.

J.3.2. Reviewer assessment

Overall summary 'verdict' *(200 words max.)*

- Although the technology employed on Solar Orbiter is not state-of-the-art, the results of the data analysis from the instrument significantly increased understanding of solar wind and space weather to better protect critical infrastructure from solar flares, prominences, and coronal mass ejections. A greater emphasis should be placed on data analysis and the infrastructure protection it has enabled.
- The prime contractor experience on Solar Orbiter likely provided significant reputational benefits, allowing RAL Space to execute the VIGIL programme successfully.
- Solar Orbiter was likely instrumental in building key expertise at RAL space, which led them to compete for more recent work.
- More evidence is needed for more quantitative assertions regarding how Solar Orbiter increased national capability and reputational contribution scores.

[129] Owen et al. (2021).
[130] RAND-led interview.
[131] UK Space Agency (2023).

Technological significance and novelty of UK element *(~300 words)*	
Questions: To what extent is the technology/approach/solution best in class (for that time)? Is it innovative or new in terms of science, engineering or application? How does it compare to other approaches/instruments? Has there been any significant progression in TRL, commercial and/or scientific understanding because of the UK contribution? **Scoring:**	
• Although the magnetometer and spectrographic methods employed are not state-of-the-art, the science they produce is. Solar Orbiter and the Parker Space Probe (launched in 2018) are the closest any human-made satellites will get to the Sun. While the Parker Space Probe will also be taking in-situ measurements, only the Solar Orbiter can take high-resolution imagery of the Sun (but the imager came from the US). • All aspects of the Solar Orbiter needed to be shielded from the intense radiation, not just temperature, from the Sun. This is a significant technical challenge given the environment and pulls from the UK's expertise in cryogenic engineering.	
Score:	2.5

Significance and additionality of UK contribution to the overall mission/investment *(~300 words)*	
Questions: Was the UK contribution(s) a major part of the mission/programme delivery compared to other non-UK elements? Was it a supporting or leading contribution in terms of science, engineering, and/or data use? What does the UK bring to ESA in this respect? What about the UK contribution appears to have been 'special' (e.g. specific expertise, facilities, pedigree)? **Scoring:**	
• For this project, the UK brought expertise in particular instruments (such as the magnetometer), expertise in complex systems integration (through BAE), and scientific analysis. Serving as a prime contractor is a significant contribution to the mission. • Other ESA countries contributed one instrument, but the UK led four instruments. • This analysis would benefit from a deeper look at the workforce, facilities and expertise related to the scientific analysis of the data returned from the Solar Orbiter.	
Score:	2.5

Potential socio-economic impact/implications of UK element *(~300 words)*	
Questions: What benefits have already been achieved or might be expected because of UK contributions, e.g. in security, space weather preparedness, climate monitoring and crisis resilience? How significant are those benefits in the context of wider space R&D/practice efforts to tackle the same problems? Where/are there any missed opportunities to have even more impact? **Scoring:**	
• The information gained from the space-science portion of the mission will help heliophysicists know more about the solar wind and how and why the Sun gives off flares and prominences and coronal mass ejections that can potentially impact critical infrastructure on Earth. However, the societal benefits of better solar monitoring could be accrued simply because the UK is a part of ESA. If it could be shown that the Solar Orbiter mission would not have occurred without the UK's contribution, then this score would be higher. • While £330m could be seen as a significant economic benefit, it is small in the context of total BAE revenue. More context is needed to understand the economic benefit.	
Score:	1

National capability and reputational contribution *(~300 words)*	
Questions: By contributing, what has the UK gained in terms of its own capability to participate in investments/missions like this? What reputational gains appear to have been made for the UK because of the individual contributions? This can be both scientific and political, as relevant. What is the general global scientific significance (the 'ends') to which the technologies contribute (the 'means')? **Scoring:**	
• Although we cannot construct a counterfactual world in which the UK had not participated in Solar Orbiter, there is good reason to believe the UK could not have executed VIGIL without that experience. • A time-phased network graph showing how Solar Orbiter investments positioned UK firms and universities to pursue follow-on work might allow for more quantitative assertions regarding how Solar Orbiter increased national capability and reputational contribution scores, which we believe are understated in the above writeup. • There may have been some missed opportunities, e.g. increased funding for solar science research and instrument development, greater collaboration with industry partners and even better PR and communications to inspire the next generation of UK scientists and engineers.	
Score:	2

Optional: Indicate any missing information / lack of evidence
More information is needed in the following areas: 1. Specific examples of technological advancements or spin-offs, e.g. new technologies or solutions developed by UK companies and institutions due to their involvement in the mission, would provide stronger evidence of capability gains. 2. Quantitative data on the UK's involvement, such as the number of UK scientists, engineers and institutions involved in the mission or impacted by it, as well as the UK's financial contribution to the project, would help to quantify the scale of the UK's participation and its significance within the overall mission. 3. Concrete evidence of reputational gains, such as statements from ESA officials, international partners, or media coverage acknowledging the UK's role and expertise. A time-phased network graph of these reputation gains is recommended. 4. Specific scientific findings and their implications, such as providing examples of key findings and their potential impact on our understanding of the Sun and space weather, would reinforce the scientific significance of the mission and the UK's contribution. 5. More public relations and communication to inspire the next generation of UK scientists. 6. Potential missed opportunities and their impact, e.g. providing 'what if' analysis focused on missed opportunities (e.g. increased funding or collaboration) and assessing how these missed opportunities might have affected the UK's gains or the mission's overall success.

Source: RAND Europe Analysis.

J.4. NAVISP

J.4.1. Investment briefing

Investment: NavISP					
Scale of investment (colours indicate low/med/high bands)					
Cumulative spending to the end of 2022 (€m)	2023 Budget (€m)	Projected Commitment (2024–2028) (€m)	Projected commitments (2029 onwards) (€m)	UK CM22 Investment (£m/€m)	% of total MS amounts at CM22
29.4	9.4	28.0	2.8	27.4/31.7	High % across elements

Summary description of the investment

The UK Space Agency offers funding for UK companies to develop innovative uses of space-based positioning, navigation, and timing (PNT) services, utilising systems like GPS, Galileo, or EGNOS. Since 2016, the European Space Agency's NavISP has invested over £40m in the UK's space PNT sector for research and development, with the UK contributing €50m since 2017 to foster innovation in space-enabled navigation products and services.

NavISP is a strategic tool to enhance innovation and competitiveness in the European PNT landscape. It aims to support the creation of innovative technologies that extend beyond traditional satellite navigation. The programme is organised into three elements:

1. **Element 1: Innovation** – This focuses on developing new PNT concepts and technologies that are fully funded by ESA.
2. **Element 2: Competitiveness** – Enhances industry capabilities and competitiveness in the global PNT market, co-funded by ESA and industry.
3. **Element 3: Support to Member States** – Supports national PNT strategies and fosters cooperation, fully funded by ESA.

NavISP offers zero-equity funding ranging from €60,000 to €2m per activity, along with personalised ESA consultancy, technical and commercial guidance, access to a network of partners, and the credibility of ESA's brand. The main goal is to aid companies in developing their PNT solutions from research to commercialisation.

Justification for evaluating this investment (agreed with client)

- **UK influence:** The UK is the foremost investor across all Phase 3 Elements.
- **Policy alignment:** Focus on UK National Space Strategy aspects of growing and levelling up the economy, defence, and delivery of services for UK citizens.

- **Socio-economic benefits:** Past programme activities have resulted in new products and services and the growth of commercial entities. Broad historical and projected socioeconomic benefits include environmental, energy efficiency, mobility and transportation, crime reduction, and healthcare.

VfM: This programme could produce some benefits that could be included quantitatively in VfM, specifically around lowered costs due to improved PNT technology and other applications on PNT. These may be hard to measure quantitatively but should feature qualitatively in the overall VfM analysis.

Key areas of UK involvement/technologies
List the three most significant contributions / use cases from the UK to the programme/mission
The UK has made significant strides in advancing resilient Positioning, Navigation and Timing (PNT) systems through initiatives like the General Lighthouse Authorities' Element 3 project.[132] These efforts include developing a UK-centric PNT system, addressing Brexit-related challenges in aviation, and bolstering navigation security. Notably, the UK has also explored and developed non-satellite-based navigation technologies, such as PNT Timing & Synchronisation for Aviation systems and quantum navigation,[133] which align with UK national quantum priorities.[134] These technologies operate independently of satellite signals, providing critical alternatives to mitigate vulnerabilities like jamming, spoofing, or signal outages. **Impact:** Integrating non-satellite navigation methods strengthens the UK's defences against PNT system disruptions, which could cost the economy an estimated £1.4bn per day.[135] Inertial navigation ensures continued functionality in environments where satellite signals are obstructed, while quantum navigation offers unprecedented precision and resilience. These advancements enhance the robustness of the UK's critical infrastructure and position the UK as a leader in cutting-edge navigation technologies, influencing government policies and setting global benchmarks for secure PNT systems.
Through NavISP Element 2, the UK has supported the development of PNT products towards market readiness, helping companies bridge the gap between innovation and commercialisation. This includes technology demonstrations[136] designed to attract investment and enable UK companies to enter new markets. COLOSSUS, ENERSYN, 5G Drone Positioning and VANTIGE-2 are all Element 2 projects to progress their technological maturity either to demonstration or towards commercialisation and enhance broader industrial capability through direct technological application or via downstream utilisation.[137]

[132] ESA (2025a).
[133] ESA (2025b); ESA (2025c).
[134] UK Government (2023).
[135] UK Space Agency & DSIT (2023).
[136] ESA (2025d).
[137] ESA NAVISP (2025).

Under NavISP, industrial partnerships with universities such as Cranfield, UCL, Imperial College, and Nottingham University have driven research and technological advancements in PNT.[138] These collaborations are nurturing the next generation of talent for the sector.

The MarRINav (Maritime Resilience and Integrity of Navigation) project was designed to support the UK's national interest by establishing a foundation for the country's future critical national infrastructure in maritime and other sectors concerning PNT resilience and integrity.[139] This initiative responds to two significant UK government reports from 2017/2018, which addressed the impact and mitigation of GNSS vulnerabilities and aims to align with and inform government policy and planning. The project's proposal involves integrating GPS/European GNSS (Galileo and EGNOS) with complementary terrestrial PNT technologies to develop a system-of-systems solution, primarily for maritime PNT resilience and integrity, but also applicable to sectors like multi-modal transport, logistics, emergency response, security, financial services, power distribution, and telecommunications.

The project was led by the prime contractor NLA International Ltd, with academic subcontractors including The University of Nottingham and University College London.

Key outcomes
List the three most significant outcomes resulting from the UK's involvement in the programme/mission
Enhanced Resilience of Critical Infrastructure The UK's investments in resilient PNT systems, including non-satellite-based solutions like inertial and quantum navigation, have and hold further potential to enhance the robustness of critical infrastructure against potential disruptions, such as jamming, spoofing, or satellite signal outages. This resilience ensures continuity in essential services, mitigates risks associated with PNT system outages and protects the UK economy from potential losses estimated at £1.4bn per day. These developments have also informed national policies on secure navigation, showcasing the UK's leadership in addressing PNT vulnerabilities.
Economic Growth and Market Expansion The UK has leveraged NavISP Element 2 to transition PNT technologies from innovation to market-ready solutions. This has enabled UK companies to attract investment, enter new markets, and expand their global footprint. These activities have created jobs, strengthened the UK's industrial base and fostered economic growth. The ability to advance TRLs for PNT innovations has also ensured the UK's competitiveness in the global navigation sector.

[138] ESA NAVISP (2025).

[139] ESA (2025e).

Establishment of a Sustainable Innovation Ecosystem
The UK's NavISP involvement has brought an increasingly sustainable innovation ecosystem through academia-industry collaborations under NavISP. These partnerships have driven research excellence, increased the number of skilled graduates entering the PNT sector, and supported the emergence of startups and spin-offs. This ecosystem has addressed skill gaps in the PNT sector and positioned the UK as a hub for cutting-edge navigation research and development. The growth in research facilities and publications has further solidified the UK's global leadership in the navigation field.

J.4.2. Reviewer assessment

Overall summary 'verdict' *(200 words max.)*
The next phase in the history of advanced PNT technology will be an integration of space-based capabilities with terrestrial capabilities to improve the net system reliability – and reduce risk for the corresponding economic and socio-economic systems that currently rely heavily on space-based PNT. NAVISP has/will make strides in that area, ranging from quantum location to other leading-edge developments.

Technological significance and novelty of UK element *(~300 words)*	
Questions: To what extent is the technology/approach/solution best in class (for that time)? Is it innovative or new in terms of science, engineering or application? How does it compare to other approaches/instruments? Has there been any significant progression in TRL, commercial and/or scientific understanding because of the UK contribution? **Scoring:**	
Integrating alternatives to/backups to space-based PNT/GNSS will be a fruitful aspect for investment. There is some probability that space-based PNT will not be reliable. Quantum Wayfinder and Marinev (integrating GPS/European GNSS (Galileo and EGNOS) with complementary terrestrial PNT) are good examples (Elements 1 & 3). That spirit of innovation, investment, and risk mitigation should be continued.	
Score:	3

Significance and additionality of UK contribution to the overall mission/investment *(~300 words)*
Questions: Was the UK contribution(s) a major part of the mission/programme delivery compared to other non-UK elements? Was it a supporting or leading contribution in terms of science, engineering and/or use of data? What does the UK bring to ESA in this respect? What about the UK contribution appears to have been 'special' (e.g. specific expertise, facilities, pedigree)? **Scoring:**
The UK is clearly in a dominant position financially thanks to being the majority investor and intellectually through the alliances with key universities that are seeding next-generation researchers in PNT. The 'transition [of] PNT technologies from innovation to market-ready solutions … has enabled

UK companies to attract investment, enter new markets, and expand their global footprint' reflects a global and EU/ESA impact.	
Score:	3

Potential socio-economic impact/implications of UK element *(~300 words)*	
Questions: What benefits have already been achieved or might be expected because of UK contributions, e.g. in security, space weather preparedness, climate monitoring and crisis resilience? How significant are those benefits in the context of wider space R&D/practice efforts to tackle the same problems? Were /are there any missed opportunities for even more impact? **Scoring:**	
Space-based PNT has become omnipresent. The reliability/robustness of this dependence is being appropriately questioned, and UK contributions to more reliable PNT, including terrestrial and combined approaches, will lead to better preparedness and resilience. This is reflected in the marketing/commercial successes achieved to date. Allusions to MEMS and ring-laser integration are mentioned but not developed.	
Score:	3

National capability and reputational contribution *(~300 words)*	
Questions: By contributing, what has the UK gained in terms of its own capability to participate in investments/missions like this? What reputational gains appear to have been made for the UK because of the individual contributions? This can be both scientific and political, as relevant. What is the general global scientific significance (the 'ends') to which the technologies contribute (the 'means')? **Scoring:**	
The UK is and will be well-placed for the coming transition phase of PNT. Just as communications via satellite were the leading edge until optical Fiber fibre, PNT will settle on a dual-mode set of media where space and terrestrial work together and complement each other, providing higher levels of reliability.	
Score:	3

Optional: Indicate any missing information / lack of evidence
Recommend dropping the term 'system of systems' and replacing it with 'system'.

Source: RAND Europe Analysis.

J.5. Vigil

J.5.1. Investment briefing

<table>
<tr><td colspan="6">Investment: Vigil</td></tr>
<tr><td colspan="6">Scale of investment (colours indicate low/med/high bands)</td></tr>
<tr><td>Cumulative spending to the end of 2022 (€m)</td><td>2023 Budget (€m)</td><td>Projected Commitment (2024–2028) (€m)</td><td>Projected commitments (2029 onwards) (€m)</td><td>UK CM22 Investment (£m/€m)</td><td>% of total MS amounts at CM22</td></tr>
<tr><td>Not reported</td><td>Not reported</td><td>Not reported</td><td>Not reported</td><td>81.3/94.1</td><td>59.3%</td></tr>
<tr><td colspan="6">Summary description of the investment</td></tr>
<tr><td colspan="6">Initially known as Lagrange, Vigil is a space weather monitoring mission currently under development by the European Space Agency (ESA).[140] Vigil is unique and distinct from previous ESA space weather or heliophysics missions such as Solar Orbiter,[141] or the Solar and Heliospheric Observatory (SOHO)[142] in that it is being designed to be an operational mission rather than scientific, while previous missions have been designed to study the Sun, Vigil is designed to monitor and provide near-real-time data to operational centres, enabling improved space weather forecasting and broadening the potential for now-casting to protect CNI from the impacts of severe space weather events and to lower or mitigate the costs of those impacts (e.g. grid going down, telecoms satellites becoming unresponsive, etc).

Once launched, Vigil will be placed at the Sun-Earth L_5 Lagrange point, offering a 'side-on' view of the Sun and providing a constant view of solar wind and other space weather artefacts that are heading towards or have the potential to interact with the Earth.

Vigil is designed to complement a forthcoming NOAA mission, Space Weather Follow On-Lagrange 1 (SWFO-L1),[143] which, as the name suggests, will be placed at the Sun-Earth L_1 Lagrange point. Thus, Vigil and SWFO-L1 will provide complementary and opposing views of the Sun-Earth interface, enabling complex and verifiable modelling and now-casting capabilities.</td></tr>
<tr><td colspan="6">Justification for evaluating this investment (agreed with client)</td></tr>
<tr><td colspan="6">• UK influence: The UK is the foremost contributor – providing over half of the total investment.
• Benefits lead time: Several years to launch, with benefits expected in the coming decades.
• Policy alignment: A focus of mission leadership, playing to UK strength in predicting space weather. The primary objective is to protect Critical National Infrastructure – acting as a successor to SOHO – will be only one of two missions supporting space weather prediction alongside the US National Aeronautics and Space Administration (NASA)/ National</td></tr>
</table>

[140] UK Space Agency (2024a).
[141] ESA (2025f).
[142] ESA (2025g).
[143] NOAA (2025).

Oceanographic and Atmospheric Administration's (NOAA) Lagrange, contributing to wider **socioeconomic benefits** associated with mitigated costs from severe space weather events.

- **VfM:** This is a key area of interest for a programme-specific VfM analysis. There is existing literature on the economic impact of space weather, and improved space weather monitoring can help reduce this.

This programme will undergo high-level M&E due to the UK's relatively high investment and leadership role. Given that the programme is early in its life cycle, a stronger focus on monitoring and benefits mapping is likely most appropriate. There is some interest in assessing historical impacts from previous space weather missions.

Key areas of UK involvement/technologies
List the three most significant contributions / use cases from the UK to the programme/mission

Summary:

- The UK contribution to Vigil totals 59.3% of ministerial spending at the last CM meeting, meaning that the UK significantly influences and leverages ESA's space weather portfolio.
- Vigil represents a strategic success story for the UK – a clearly identified need, priority and existing expertise/heritage led to strong UK involvement in all mission stages (Airbus as industrial lead and PM, UK institutions leading on key instrument design and Met Office involvement in operational aspects).
- Vigil is perceived as an operational mission, requiring reliable, continuous data, presenting unique opportunities for improved fore- and now-casting capabilities in the UK (especially when complemented with NOAA capabilities) and raising challenges around downstream utilisation of that data.

The UK's leadership in Vigil leverages the nation's instrument development heritage, industrial capabilities and operational leadership to further the UK's strategic objective of leadership in space safety (of which space weather is a crucial component). Airbus UK is the prime contractor for payload design and manufacture and project management. In contrast, instruments are being designed and built by Imperial College London (MAG – Magnetometer)[144] and UCL Mullard Space Science Lab (UCL MSSL) (PLA - Plasma Analyser),[145] two institutions with long-standing and world-leading expertise in developing instruments. Within the UK, operational capacity derives primarily from the Met Office[146] and its Space Weather Operations Centre (MOSWOC), recognised globally as a leading provider of space weather data and expertise.

UCL MSSL recently produced a demonstrator model for PLA, which highlighted a few problem areas. While work continues, a preliminary design review is scheduled for February 2025, and a critical design

[144] Eastwood (2024).
[145] Zhang et al. (2024a).
[146] Met Office (2025).

review will take place 18 months later in mid-2026. UCL MSSL is on track for a built and tested flight unit for delivery to Airbus in May 2027 ahead of launch in 2032.

Critically, Vigil does not represent a significant technical advancement – the satellite bus developed by Airbus is an existing design, and the instruments are derived largely from previous missions. For example, Imperial's MAG instrument is primarily (estimated in an interview at 90%) derived from similar magnetometers on ESA's Juice (Jupiter Icy Moons Explorer) and Solar Orbiter missions, allowing for a slightly faster development time than usual and increasing the confidence that Airbus has in successful and timely delivery while allowing for alterations to the design. This also means that a large amount of technical documentation and test reports are available for review by the engineering and design teams, allowing lessons learned to be implemented during the design and build phase.

The crucial difference is the requirement for reliable, continuous and near-real-time data. While other satellites can go offline for a day or two for an update, Vigil is expected to be online and transmit data as much as possible, a key distinction between a scientific satellite and an operational one. This means that the design and engineering focus is mainly on increasing reliability rather than incrementing data and instrument quality.

Key outcomes

List the three most significant outcomes resulting from the UK's involvement in the programme/mission

Summarising from above:

- Direct financial return to UK companies (Airbus as prime) and institutions (Imperial, UCL).
- Increased fore- and now-casting abilities for space weather and potential for increased cost mitigation from severe space weather events.
- The UK is positioned as a global leader in space weather mission design and operations, positioning institutions like the Met Office at the forefront of future space weather missions, programmes and projects.

The primary outcome of the UK's investment in Vigil is the awarding of the prime contract to Airbus UK and the design, manufacture and testing of the satellite and two key instruments in the UK ahead of launch in 2032. As noted through interviews, a key benefit for UK academic institutions is the maintenance of instrument design and engineering expertise, following on from previous missions like Solar Orbiter. If the UK had not contributed to Vigil, instrument design and engineering work (such as designing the magnetometers) would have been lost to another ESA member state, and the existing teams and wealth of expertise housed in institutions like Imperial would have degraded as individuals moved on to industry or other projects. This capability maintenance is a key benefit of continued engagement with ESA space science and space weather programmes and helps build a case for future involvement.

Vigil (in conjunction with SWFO-L1) is key to maintaining and evolving international space weather fore- and now-casting capabilities. There are only three operational space weather data centres worldwide: NOAA in the US, MOSWOC in the UK and a third in South Korea. NOAA and MOSWOC are world leaders in space weather operations, but data relies on ageing US science satellites like STEREO and other

ageing solar monitoring infrastructure. Vigil and SWFO-L1 will replace that data source with something more operationally focused while also continuing to establish the reputation of the Met Office (and the UK more generally) as a world leader in space weather, opening up opportunities for involvement in future missions, programmes and projects including bilateral opportunities with NOAA/NASA. Some concerns exist around the ability of countries like the UK to capitalise on and fully implement these new data products downstream. ESA is developing a Space Weather Payload Data Centre to collate, host and process data products from space weather and heliophysics missions worldwide. Suggestions have been raised through interviews that the UK needs to do more to develop national operational capabilities to enable the complete transfer of data from high-level, early-stage operations centres like ESA's SWPDC to end-users like electrical grids and transportation operators.

J.5.2. Reviewer assessment

Overall summary 'verdict' *(200 words max.)*
Much of the socioeconomic benefit of Vigil (such as access to enhanced space weather data) is not specifically dependent on the UK being the source of funds. These benefits will be realised as long as the project is funded. More direct economic benefits accrue to UK companies and educational institutions based on their direct participation, facilitated by UK investment in the project. The project also protects UK national capabilities and maintains the UK's reputation for leadership in space weather. Vigil is a unique investment with a pay-off for all spacefaring activities, placing the UK in a dominant role in space weather.

Technological significance and novelty of UK element *(~300 words)*	
Questions: To what extent is the technology/approach/solution best in class (for that time)? Is it innovative or new in terms of science, engineering or application? How does it compare to other approaches/instruments? Has there been any significant progression in TRL, commercial and/or scientific understanding because of the UK contribution? **Scoring:**	
While the technology is not new, it provides vital resilience and redundancy to space weather data collection. It also provides continuity of experience for UK researchers in this field. The UK's willingness to fund this project undoubtedly contributes to the award of the satellite bus and two of the instruments to UK entities. The technology here is operational, not leading-edge, so while the UK's involvement is leading the world-class approach to measuring and predicting space weather along with NOAA, the technologies are proven and reliable.	
Score:	2

Significance and additionality of UK contribution to the overall mission/investment *(~300 words)*	
Questions: Was the UK contribution(s) a major part of the mission/programme delivery compared to other non-UK elements? Was it a supporting or leading contribution in terms of science, engineering and/or use of data? What does the UK bring to ESA in this respect? What about the UK contribution appears to have been 'special' (e.g. specific expertise, facilities, pedigree)? **Scoring:**	
UK contributions are significant. UK entities supply the satellite bus and two of the instruments, as well as the processing and distribution of the resultant space weather data. Both in space and terrestrially, yes. The UK manages one of three space weather analysis centres along with the US and South Korea. The off-edge aspect of Vigil at Earth/Sun L5 will provide the key perspective for observing the sun's activities that lead to damaging radiation. The difficulties of working/communicating at L5 (versus L1) make Vigil the more difficult system to develop and operate.	
Score:	3

Potential socio-economic impact/implications of UK element *(~300 words)*	
Questions: What benefits have already been achieved or might be expected because of UK contributions, e.g. in security, space weather preparedness, climate monitoring and crisis resilience? How significant are those benefits in the context of wider space R&D/practice efforts to tackle the same problems? Were/are there any missed opportunities to have even more impact? **Scoring:**	
The UK is already one of the leaders in the processing, analysing and distributing space weather data, and this project improves the resilience of space weather data collection and maintains UK expertise. There may have been a missed opportunity to tie this project more tightly to improvements in the UK's space weather analysis MOSWOC. Advanced work, such as by UCL MSSL, will iteratively lead to a more reliable and accurate system. Once the new-generation space weather forecasting capability is fully operational in the US and UK, effective integration with space commerce and the development of improved space weather risk contingencies should be the next phase of investment.	
Score:	2

National capability and reputational contribution *(~300 words)*	
Questions: By contributing, what has the UK gained in terms of its own capability to participate in investments/missions like this? What reputational gains appear to have been made for the UK because of the individual contributions? This can be both scientific and political, as relevant. What is the general global scientific significance (the 'ends') to which the technologies contribute (the 'means')? **Scoring:**	
This project cements the UK's leadership position in space weather collection, analysis and distribution. It is probably best to consider this investment as maintaining a position (i.e. not losing capability and reputation) instead of gaining. The UK is recognised among the world leaders in this area and unique in ESA in that capacity. Vigil is a singular activity (along with NOAA SWFO-L1) that will contribute to virtually all other space activity and commerce. That is impressive.	
Score:	3

Optional: Indicate any missing information / lack of evidence
This review would benefit from additional data regarding the UK MOSWOC.

Source: RAND Europe Analysis.

Annex K. List of organisations consulted for this evaluation

K.1. Organisations consulted for this evaluation:[147]

Aalyria UK Ltd

Airbus

Airbus Defence and Space

Astroscale

Atout Process

Broadcast Critical

Centre for Environmental Data Analysis

CGI UK

ClearSpace

Craft Prospect

Cranfield University

Deimos UK

D-Orbit UK

EarthWave Ltd

European Centre for Medium-Range Weather Forecasts

European Space Agency

Fluid Gravity

Flylogix Holdings Ltd

GMV NSL Ltd

Honeywell

Imperial College London

Lumi Space

[147] NB: This list only includes organisations which participated in data collection interviews. It does not include organisations that refused participation or were unresponsive to requests from the evaluation team. Some organisations did not wish to be named and are excluded from this list.

McKenzie Intelligence Service Ltd

MDA Space

Messium

Met Office

Nammo UK

National Centre for Earth Observation

National Oceanography Centre

National Physical Laboratory

Open Cosmos

Oxford Space Systems

Pixalytics Ltd

RAL Space

Reaction Engines

Satellite Applications Catapult

Science and Technology Facilities Council

Sheffield University

Skyports Deliveries

Starion

Surrey Satellite Technology Ltd

Teledyne e2v Detectors

Telespazio-UK

The Open University

Trade In Space Ltd

Twi Limited (The Welding Institute)

UK Space – EO Committee

UK Space Agency

University College London

University College London

University of Aberystwyth

University of Cambridge

University of Cardiff

University of Leicester

University of Oxford

University of Reading

University of Southampton

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