Economic evaluation of the International Partnership Programme (IPP): Cost-Effectiveness Analysis

Prepared for the UK Space Agency

PUBLIC

LE London Economics

September 2019

About London Economics

London Economics (LE) is one of Europe's leading specialist economics and policy consultancies, with a dedicated team of economists specialised in the space sector.

As a firm, our reputation for independent analysis and client-driven problem solving has been built up over 30 years. From our headquarters in London, and associate offices in five other European capitals, we advise an international client base.

As a team, we have been pioneering innovative analytical techniques and advising decision-makers across the space industry, space agencies and international governments since 2008. Drawing on our solid understanding of the economics of space, expertise in economic analysis and industry knowledge, we use our expertise to reduce uncertainty and guide decision-makers.

Our consultants are highly-qualified economists with extensive experience in applying a wide variety of best practice analytical techniques to the space sector, including:

- Market sizing, analysis and demand forecasting;
- Business case support (economic and financial feasibility);
- Value-for-Money (Cost-Benefit Analysis, Cost Effectiveness Analysis);
- Impact assessment and policy evaluation (especially public utility and spillover benefits);
- Sophisticated statistical analysis (econometrics, regression);
- Analysis of industry structure and competitive dynamics;
- Commercial due diligence.

London Economics has been selected to provide the UK Space Agency's International Partnership Programme with specialist economic evaluation support and analysis, in collaboration with Caribou Space.

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About Caribou Space

Caribou Space work with governments, space agencies, development agencies and private sector space companies to bridge the space and development worlds.

Caribou Space is the selected partner for UK Space Agency International Partnership Programme providing ODA compliance, monitoring & evaluation (M&E), knowledge sharing and communications, sustainability and programme strategy support. London Economics has partnered with Caribou Space to provide the economic analysis support for the IPP.

About UK Space Agency

The UK Space Agency leads the UK efforts to explore and benefit from space. It works to ensure that our investments in science and technology bring about real benefits to the UK and to our everyday lives. The agency is responsible for all strategic decisions on the UK civil space programme. As part of the Department for Business, Energy and Industrial Strategy, the UK Space Agency helps realise the government's ambition to grow our industry's share of the global space market to 10% by 2030.

The UK Space Agency:

- Supports the work of the UK space sector, raising the profile of space activities at home and abroad;
- Helps increase understanding of our place in the universe, through science and exploration and its practical benefits;
- Inspires the next generation of UK scientists and engineers;
- Regulates and licences the launch and operation of UK spacecraft, launch operators and spaceports;
- Promotes co-operation and participation in the European Space Agency and with our international partners.

The International Partnership Programme (IPP) is a five-year, £152 million programme run by the UK Space Agency. IPP focuses strongly on using the UK space sector's research and innovation strengths to deliver a sustainable economic or societal benefit to emerging and developing economies around the world.

IPP is part of and is funded from the Department for Business, Energy and Industrial Strategy's Global Challenges Research Fund. This is a £1.5 billion fund announced by the UK government to support cutting-edge research and innovation on global issues affecting developing countries.

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Table of Contents

Executive Summary

Study aims

The aim of this study is to evaluate the cost-effectiveness of the UK Space Agency's International Partnership Programme (IPP) and to assess the case for space-based solutions for development more generally. This objective meets the OECD Development Assistance Committee's (DAC) criteria of 'efficiency' which signifies that aid uses the least costly resources to achieve their desired impact.

This study presents the interim results of a pioneering exercise to assess the cost-effectiveness of IPP (space) projects relative to alternative (non-space) solutions. These results of this Value-for-Money analysis will be updated in 2021 once project-level impacts have been realised.

Study scope and methodology

The analysis in this report is based on the cost-effectiveness of the portfolio of IPP (space) projects relative to alternative (non-space) solutions. All 33 IPP projects have implemented their own standardised cost-effectiveness analyses (CEA)[1]. All grantees have assessed cost and impacts over a Short (to 2021) and Longer (to 2023) time period and converted costs and impacts to 'common units' to account for inflation, exchange rates, and the fact that people value costs and impacts differently across different time periods.

For projects involving the development areas agriculture (improvements to yield), forestry (reduction in deforestation) and disaster resilience (reduction in persons killed, missing or injured), the evidence (sample size and consistency of data) are sufficient to derive cost-effectiveness estimates per development area. IPP projects that target other development areas, such as disaster resilience (reduction in economic loss), maritime, renewable energy and tax collection are presented in case studies.

Study limitations

The methodology used, and assumptions made, follow best practice. Nonetheless, the reader should note the following limitations and caveats:

- CEA allows comparison between space and non-space solutions for a given application, not across applications;
- Space-based solutions have additional benefits not reflected in the CEA (such as lower error rates);
- CEA results are sensitive to assumptions of both time periods and scale of deployment;
- Some non-space alternatives are less scalable than IPP solutions;
- The CEAs are based on (uncertain) projections of costs and impacts;
- Some projects have to double count costs across multiple impacts,
- Authorities may not act on the information provided by different IPP and alternative solutions in the same way.

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[1] A comprehensive and bespoke methodology was circulated to project grantees to support consistent implementation in line with rigorous UK Government and OECD monitoring and evaluation requirements.

Key findings

- **All IPP projects in this study are forecast to deliver impacts more cost-effectively than alternative (non-space) methods.** For example:
    - **Forestry:** Space-enabled solutions for forestry are on average **x8 times more cost-effective** than the non-space alternatives (aerial photography, drones, patrols) in the short term (and up to **x11.8 times** in the longer term). In the longer term, this corresponds to an average cost of £12.84 per hectare of deforestation avoided.
    - **Agriculture:** Space-enabled solutions for agriculture are on average **x6 times more cost-effective** than the non-space alternatives (drones, patrols, extension workers) in the short term (and up to **x6.7 times** in the longer term). In the longer term, this corresponds to a cost of £0.05 per £1 of additional crop yield gained.
    - **Disaster resilience:** Space-enabled solutions for disaster resilience are on average **x1.7 times more cost effective** than the non-space alternatives in the short term (and up to **x1.8 times** in the longer term). In the longer term, this corresponds to a cost of £20,047 per killed, missing or injured (KMI) person avoided.
    - **Space-enabled solutions are also more cost-effective than non-space alternatives in other development areas, such as disaster resilience** (reduction in economic loss)**, maritime, renewable energy and tax collection.**
- The following key themes also emerge from this study:
    - **Space-enabled solutions are more cost-effective than alternative solutions in the long run**: the cost-effectiveness ratio of IPP solutions is better than that of the alternatives for all projects surveyed in this study over the longer time horizon (to 2023).
    - **IPP projects are increasingly cost-effective over longer time horizons.** As well as the cost-effectiveness improving in an absolute sense, it also improves relative to the improvements in cost-effectiveness of the alternatives over time. This is because these solutions tend to be far more labour intensive, resulting in high operating costs and few, if any, economies of scale.
    - **IPP projects are increasingly cost-effective at large scale**: most projects can be deployed to cover new geographic areas at a decreasing marginal cost. This is particularly the case with satellite-enabled EO projects.
    - **Alternatives are not always viable at large scale**: all the alternatives to the IPP solutions exist in some form in the real world. However, they are typically localised solutions that are not amenable to large-scale deployment e.g. drones and aerial photography.
    - **Some development areas cannot substitute for space entirely**: space technologies cannot be entirely replaced in practice as some alternatives – including ground-based patrols and aerial-based monitoring – would still require the use of satellite phones and GIS maps. For example, EO-based solutions validate satellite-derived imagery with non-satellite sources of data (e.g. ground truthing) to enhance their predictive models.
    - **Space-based solutions have additional benefits that are not reflected in the CEA**: This means that the CEA may underestimate the benefits of projects, for example: satellite solutions are less prone to human error than more manual alternatives and use of satellite imagery reduces risk to humans in environments that may otherwise be too dangerous for human monitoring.

1 Introduction

1.1 Context

The United Nations (UN) 2030 Agenda outlines 17 Sustainable Development Goals (SDGs) to secure economic and social development for all countries[2]. These goals recognise that development is linked to strategies that improve health and education, and humanity's resilience to disasters and climate change.

Space-based technology is one of several technologies that can provide data and services that can directly contribute to achieving the SDGs or to monitor progress towards achieving them. This is because space-based technologies rely on orbiting satellites with sensors that cover vast and remote areas of the Earth. For example:

- **Earth Observation (EO)** satellites are used to monitor the land, oceans and ice-caps of the planet and its atmosphere, and to identify patterns or changes in the environment. EO solutions can therefore be used to provide users with intelligence to target resources to improve development outcomes (e.g. to mitigate deforestation, to optimise agricultural input use, to estimate disaster risk).
- **Global Navigation Satellite Systems (GNSS)** are used to measure a user's position, velocity and time with high accuracy. This data can be used on its own or integrated with EO to provide geolocation information to support asset monitoring (e.g. of timber, fishing vessels, infrastructure).
- **Satellite communications (Satcom)** satellites relay and amplify radio signals between different points on the Earth to support telecommunications in isolated environments that lack access to terrestrial infrastructure. This makes satcom solutions particularly suitable for resilient communications in disaster situations and for communicating intelligence (e.g. from EO) to remote communities (e.g. rural schools/hospitals, farmers, etc.).

In many cases, these technologies are used in combination, supporting a wider variety of applications including: the monitoring of the natural and built environment, agriculture, disaster management, and meteorology.

The provision of timely information to inform the response of end users is a common theme for space-based solutions – either by providing precise monitoring data, decision support, or resilient communications, potentially more efficiently or effectively than alternative solutions. However, space for development is an emerging domain. Little quantitative evidence exists on the value of space-enabled applications for development, and how it compares to solutions that rely on alternative (e.g. terrestrial) sources of data. Without this evidence, it is difficult to convince funders of the benefit of investing in space-based solutions for development.

1.2 The International Partnership Programme (IPP)

The International Partnership Programme (IPP) is a five-year, £152 million programme run by the UK Space Agency (UKSA). It is funded by the Department for Business, Energy and Industrial

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[2] Please see: https://sustainabledevelopment.un.org/?menu=1300

Strategy's (BEIS) Global Challenges Research Fund (GCRF) and forms part of the UK's Official Development Assistance (ODA) commitment.

The IPP uses the **UK space sector's research and innovation strengths to deliver space-enabled solutions in developing countries through partnerships with local organisations.** These solutions are intended to enhance the capacity of these countries to respond to a variety of development challenges, including deforestation, disaster response, agricultural production, maritime communications and renewable energy. A total of 33 projects have been commissioned as of March 2019, involving UK organisations across industry, academia and the non-profit sector.

The impact of the IPP on the developing world is the primary focus of this five-year ODA programme. A rigorous Monitoring & Evaluation (M&E) function has therefore been implemented by Caribou Space to measure and communicate the benefit and impact of IPP on developing countries. All IPP grantees are required to evaluate their project-level impact to support this work. Further information on the projects, and various reports on the potential areas that space can help in developing countries, can be found at www.spacefordevelopment.org.

IPP has implemented **Cost-Effectiveness Analysis (CEA)** – a type of Value-for-Money analysis that compares the costs of alternatives that target the same impact. Assessing the cost-effectiveness of a programme is recommended by both the UK Government and the OECD[3]. For example, if the type of impacts achieved by two forestry projects are the same (i.e. hectares of forest saved from deforestation), it is possible to compare the 'cost per unit of impact' to estimate which project is more cost effective (e.g. cost per hectare of forest saved from deforestation). This avoids the need to monetise impacts that are difficult to value.

A programme-level study of this nature is reliant on robust and consistent cost-effectiveness data from the individual projects that make up the IPP portfolio. To this end, London Economics and Caribou Space prepared a guidance manual and programme of support to allow individual grantees to conduct their own cost-effectiveness analysis.[4] A high-level summary of this bespoke methodology is outlined in 2.1.

1.3 Research objective

This report provides an evidence-based economic evaluation of the IPP using cost-effectiveness analysis and adds to the evidence base on the effectiveness of space for development.

It does so by presenting the interim results of a pioneering exercise to assess the cost-effectiveness of the portfolio of IPP (space) projects relative to alternative (non-space) solutions. This has been possible because all **33 IPP projects** have implemented consistent forward-looking cost-effectiveness analyses (CEA) that are in line with rigorous UK Government and OECD monitoring and evaluation requirements. This project-count and consistency make it possible to assess cost-effectiveness across three development areas: **agriculture** (improvements to yield), **forestry** (reduction in deforestation) and **disaster resilience** (reduction in persons killed, missing or injured). The case for space-enabled solutions in other areas – such as maritime, land use, health and

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[3] Please see: HM Treasury's The Magenta Book and also the OECD's *Development Assistance Committees' (DAC) Criteria for Evaluating Development Assistance*. HM Treasury (2011). *The Magenta Book: Guidance for evaluation*, April 2011. Available here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220542/magenta_book_combined.pdf, and here: www.oecd.org/dac/evaluation/daccriteriaforevaluatingdevelopmentassistance.htm.

[4] London Economics (2018). *Cost-Effectiveness Analysis: A Guidance Manual. Issue 2.0, June 2018*.

education – is also considered. Some projects that were analysed as part of the study cannot be presented in this report to protect commercial confidentiality.

1.4 Structure of this report

This report presents the **interim results** of this programme-level CEA study. These results will be updated in 2021 once project-level impacts have been realised.

Since cost-effectiveness analysis is recognised by governments and stakeholders in industry and the development sector, this report will be informative to potential end-users, providers, and funders of space-based solutions for development. To this end, this study is arranged as follows:

- **Chapter 2** details the methodology (scope, approach and limitations) of the study;
- **Chapter 3** assesses the cost-effectiveness of space enabled-solutions for agriculture, forestry, disaster resilience and other areas;
- **Chapter 4** concludes on the emerging evidence from this study on the use and value of space-enabled solutions for development; identifies common themes, and outlines the planned development of the IPP evidence-base.

Note: All IPP projects are still **ongoing** at the time of writing this report. The estimates of cost-effectiveness of individual projects, and of space-based solutions overall, are reliant on (uncertain) **projections** of costs and impacts beyond late-2018. The results of this report should be considered **indicative** and **will be updated** in a 2021 update of this report as actual data on costs and impacts become known.

2 Methodology

2.1 Cost-Effectiveness Analysis (CEA) methodology

The bespoke CEA approach used in this study is grounded in best practice from the UK Government and international development context but makes some simplifications for the purpose of practical implementation[5]. **A comprehensive methodology and case study were circulated to project grantees to support grantee development and CEA implementation.**[6] The main steps for the project-level analyses that underpins this programme-level study can be summarised as follows:

- **Step 1: Define** – the first step is to define the scope of costs to be considered in the analysis. This includes a definition of the project e.g. in terms of the project setting, the activities of the project, the population of users targeted by the project, and the extent of coverage. Likewise, the next best (non space) alternatives to the IPP space solution that could theoretically deliver the same impacts as the project must also be defined at this point.
  - Time period of analysis: All project CEAs estimate cost-effectiveness for their project and their alternatives over two time periods, forecasting costs and impacts beyond late-2018:
    - Short term (to 2021): To cover the length of the IPP. Projections of costs beyond late-2018 are grounded in IPP budget estimates;
    - Longer term (to 2023): This longer time period was chosen to demonstrate how the relative cost-effectiveness of space-enabled solutions changes over time. Costs and impacts over this period must reflect an extension of the 'business as usual' scenario – i.e. continuation of the project (at IPP scale) on a sustainable (potentially commercial) basis.
- **Step 2: Impacts** – CEA is, by definition, focused on the costs a project incurs in order to deliver improvements to a single impact. For this study, these impacts were defined and measured (net of the counterfactual – i.e. any changes that would have occurred in the hypothetical situation if the IPP project had not gone ahead) as part of a separate but related impact evaluation. In the same way, grantees must identify the *additional* impacts of their chosen alternatives.
- **Step 3**: **Costs** – this step considers the resources that are consumed by the project. Since the goal of CEA is to determine how much it would cost to replicate the project in a commercial setting, it is crucial that detailed information on the quantity and cost of all project resources (and the alternatives) are identified[7]. There are four stages to doing this cost analysis comprehensively: **identify**, **allocate**, **measure**, and **value**.
- **Step 4: Standardise** – all costs and impacts must be converted into 'common units' (i.e. converting costs and impacts to present value terms). For costs, the objective is to account for inflation, exchange rates, the fact that people prefer to delay the payment of costs , and differences in the year of implementation. For impacts, the objective is to account for the fact that people place a greater value on impacts that accrue now than in the future.

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[5] For example: HM Treasury (2011). The Green Book: Appraisal and Evaluation in Central Government; Dhaliwal, I., Dufflo, E., Glennerster, R., Tulloch, C., (2012). Comparative Cost-Effectiveness Analysis to Inform Policy in Developing Countries: A General Framework with Applications for Education.

[6] London Economics (2018). *Cost-Effectiveness Analysis: A Guidance Manual. Issue 2.0, June 2018*.

[7] All project-level CEAs therefore include all resource costs that are either procured for free or provided in-kind. For the same reason, all M&E costs, and a proportion of project management and knowledge sharing costs that would not be incurred in a commercial setting are excluded from the analysis.

- **Step 5: Compute** – this step divides the present value (PV) of costs by the units of effectiveness (also expressed in PV terms) to calculate a cost-effectiveness ratio which provides a single measure of project effectiveness. The result can be interpreted as '*£ cost per unit of effectiveness*'. To address optimism bias and uncertainty around cost estimates, sensitivity analysis is encouraged.
- **Step 6: Report** – in CEA, the project must be compared with alternative options for achieving the same impact, the 'unit of effectiveness'. The means the project or alternative that has the lowest cost-effectiveness ratio is the most economically viable/attractive. To support this programme-level evaluation, all grantees were encouraged to report their results and write-up in a standardised format. The result was an Excel model and an accompanying narrative report.

The broader impacts of the programme (i.e. on UK economy and society), are considered in a separate but accompanying London Economics report.

2.2 Caveats and limitations of the evaluation

This evaluation has been conducted by professional economists with specialist knowledge of space applications. Best practice and judgement have been used to develop the guidance for the project-level CEAs that underpin this study, and to inform the aggregate analysis of this programme-level study. The methodology used, and assumptions made, are described in this report. Nonetheless, the reader should note the following limitations and caveats:

- The **purpose is not to compare projects** – projects are subject to specific contexts and operate at different scales, which will influence their cost-effectiveness. For example, unit labour costs and specific user requirements vary significantly across countries, and impacts depends on the operating scale of different projects. For this reason, the CEA results of different projects cannot be compared. As a result, **it is not possible to make conclusions about which solutions are better, nor is it possible to distinguish between bad implementation and a bad project *per se***. Conclusions on which types of solutions are best is therefore impossible to make on the basis of this study. Instead, the cost-effectiveness of different projects should be compared to the specific alternatives that have been identified for the specific context of the project.
- Space-based solutions have **additional benefits that are not reflected in the CEA**. This means that the CEA may underestimate project benefits. For example: satellite solutions are not subject to the same risk of human error as manual methods, they are scalable and satellite imaging is non-invasive. The latter point means that satellite-based EO can be used to monitor areas too dangerous for alternative methods such as human monitoring. However, this also means that satellites lack the deterrence effect of 'boots on the ground'.
- The CEAs used in this study compare the cost of building and operating both space and non-space solutions over set **time periods** and over **specific geographies**. The CEA is sensitive to both assumptions, for example:
  - Space solutions are typically characterised by low operating costs so tend to become more cost-effective over time, relative to non-space alternatives.
  - Space solutions can be scaled to cover larger geographies at low marginal costs so tend to become more cost-effective at scale, relative to non-space alternatives.

  For example, satellite-derived EO data from certain sources with large public investments (e.g. LandSat and Copernicus/Sentinels) are 'free at point-of-use'. As a result, most EO applications are relatively cheap to scale or operate long-term once the cost of the analytical software or models have been covered. The results of this study are therefore tied to the (arbitrary) project-level assumptions of both the time period of analysis and the assumed scale of the projects over time.

- This study aims to **compare the cost-effectiveness of space solutions with non-space solutions** for delivering the **same impact**. This meant that all alternatives had to be 'non-space'. In some cases, non-space alternatives may not be practical or implementable at a scale or impact that is comparable to space solutions. For example, multiple visits of forest areas by 'boots on the ground' may not be feasible in remote and dense areas of forest. Similarly, the avoidance of all space technologies is implausible in practice as some alternatives – including ground-based patrols and aerial monitoring – would still require the use of satellite phones and GIS maps.
- In many cases, the **alternatives**, particularly for EO-based solutions, have been constructed to **substitute satellite data for non-satellite data sources** (e.g. from drones, aircraft or boots on the ground). In this sense, the alternatives deliver the same type of change detection or risk modelling system as the IPP solutions. However, it may be possible to deliver impacts through entirely different means that are not technology-based.
- **All IPP projects are still ongoing at the time of writing this report**, with most still at the early stages of implementation or operation. The estimates of cost-effectiveness of individual projects, and of space-based solutions overall, are **reliant on (uncertain) projections of costs and impacts beyond 2018**. For cost projections, assumptions of potential operating models post-IPP have been made, while uncertainty on the 'time to impact' are acknowledged with projections of future impact. The results of this report should be considered indicative and will be updated in later editions of this report as actual costs and impacts become known.
- Estimates of the **cost-effectiveness of alternative 'non-space' solutions** are based on either existing studies, or on research of theoretical (if not existing) alternatives. To avoid uncertain assumptions of impact, most projects devised alternatives that could achieve the same impact as their space solution. The CEA was therefore often reduced to a comparison of costs between the IPP project and the alternatives. Nevertheless, there remains inherent uncertainty over the costs of alternatives in particular project contexts.
- The CEA methodology aims to demonstrate the **cost of delivering a unit of a singular impact** in a real-world setting. This means that projects with multiple impacts that are delivered through a discrete platform or device (e.g. satcom equipment) must account for the costs of these items across all relevant impacts (the relevant impact considered in this study and all others) that require the platform or device. Splitting the cost of a device between both impacts would misrepresent the true cost of delivering either impact as both impacts require the use of the whole device. This approach means that **some projects have had to double count some costs across multiple impacts.** This approach differs from traditional appraisal where the cost of a discrete cost is allocated across multiple impacts (economies of scope) since this study is focused on only one project impact.
- By providing precise monitoring data, decision support, or resilient communications, space-based solutions are tools that can support users to take actions that ultimately deliver impact. For example, EO data can be used to detect change in forest cover and to direct the efforts of forest authorities to respond. The **extent of impact** (a reduction in deforestation) **depends on the authorities' capacity to act** on this information. In this respect, the impacts associated with IPP projects depends on both the quality of the space solution and the responsiveness of end users to the solution. For the purpose of the forward-looking CEAs, this 'responsiveness' is assumed and considered the same for both space and non-space solutions.

3 Cost-effectiveness of IPP solutions

This chapter presents evidence on the **cost-effectiveness of IPP space-enabled solutions compared to non-space alternatives**.

While the IPP portfolio covers a diverse range of projects targeted at a variety of development areas, aggregation of project-level CEAs is possible across three areas: **forestry**, **agriculture** and **disaster resilience**. This is because several projects target the **same common impact indicators** – of reduced deforestation and improved crop yields, respectively. The aggregate CEA results of projects that target these indicators are presented in the first half of this chapter. This is followed by case studies of the cost-effectiveness of IPP projects that target other development areas, such as maritime, renewable energy and tax collection.

The cost-effectiveness of all solutions and their respective alternatives are estimated over **two time periods**: **Short term (start to 2021)** and **Longer term (start to 2023)** and are specific and the assumptions outlined in 2.1.

3.1 Forestry

Deforestation and degradation are the biggest threat to forests worldwide, with an annual average loss of 3.3 million hectares between 2010 and 2015. This trend is most pronounced in the developing world which hosts some of the world's most valuable forestry resources[8]. This loss is driven by population growth and economic development – two pressures which increase demand for urban settlement, agricultural land, and forestry commodities.

Given the critical role that forests play as a source of biodiversity, carbon capture and disaster risk reduction, sustainable forest management is vital to the livelihoods of forest dependent communities and climate change resilience.[9] The success of forest management relies on the regular monitoring of forests to identify change and direct the efforts of resource-constrained forest management authorities.

Space-derived data can support several solutions that enhance forest management. For example, EO offers consistent, accurate, large-scale, and analysis-ready optical and radar data at a range of spatial and temporal resolutions. EO can therefore support wide-area monitoring; GNSS can enhance the location and tracking of forest resources, and Satcoms can be used to link this information to officials on the ground. Together, these space-enabled solutions can be grouped into three categories[10]:

- **Active monitoring systems** – frequent monitoring of forest area for change detection;
- **Mapping systems** – for landscape classification and deforestation risk modelling;
- **Decision support tools** – integration of various input datasets to support forest management authorities to make informed decisions.

Each of these solutions are represented within the IPP portfolio. In all cases, satellite data is used as an input in models that can inform the activities of forest management authorities to reduce the

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[8] Food and Agriculture Organisation of the United Nations (2016). *Global Forest Resources Assessment 2015*.

[9] Please see: http://www.euredd.efi.int/deforestation

[10] Caribou Digital (2017). *UK Space Agency International Partnerships Programme: Space for Forestry in Developing Countries*. Available at: https://www.spacefordevelopment.org/topic/2018/07/forestry/

levels of deforestation as measured in absolute hectares. The cost-effectiveness of all six forestry projects considered for this study are therefore assessed in terms of the **'absolute area of forest loss avoided'**.

As shown in the impact chain below, the achievement of reduced deforestation relies on both the provision of satellite-derived intelligence and the capacity of the authorities to act on this intelligence. The capacity of forestry management authorities to respond is related to factors beyond the scope of most projects (e.g. agency budgets), so this **analysis assumes that these authorities can act on the intelligence derived from satellite data**.

Figure 1 Impact pathway of IPP forestry projects

Source: London Economics

These types of solutions are difficult to replicate on a large-scale using alternative 'non-space' based methods. This is because the area of forests that need to be monitored and enforced are vast. Even so, the **non-space alternatives** identified for IPP forestry projects largely involve **substituting the data from satellite with data collected by ground-based teams, drones, or aerial-mounted optical or radar equipment.** While there are limits to the scalability of labour-intensive ground-based teams, drone and aerial methods of monitoring can collect data that generate the same kind of change detection and risk analysis that is produced by satellite data. In this sense, **the cost-effectiveness of space-based projects within the forestry domain is dependent on the relative cost of data collection over forest areas.**

As detailed in Table 1 below, the six forestry projects in this analysis project a total present value (PV) impact of **2.3m hectares of avoided deforestation by 2021** and at an average cost of **£21.22/hectare of avoided deforestation**.

After two further years of operation, these projects expect to deliver a further **2.0m hectares – or cumulative PV total of 4.3m hectares – of avoided deforestation by 2023** at an improved average cost-effectiveness of **£12.84/hectare of avoided deforestation**.

Table 1 Cost-effectiveness of IPP forestry projects

	Short term (to 2021)	Longer term (to 2023)
Total costs, PV (£)	48,201,925	55,226,792
Total impacts, PV (ha)	2,271,118	4,302,165
CEA (£/ha)	**21.22**	**12.84**

Source: London Economics analysis of project-level CEAs from IPP forestry projects

This compares to a cost-effectiveness of **£163.38/hectare** and **£151.44/hectare** for the non-space alternatives over the same time horizons (Table 2).

Table 2 Cost-effectiveness of IPP forestry project alternatives

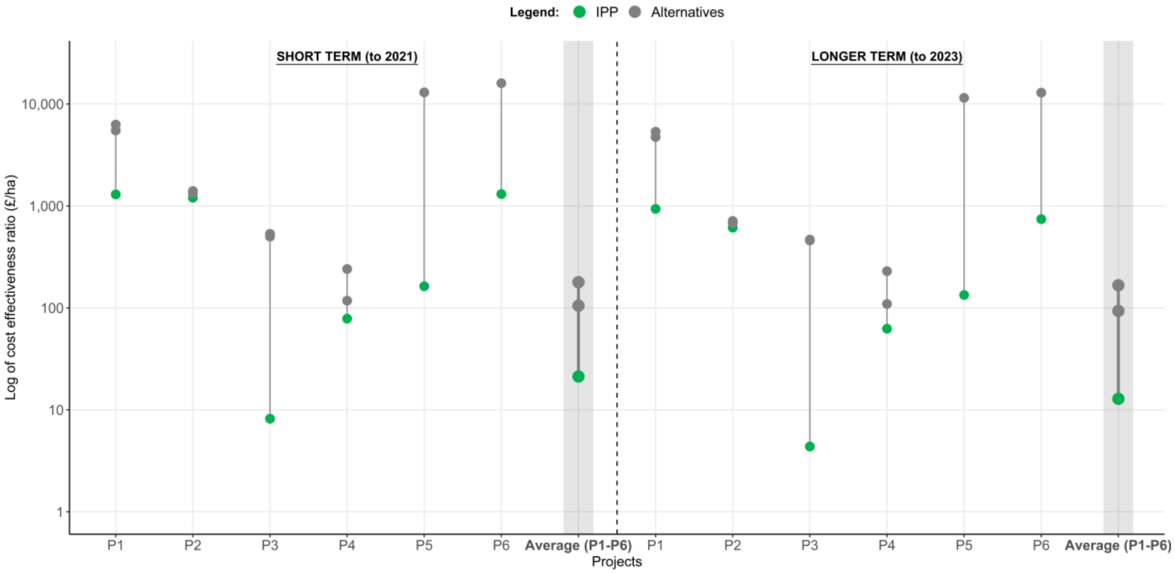
	Short term (to 2021)	Longer term (to 2023)
Total costs, PV (£)	891,621,497	1,199,368,504
Total impacts, PV (ha)	5,457,299	7,919,757
CEA (£/ha)	**163.38**	**151.44**

Note: Alternative CEAs based on aggregation of results for up to two non-space alternatives for each IPP project.

Source: London Economics analysis of project-level CEAs from IPP forestry projects

This analysis suggests that **IPP (space) solutions are on average almost 8 times more cost-effective than the non-space alternatives in the short term** and **significantly more cost-effective (x12) in the longer term**. This difference in cost-effectiveness between the IPP and alternative solutions is demonstrated in Figure 2 below. It shows that **the space-enabled IPP solution** (● green dot) **was more cost-effective than the non-space alternatives** (● ● grey dots) **in all six forestry projects analysed for this report**.

Figure 2 Comparison of IPP-v-Alternatives cost-effectiveness: Forestry



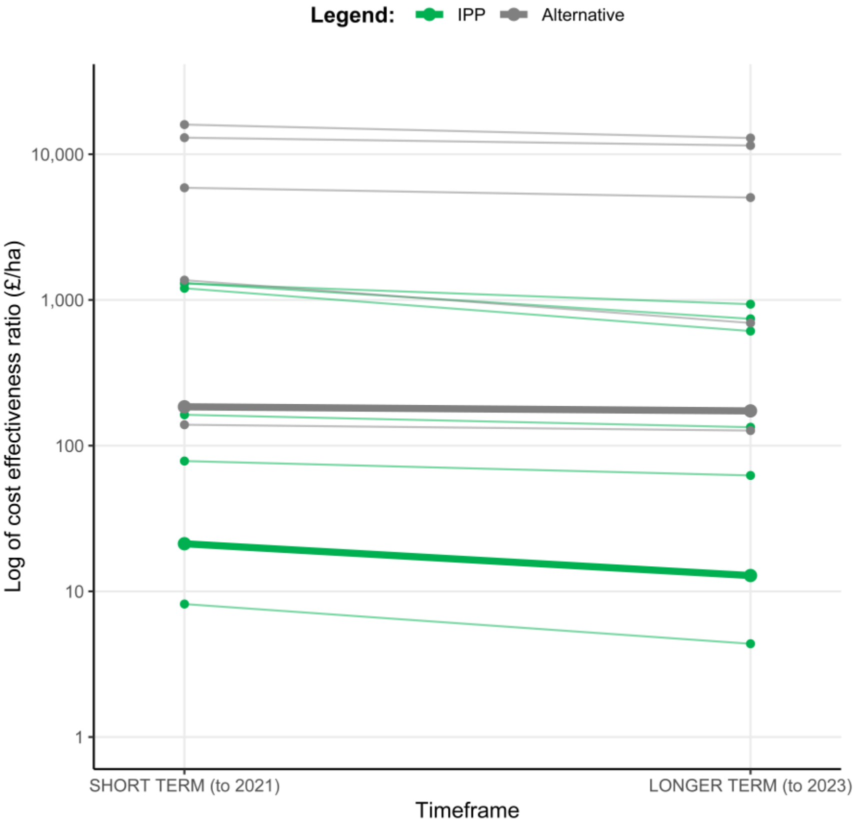
Note: The scale of the Y-axis (cost-effectiveness ratio) is expressed in logarithmic form because of the large range of CER data.
Note: The "Average (P1-P6)" is calculated as the total costs divided by the total impacts.

Source: London Economics analysis of IPP forestry project CEAs

As shown in Figure 3, the **case for space solutions in forestry improves over time** because the cost-effectiveness ratio (CER) of the average space solution improves significantly over time (-40%), while the cost-effectiveness of the average non-space solutions improves only marginally over time (-7%).

The reason for this can be seen by comparing the solutions against four variables: upfront development costs, ongoing operating costs and impact, as show in Table 3 below.

Figure 3 Comparison of cost-effectiveness over time: Forestry



Note: The average change in CER over time is indicated by the thick line.

Source: London Economics analysis of IPP forestry project CEAs

Table 3 Solutions by cost-effectiveness variables

Solution	Development costs	Operating costs	Impact	CER trend
Space-enabled	High	Low	High	-40%
Alternatives	Medium	High	Medium	-7%
Aerial	Medium	High	High	-8%
Drones	Medium	High	Low	-19%
Patrols	Low	High	Low	-11%
Other	Medium	Low	Medium	-7%

Source: London Economics analysis of IPP forestry project CEAs

Space-enabled solutions in forestry are typically high-development cost, high-impact solutions but have very low marginal costs once they are operational. This is because they integrate the low marginal costs of machine learning and AI with the large geographic coverage and high frequency of satellite-derived EO data. These software solutions require significant effort and lead-time to develop, but once they are operational, they can automate change detection across forest areas and provide intelligence to authorities on the ground. This means that **space-enabled solutions are both increasingly cost-effective over time and are scalable across wider geographic deployments.**

By comparison, non-space methods are typically used for more localised surveys. While the economies of data analysis are the same as for the space solutions, data collection via non-space alternatives lack any economies of scale – in other words, their wider implementation would require reproducing the same effort at a similar marginal cost.

3.2 Agriculture

The global agriculture sector faces multiple challenges. A combination of population growth, rising incomes, extreme weather patterns resulting from climate change, and an increasing scarcity of agricultural inputs (water and land)[11] mean that the world will have to substantially increase the yield, resilience and efficiency of food production.

These problems are acute for the developing world. These countries will see most of the population growth, increase in incomes, and effects of climate change and are already characterised by a substantial yield gap for important food staples. Rice and wheat yield in the developing world, for example, are at half the level found in high-income countries[12]. Agriculture also represents an important route to development, given its 20-30% contribution to GDP in sub-Saharan Africa[13] and its status as the main source of income for the world's poorest households.

Space-enabled solutions are well placed to address these challenges. For example, the wide area, frequent and in-season monitoring data from optical and radar EO satellites can provide intelligence on plant health, crop performance and land use. This can be used to guide the decisions of stakeholders throughout the agricultural supply chain. These space-enabled solutions can be grouped into three solution areas:

- **Decision support tools** – frequent monitoring data to support decision-making across the agricultural value chain;
- **Early warning systems** – frequent monitoring data to support early detection and mitigation of adverse events that may compromise agricultural yield;
- **Credit products** – accurate and frequent mapping data to support land use mapping and change detection. This data can be used to bycredit companies to offer financing to credit constrained agricultural producers in the developing world.

These solutions are represented by several projects across the IPP portfolio. In all cases, EO data is used as an input in models that allow agricultural end users to take actions that improve the input efficiency, yield and resilience of their produce. The cost-effectiveness of all four IPP agricultural projects considered for this study is therefore measured in terms of the **'absolute value of the change in crop yield (£)'**. This impact indicator has been chosen to allow aggregation of all agricultural projects regardless of crop type and unit price[14].

As shown in the impact chain below, the achievement of an increase in the absolute value of crop yields (reflecting convergence of yield to efficient global standards) relies on both the provision of satellite-derived intelligence and the response of agricultural end users to this intelligence. The capacity of these end users to respond to this intelligence is often related to factors beyond the

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[11] Food and Agriculture Organisation (FAO). How to Feed the World in 2050.

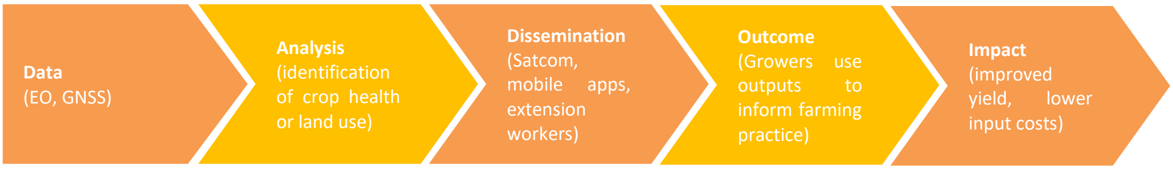
[12] Food and Agriculture Organisation (FAO). The Future of Food and Agriculture, Trends and Challenges

[13] Food and Agriculture Organisation (FAO). Review of the available remote sensing tools, products, methodologies and data to improve crop production forecasts.

[14] Standardised prices from the FAOSat Producer Price Index (based on a 3 year average of annual prices for each crop) have been used for crop valuations. All projects adopted a standardised set of crop prices to stop out crop movements and its distorting effect on the impact indicator. For example, the impact of a yield increase in a localised market may be offset by a subsequent reduction in unit price.

scope of most projects (e.g. the resources available to farmers). This forward-looking **analysis therefore assumes that end users can act on the intelligence derived from satellite data**.

Figure 4 Impact pathway of IPP agriculture projects



Source: London Economics

Agricultural producers may also respond to this intelligence in ways that do not increase yield but nevertheless represent a positive development outcome. For example, some farmers may use this new intelligence to increase their income by producing the same yield but with lower inputs. A focus purely on yield may therefore underestimate the value of space solutions in agriculture. Even so, a lack of project data on input costs means that a broader 'net income' impact indicator that captures both the yield increase and input cost decrease impact channels is beyond the scope of this analysis.

As with forestry, most **non-space alternatives** for agriculture projects involve **substituting the satellite data inputs in model-based solutions with data from drones or ground-based teams.** The relative cost-effectiveness of these solutions is therefore dependent on the relative costs of data collection.

Other non-space alternatives that were identified involved the use of agricultural 'extension workers' to provide direct training and support to farmers. Like the model-driven solutions that rely on farmers responding to data on yield or risk, extension-based solutions rely on farmers responding to guidance. Even so, they typically represent a more intensive category of intervention.

As detailed in Table 4 below, the four agriculture projects in this analysis project a total present value (PV) impact of **£240.5m worth of crop yield by 2021** and at an average cost-effectiveness of **£0.08 per £1 of additional crop yield**.

After two further years of operation, these projects expect to deliver a further **£132.4m worth of crop yield – or cumulative PV total of £372.9m – by 2023** at an improved average cost-effectiveness of **£0.05 per £1 of additional crop yield**.

Table 4 Cost-effectiveness of IPP agriculture projects

	Short term (to 2021)	Longer term (to 2023)
Total costs, PV (£)	18,296,311	20,430,281
Total impacts, PV (£ crop yield)	240,526,122	372,904,332
CEA (£/£1 crop yield)	**0.08**	**0.05**

Source: London Economics analysis of project-level CEAs from IPP agriculture projects

This compares to a cost-effectiveness of **£0.43 per £1 of additional crop yield** and **£0.37 per £1 of additional crop yield** for the non-space alternatives over the same time horizons (Table 5).

Table 5 Cost-effectiveness of IPP agriculture project alternatives

	Short term (to 2021)	Longer term (to 2023)
Total costs, PV (£)	185,650,885	249,454,064
Total impacts, PV (£ crop yield)	433,127,563	679,859,998

CEA (£/£1 crop yield)	**0.44**	**0.38**

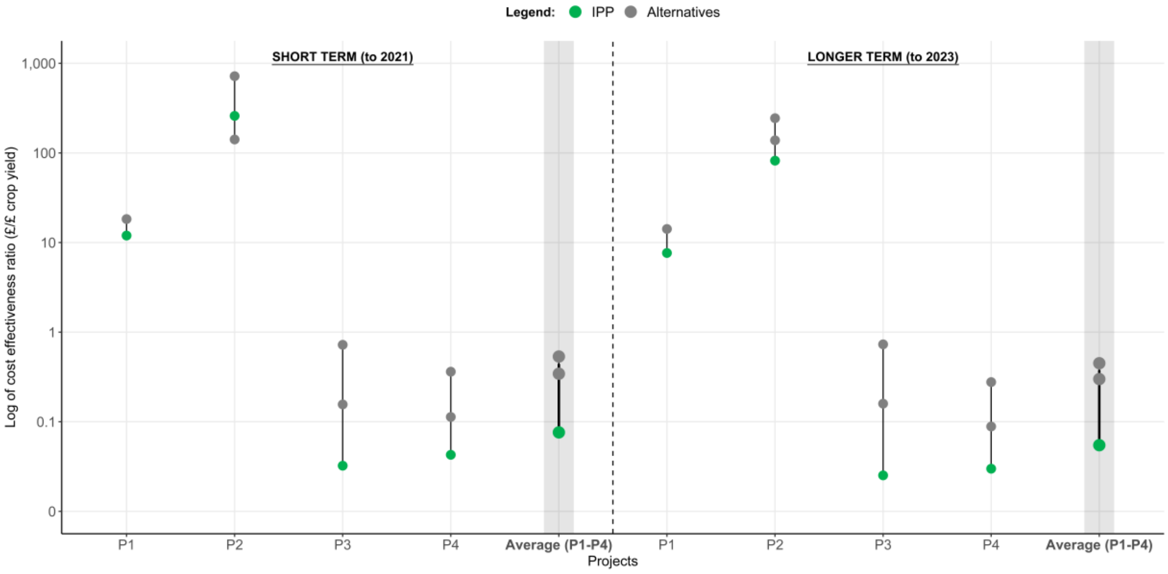
Note: Alternative CEAs based on aggregation of results for up to two non-space alternatives for each IPP project.

Source: London Economics analysis of project-level CEAs from IPP agriculture projects

This analysis suggests that **IPP (space) solutions are on average both cost-effective in an *absolute* sense** (costing less than £1 per £1 of value delivered), and ***relative* to the non-space alternatives.**

IPP solutions are almost 6 times more cost-effective than the non-space alternatives in the short term and **significantly more cost-effective (x6.7) in the longer-term.** This difference in cost-effectiveness between the IPP (● green dot) and alternative solutions (● ● grey dots) is demonstrated in Figure 2 below.

Figure 5 Comparison of IPP-v-Alternatives cost-effectiveness: Agriculture



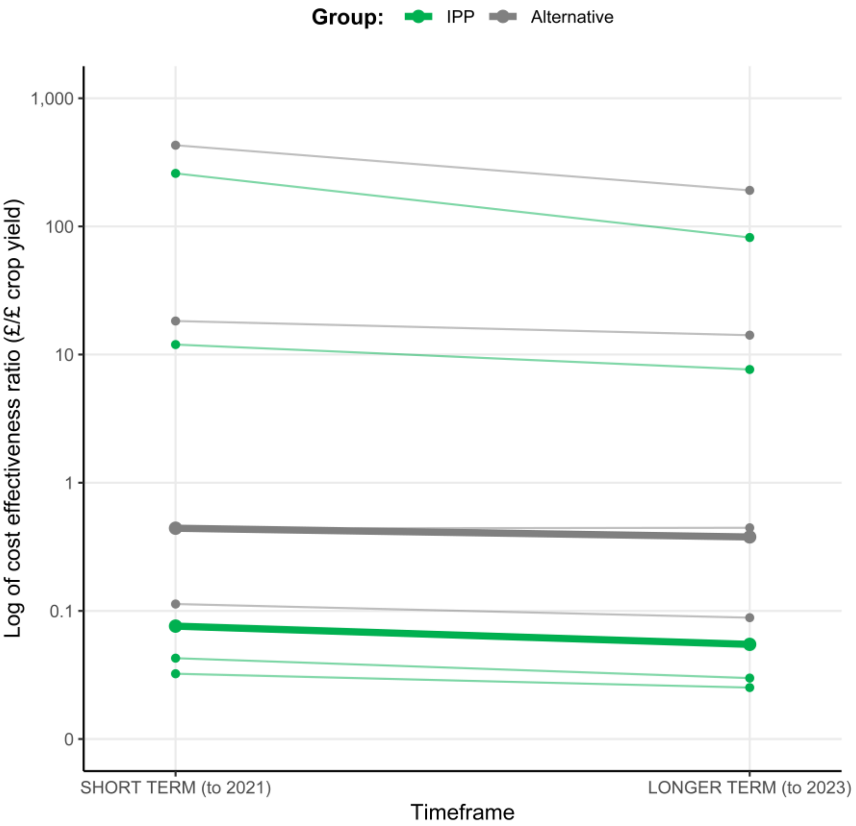
Note: the scale of the Y-axis (cost-effectiveness ratio) is expressed in logarithmic form because of the large range of CER data.
Note: The "Average (P1-P4)" is calculated as the total costs divided by the total impacts.

Source: London Economics analysis of IPP agriculture project CEAs

Figure 5 shows that **the space-enabled IPP solution was more cost-effective than the non-space alternatives in all 4 agriculture projects analysed for this report**, with the exception of a single alternative in the short term only.

As shown in Figure 6, as with forestry projects (Figure 3), the **case for space solutions in agriculture improves over time** because the cost-effectiveness ratio (CER) of the average space solution improves significantly over time (-28%), while the cost-effectiveness of non-space solutions improves at a lower rate over time (-14%).

Figure 6 Comparison of cost-effectiveness over time: Agriculture



Note: The average change in CER over time is indicated by the thick line.

Source: London Economics analysis of IPP agriculture project CEAs

The reason for this can be seen by comparing the solutions against the variables detailed in Table 6.

Table 6 Solutions by cost-effectiveness variables

Solution	Development costs	Operating costs	Impact	CER trend
Space-enabled	High	Low	High	-28%
Alternatives	Medium	High	High	-14%
Drones	Medium	High	High	-13%
Ground-based teams	Medium	High	High	-23%
Extension workers	High	High	High	+10%

Source: London Economics analysis of IPP agriculture project CEAs

Since all solutions can be scaled to reach the same audience and all involve the delivery of information that allows farmers and other grows to optimise farming, their impacts are comparable. However, the **space-enabled IPP solutions are typically high-development cost, low-operating cost projects, while the alternatives generally involve lower leads costs but much higher operating costs.** This is because the lead-time of IPP projects are typically focused on the development and calibration of crop models, which can be scaled to cover larger geographies with the acquisition of satellite data over the expansion areas. Drone-based, ground-based and extension worker alternatives, by contrast, are labour intensive methods that have much lower economies of scale – indeed, the marginal cost of extension workers methods may even increase with time and scale as costs increase at a faster rate than the impacts they are intended to deliver (i.e. the marginal product of labour falls due to the law of diminishing marginal returns).

3.3 Disaster resilience

Natural hazards have a large negative impact on economic development and government finances in affected countries. This is because natural disasters such as floods, droughts and earthquakes expose populations to loss of life, displacement from property and loss of assets, such as homes, livestock and crops[15]. During the 1980-2015 period, such hazards affected an average of 169 million people per year, resulting in the loss of 50,000 lives per year and $2.6 trillion in in total economic damage over the period[16].

Developing countries are particularly vulnerable to such disasters. Their populations are eight times more likely to be affected by disasters, suffer five times as more in direct damage (as a share of GDP), and have much lower levels of insurance against such losses, compared to developed contries. This places the burden of post-disaster relief on government, reducing development expenditures and their capacity to manage sovereign debt risk[17]. For these reasons, disaster resilience is a critical component to global developement.

Space solutions can enhance disaster resilience across each stage of the disaster lifecycle (disaster preparedness, response and recovery). For example the wide coverage of EO can be used to assess the vulnerability of populations and assets to natural disasters and to plan, predict, and observe natural disasters and their aftermath. Similarly, satellite communications can provide resilient connectivity in disaster-hit areas. These technologies are enhanced by GNSS which provides accurate positioning and timing data across the globe. These space-enabled solutions can be grouped into four solution areas:

- **Disaster forecasting –** EO improves the accuracy of disaster forecasting e.g. by improving environmental and meteorological measurement;
- **Planning and response prioritisation –** EO and GNSS data provides authorities with near real-time intelligence on disaster exposure. This allows them to plan mitigation and prioritise response, reducing potential deaths and economic losses.
- **Supporting insurance –** EO and GNSS data can be used to identify, categorise and value physical assets (supporting accurate insurance pricing) and to improve the accuracy of post-disaster assessments (improving the accuracy of insurance payments);
- **Reslient communications –** fixed and mobile satcoms offer telephony and internet access during and after disaster events in areas that either lack terrestrial coverage or where the network has been damaged.

Each of these solutions are represented within the IPP portfolio. In all cases, satellite solutions are used to reduce the levels of economic loss (measured in £s) and/or disaster-related casualties as measured in the numbers of killed, missing and injured (KMIs). The cost-effectiveness of all five disaster resilience projects considered for this study are therefore assessed in terms of either the **'the change in total direct economic loss attributed to disasters (£)'** or **'the change in the total**

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[15] Caribou Space (2018). UK Space Agency International Partnerships Programme: Space for Disaster Resilience in Developing Countries. Available at: https://www.spacefordevelopment.org/wp-content/uploads/2018/10/6.4724_UKSA_Disaster-Resilience-Report_A4_web.pdf

[16] Moody's Investor Services (2018). *Understanding the Impact of Natural Disasters: Exposure to Direct Damages Across Countries*, Available here: https://www.eenews.net/assets/2016/11/30/document_cw_01.pdf. Accessed July 2018

[17] Moody's Investor Services (2018). *Understanding the Impact of Natural Disasters: Exposure to Direct Damages Across Countries*, Available here: https://www.eenews.net/assets/2016/11/30/document_cw_01.pdf. Accessed July 2018

number of persons killed, missing or injured (KMI)'. The aggregate analysis presented in this report focuses on the KMI indicator because of its larger sample size.

As shown in the impact chain below, the achievement of reduced KMI or economic losses relies on both the provision of satellite solutions and the capacity of the authorities to use and benefit from these solutions to support disaster resilience at all stages of the disaster lifecycle. The capacity of disaster planning, response and relief authorities to do this is often related to factors beyond the scope of most projects (e.g. agency budgets), so this **analysis assumes that these authorities can act on the satellite solutions they are provided with**.

Figure 7 Impact pathway of IPP disaster reslience projects

Source: London Economics

These types of solutions are difficult to replicate on a large-scale using alternative 'non-space' based methods. Satellite-derived EO is, for example, a more feasible means to map disaster risk areas at a sufficient frequency to make them useful inputs in disaster forecasting or post-disaster mapping tools, than say drone or ground-based alternatives. Likewise, satellite communications is the only technology that can be deployed quickly enough to support communications in disaster-hit areas that lack connectivity, sometimes as a result of the disaster.

As detailed in Table 7 below, the three disaster resilience projects in this analysis project a total present value (PV) impact of **450 avoided persons killed, missing or injured by 2021** and at an average cost of **£25,899/KMI avoided**.

After two further years of operation, these projects expect to deliver a further **238 – or cumulative PV total of 688 – of avoided persons killed, missing or injured by 2023** at an improved average cost-effectiveness of **£20,047/KMI avoided**.

Table 7 Cost-effectiveness of IPP disaster resilience projects

	Short term (to 2021)	Longer term (to 2023)
Total costs, PV (£)	11,653,468	13,795,217
Total impacts, PV (KMI)	450	688
CEA (£/KMI)	**25,899**	**20,047**

Source: London Economics analysis of project-level CEAs from IPP disaster resilience projects

This compares to a cost-effectiveness of **£43,081/KMI avoided** and **£35,770/KMI avoided** for the non-space alternatives over the same time horizons (Table 8).

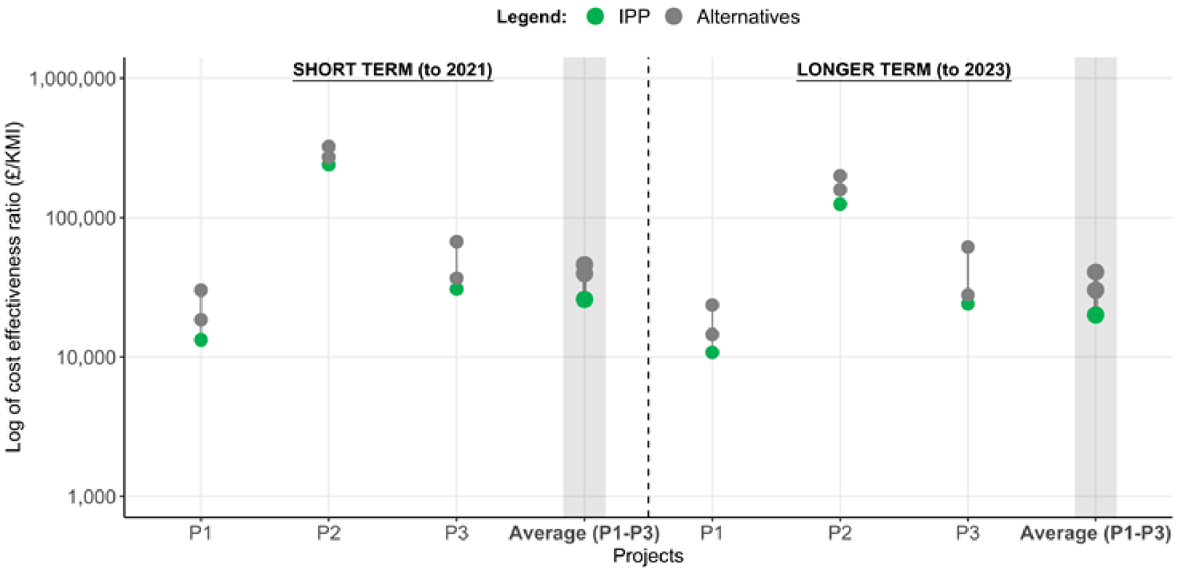
Table 8 Cost-effectiveness of IPP disaster resilience project alternatives

	Short term (to 2021)	Longer term (to 2023)
Total costs, PV (£)	18,301,568	23,309,656
Total impacts, PV (ha)	425	652
CEA (£/ha)	**43,081**	**35,770**

Note: Alternative CEAs based on aggregation of results for up to two non-space alternatives for each IPP project.
Source: London Economics analysis of project-level CEAs from IPP disaster resilience projects

This analysis suggests that **IPP (space) solutions are on average almost 1.7 times more cost-effective than the non-space alternatives in the short term** and **marginally more cost-effective (x1.8) in the longer term**. This difference in cost-effectiveness between the IPP and alternative solutions is demonstrated in Figure 8. It shows that **the space-enabled IPP solution** (● green dot) **was more cost-effective than the non-space alternatives** (● ● grey dots) **in all 3 disaster resilience projects analysed for this report**.

Figure 8 Comparison of IPP-v-Alternatives cost-effectiveness: Disaster resilience



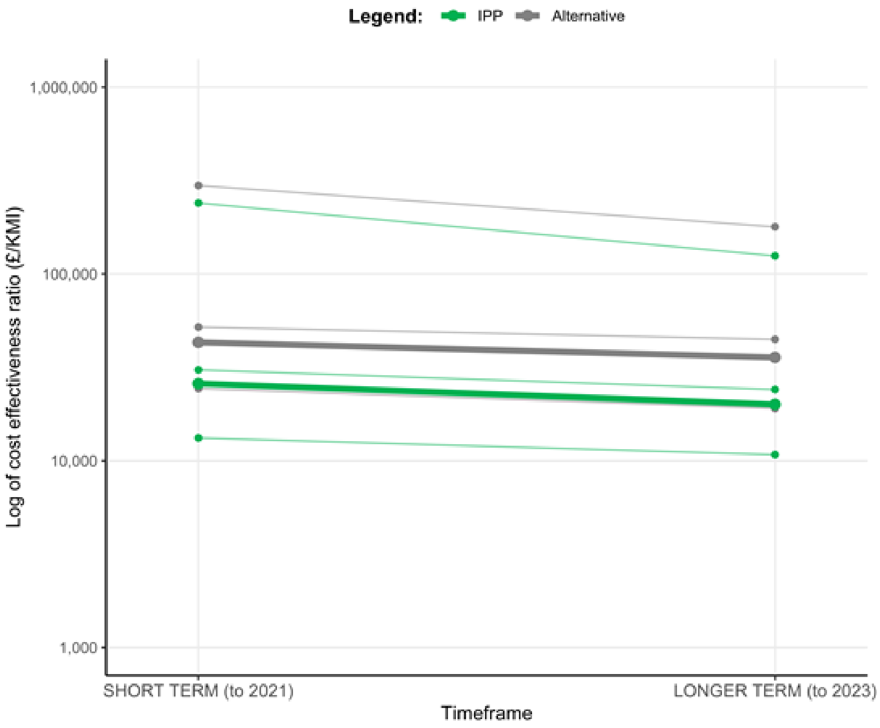
Note: The scale of the Y-axis (cost-effectiveness ratio) is expressed in logarithmic form because of the large range of CER data.
Note: The “Average (P1-P3)” is calculated as the total costs divided by the total impacts.

Source: London Economics analysis of IPP disaster resilience project CEAs

As shown in Figure 9, the **case for space solutions in disaster resilience projects improves over time** because the cost-effectiveness ratio (CER) of the average space solution improves significantly over time (-23%), while the cost-effectiveness of the average non-space solutions improves at a marginally slower rate (-17%).

As for forestry and agriculture projects, this pattern of cost-effectiveness is driven by three variables: upfront development costs, ongoing operating costs and impact. For example, non-space based methods of remote sensing and environmental monitoring are characterised by operating costs that are much higher than satellite-derived EO. For projects that require situational awareness and mapping, the relative cost-effectiveness of non-space alternatives could therefore improve significantly if the frequency of data acquisition is reduced. Likewise, the large upfront costs of non-space based methods of communication (e.g. terrestrial or line-of-site transmission) render them significantly less attractive than satellite communications which also offer more flexibility and faster set-up times.

Figure 9 Comparison of cost-effectiveness over time: Disaster resilience



Note: The average change in CER over time is indicated by the thick lines.

Source: London Economics analysis of IPP disaster resilience project CEAs

3.4 Cost-effectiveness of space in other development areas

This section presents case studies on **five IPP projects** that target **unique impact indicators**: disaster resilience (mitigating economic loss); tax collection; fossil fuel substitution (renewable energy uptake); maritime search and rescue costs, and disaster resilience (mitigating human casualties).

3.4.1 Disaster resilience: mitigating economic loss

The SIBELIUS project is an IPP project led by eOsphere Limited and supported by Deimos Space UK, University of Leicester and Micro-insurance Research Centre UK. The project uses satellite-derived environmental information to identify grazing capacity and identify meteorological conditions as soon as possible, which might impact on the Mongolian herding community.

In doing so, this project aims to provide greater severe-weather resilience for Mongolian herding communities by distributing new and upgraded environmental products to stakeholders these communities. These stakeholders include insurers of livestock; government agencies that coordinate land use for grazing, and the herders themselves. The availability of this data will support a reduction in economic risk because of the increased uptake of livestock insurance and a reduction in the mortality of livestock because of improved pasture management.

The alternatives for this solution are the collection of environmental data (to assess environmental conditions and pasture biomass) via ground surveys or airborne surveys.

The cost-effectiveness analysis demonstrates that **satellite-based solution is cost-effective in an absolute sense and relative to the non-space alternatives**. More specifically, SIBELIUS has a cost-effectiveness ratio (CER) of £0.15 per £1 of economic value delivered, compared to £1.11 and £43.83 for the ground survey and aircraft survey alternatives. The cost-effectiveness of all solutions is expected to improve over time, but much more notably for SIBELIUS (CER of £0.05) than for the alternatives (with CERs of £1.08 and £42.74, respectively).

3.4.2 Tax collection

The IPP Dakar Change Monitoring project was launched by Airbus Defence & Space in January 2017 and completed in December 2018. This project used GNSS-based field surveys and a combination of high-resolution satellite imagery and field data collection to map new buildings and detect urban change in Dakar City, Senegal and potentially other cities across Africa.

In doing so, the project aims to provide these cities with an operational system for creating and maintaining an urban land use and building reference map. This data will support more effective property tax collection and ultimately the maintenance of city infrastructure and services[18].

The alternatives for this type of solutions are focused on the relative costs of different methods of change detection and, in the first instance, the relative costs of different methods of raw data collection on land and property characteristics. Viable alternatives include acquisition by satellite, drone, aerial photography or by field methods.

While all methods are expected to be cost-effective in an absolute sense, the cost-effectiveness analysis suggests that the **satellite-based project is more cost-effective than the non-space alternatives**. More specifically, the **satellite-based methods generate additional PV revenues of £1.6m and at a cost-effectiveness ratio of £0.37 per £1 of tax revenue collected**. This compares to **lower impacts of £0.77m from field-based methods, and at a higher CER of £0.65 per £1 of tax revenue collected, and aerial methods with a CER of £0.40 per £1 of tax revenue collected.** The benefits and **cost-effectiveness advantage of the project are projected to be more pronounced over time** and as the project expands to other cities.

3.4.3 Renewable energy

The RE-SAT (Renewable Energy Space Analytics Tool) project, led by the Institute of Environmental Analytics in collaboration with UNDP and the governments of Small Island Developing States (SIDS), aims to provide data that can support the transition of SIDS from heavy reliance on fossil fuels to renewables. Since SIDS rely on fossil fuels for 95-99% of their energy needs, this reliance negatively impacts current account balances and public expenditures.

The project aims to contribute to a solution by providing an EO-based platform that allows planners to evaluate factors relevant to renewable energy production and calculate potential energy generation to support evidence-based decisions on renewable energy deployment.

The alternative to this space-based solution is to substitute input weather data from satellite for in-situ based methods. The purchasing, installation, maintenance, calibration and running costs of such weather station network makes the alternative project less attractive than RE-SAT. More

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[18] In economic terms, tax collection is considerd a transfer (from tax payers to recipient authorities) and not an impact. However, tax revenues are considered a relevant impact for this study since it is often key component in the achievement of sustainable development outcomes.

specifically, and for the case study in the Seychelles, the **CER of the IPP project (£0.57 per litre of fuel of avoided)** compared to the **Alternative (£3.42 per litre of fuel avoided)** means that the **satellite-based project is more cost-effective than the non-space alternatives** in the shorter term, **by a factor of almost 6**. The cost-effectiveness of both improves over the longer term to £0.38 per litre of fuel avoided for the IPP project and £1.45 for the Alternative. This is expected given the high upfront costs associated with both solutions. However, the **space-enabled solution is considerably more scalable across geographies** since the alternative relies on infrastructure that must be installed and maintained in proportion to the level of geographical coverage.

3.4.4 Maritime

The 'sOuth Africa Safety Initiative for Small Vessels' Operational Take-Up (OASIS-TU) project is an IPP project led by exactEarth Europe Limited (eEE) that aims to equip small boat operators in South Africa with GNSS and satcom enabled tracking devices (AIS transponders). This solution will provide the South African Maritime Safety Authority (SAMSA) and search and rescue services with real-time data on vessel positioning and will allow vessels to active SOS alerts during emergencies. In doing so, this solution aims to reduce maritime accidents – saving lives and reducing the costs of search and rescue activities.

The two alternatives for this solution include the use of radio distress beacons that are triggered during accidents at sea, and the use of manned slipways that would allow staff to raise an alert to authorities. While both alternatives provide information in the event of an incident, neither provide the real-time tracking or collision avoidance data of the eEE solution.

For these reasons, the **cost-effectiveness of the solution only provides a partial view of its relative attractiveness compared to the alternatives**. Even so, the results suggest that the **satellite-enabled AIS solution is the most cost-effective of the three solutions in both the short and longer term**.

3.4.5 Disaster resilience: mitigating human casualties

The 'Satcoms for natural disasters in the Philippines' project, led by Inmarsat, aims to transform disaster response by prepositioning new satellite communication terminals to support crisis coordination and response.

The robust and easily-deployable terminals allow communications at speeds not previously possible for emergency response teams. This will improve disaster site evaluation and response efforts, mitigating potential loss of life, injuries and economic loss.

The capability of satellite communications for disaster response in terms of speed of deployment and information exchange is not matched by any non-satellite-based alternative. For example, manual approaches for assessing disaster sites and coordinating response efforts would involve a combination of aerial support (helicopters) and off-road vehicles to navigate disaster terrains. Such an approach is very far from supporting real-time information exchange. Another alternative, albeit one with a satellite component, is the use of mobile base stations with satellite backhaul. While this solution can support different bandwidth requirements like the Inmarsat solution, its equipment is much less mobile and therefore slower to deploy.

Even without consideration of these other advantages, the **satellite solution is estimated to be the most cost-effective solution** for mitigating loss of life and injuries in a post-disaster environment where terrestrial communications and power are not available.

4 Conclusions

This study detailed evidence of the cost-effectiveness of space-enabled programmes compared non-space alternatives based on the CEAs conducted by the **33** projects within the IPP portfolio.

The findings are limited to consideration of project costs and impacts to **two time horizons**: Short term (to 2021) and Longer term (to 2023). The cost-effectiveness of projects beyond these time horizons are not considered. Many projects also **deliver other impacts not captured by the cost-effectiveness analysis**, which is focused on the costs to deliver improvements to a single impact (net of any counterfactual impacts). The impacts outlined in this report should therefore be seen as an **underestimate of the programme's value as a development programme**.

In addition, the **broader impacts of the programme (i.e. on the UK economy)**, are considered in a separate but accompanying London Economics report.

4.1 Present Value of impacts delivered by the IPP

At a high-level, analysis of the portfolio suggests that the following present value of impacts are projected by 2023:

- **Avoidance of a cumulative total of 4.3m hectares of deforestation;**
- **Gains of £372.9m in additional crop yield;**
- **Avoidance of 688 persons killed, missing or injured;**
- **Gains of £44.3m in additional economic value for herding communities;**
- **Gains of £9.3m in additional tax revenue;**
- **Saving a cumulative total of 5.3m litres of heavy fuel oil;**
- **Connectivity of 59 isolated communities with emergency communications within 24 hours from the onset of a disaster, and**
- **Internet connectivity for 437,000 school children.**

All IPP projects in this study are forecast to deliver these impacts more cost-effectively than their alternatives. This cost-effectiveness advantage for space solutions is expected to increase over time due to the low marginal costs of space solutions. These low marginal costs also mean that space solutions are much more scalable than non-space alternatives.

4.2 Cross-cutting themes

The preceding chapter presents evidence of the cost-effectiveness of space-enabled IPP solutions compared to non-space alternatives. The variety of different impact indicators – such as the number of hectares of deforestation avoided to the increase in agricultural yield – means that it is not possible to aggregate this analysis to a programme-level comparison of the overall cost-effectiveness of the programme compared to non-space alternatives. Nevertheless, the following key themes emerge from the **33 project CEAs** that have been conducted for the study:

- **Space-enabled solutions are more cost-effective than alternative solutions in the long-run:** the cost-effectiveness ratio of IPP solutions is lower than that of the alternatives for all projects surveyed in this study in the longer time horizon (Longer term (to 2023)). For example, forestry, agriculture and disaster resilience solutions are on average 11.8x, 6.7x and 1.8x more cost-effective than their non-space alternatives, respectively. This is also true for projects with other impact indicators, such as those detailed in 3.3. Up to the short time horizon (Short term (to 2021)), some alternatives – i.e. those with low build costs – are more cost-effective than their IPP projects (with more significant build costs), although this advantage is lost over time because of the lower marginal costs of space solutions, as detailed below.

- **IPP projects are increasingly cost-effective over longer time horizons:**
  - Across all projects, cost-effectiveness is higher in the longer time horizon (Longer term (to 2023)) than the shorter time horizon (Short term (to 2021)). For example, the average cost-effectiveness ratios of IPP forestry, agriculture and disaster resilience projects improve by 40%, 28% and 23% between these two time horizons, respectively. This is unsurprising since all IPP solutions involve a substantial development cost. For example, solutions that require satellite telecommunications tend to involve the procurement and installation of receiver and device hardware, while solutions requiring EO-based change detection require the development and testing of machine-learning or predictive risk models. Once these solutions have been built, the marginal cost of operation tends to be quite low since the solutions themselves require little human inputs, aside from their final interface with end users. For example, satellite-derived EO data from certain sources with large public investments (e.g. LandSat and Copernicus/Sentinels) are 'free at point-of-use'. As a result, most EO applications are relatively cheap to scale or operate long-term once the cost of the analytical software or models have been covered. This fact justifies the case for programmes like the IPP that can support build costs – which are often beyond the budgets of developing countries – but allows UK suppliers to provide operational services that ODA countries are able to procure on a sustainable longer-term basis.
  - As well as the cost-effectiveness improving in an absolute sense, it also improves relative to the improvements in cost-effectiveness of the alternatives over time. This is because these solutions tend to be far more labour intensive, resulting in high operating costs and little if any economies of scale. For example:
    - **Ground-based monitoring techniques** are cost-ineffective since large numbers of human resources need to be deployed at national scale. The coverage of patrols over a given time is limited and this laborious process would need to be repeated on a continuous basis to detect change at the same frequency as other methods. While this benefit may have a physical deterrence effect, detection will be subject to human error and may be limited to only accessible parts areas.
    - **Aerial** and **drone-based** methods can cover larger areas than ground-based teams, but they are capital-intensive and incur high running costs. The project-level CEAs demonstrate, however, that these methods can be cost-effective over targeted areas – e.g. to map hotspots at higher resolution than satellite – or be used to calibrate space-based methods of change-detection.

  This difference in cost-effectiveness over time means that the relative cost-effectiveness of space solutions compared to non-space solutions diverges over time. This fact is captured by the 'cost-effectiveness ratio multiple' (the ratio of space to non-space CERs), which increases from 7.7 to 11.8 for forestry projects, from 5.6 to 6.7 for agriculture, and from 1.7 to 1.8 for disaster resilience projects.

- **IPP projects are increasingly cost-effective over large scale:** most projects can be deployed to cover new geographic areas at a low marginal cost because of their economies of scale. This is particularly the case with satellite-enabled EO projects where most of the build costs are focused on the development and calibration of machine-learning algorithms or predictive risk models. Once these have been developed, they can provide end-user outputs from satellite data inputs in an automated way. Coverage of large geographies would largely imply data inputs that cover the extended area, which are relatively cheap to acquire (or free in the case of Landsat or Copernicus/Sentinel data). Solutions involving satellite telecommunications and location data have higher marginal costs because they require the procurement and installation of equipment (e.g. VSATs and responders). These solutions are somewhat less scalable across geographies, but are still much more so compared to their alternatives (e.g. terrestrial infrastructure for Satcoms).

- **Alternatives are not always viable at large scale:** all the alternatives to the IPP solutions exist in some form in the real world. However, they are typically localised solutions that are not used for the type of large-scale deployment that makes them comparable to the wide area coverage offered by satellite-based solutions. For example, both drones and aerial photography are used to provide higher resolution imagery over high-risk hotspots (e.g. in forests) that are initially identified by satellite, but they are not typically used to replace satellite imagery all together because of the high marginal costs involved. Likewise, 'boots on the ground' cannot cover all geographic areas that satellite can without a significant labour force. Even so, the hypothetical alternatives that have been constructed for the IPP serve to demonstrate the strengths of satellite-based solutions at scale.
- **Some development areas cannot substitute for space entirely:** space technologies cannot be entirely replaced in practice as some alternatives – including ground-based patrols and aerial-based monitoring – would still require the use of satellite phones and GIS maps. For example, EO-based solutions validate satellite-derived imagery with non-satellite sources of data (e.g. ground truthing) to enhance their predictive models. This fact demonstrates the ubiquity of space technology, particularly in a developing world context characterised by a lack of terrestrial infrastructure, large and remote geographies and the need for frequent monitoring.
- **Space-based solutions have additional benefits that are not reflected in the CEA:**

  This means that the CEA may underestimate the benefits of projects, for example:

  - Satellite solutions are **not subject to the same risk of human error** as manual methods. For example, machine learning techniques that are applied to satellite imagery can interpret the same image consistently, unlike techniques that rely on manual monitoring where imagery may be interpreted very differently.
  - Satellite imagery is **non-invasive**. This means that it can be used to monitor environments that may otherwise be too dangerous for human monitoring. In the same way, 'boots on the ground' approaches may have an additional deterrence effect that non-invasive satellite imagery lacks.
  - Satellite solutions are **scalable**. Their distance from Earth means that they can provide global coverage – EO solutions can be extended to cover other geographies at low marginal cost, while satcom can be extended with the provision of additional user devices and equipment. In contrast, alternative (terrestrial) solutions often require significant additional investments to extend coverage, as previously detailed.

4.3 Lessons for implementing the programme-level CEAs

This programme-level cost-effectiveness analysis has been possible because of a coordinated effort to standardise individual CEAs from the **33 projects** that make-up the IPP portfolio. This has been possible because of a determination by the UK Space Agency to generate pioneering evidence on the value of satellite-based solutions in the development context and to demonstrate the achievement of the OECD Development Assistance Committee's (DAC) criteria of 'efficiency' (i.e. that IPP projects have used the least costly resources to achieve their desired impact).

To this end, the programme's independent evaluators – Caribou Space – obtained specialist support from London Economics to design a cost-effectiveness framework that all projects were required to implement and provide specialist support to ensure the implementation of this framework. As a result, several issues of 'CEA Guidance Manuals', case studies, Excel templates, FAQ documents, supplementary notes, workshops, one-to-one workshops, and on-going support and review were delivered to provide projects with the capabilities to produce their own CEAs in a standardised manner.

Implementation of this project- and programme-level cost-effectiveness economic evaluation has proved to be a demanding task, but it has yielded some important lessons for those wishing to undertake programme-level CEAs in the future:

1. **CEAs must be planned well in advance** (even before M&E budgets are agreed);
2. **Project-level buy-in is crucial** – they are the source of the raw inputs for a programme-level analysis;
3. **CEAs are time-consuming** – dedicated staff time is required to co-ordinate the programme-level evaluation (e.g. to ensure standardisation across sectors);
4. **Standardisation is vital** – aggregation of impact indicators across sectors yield insightful results and makes it possible to publish results without comprising confidentiality. Standardisation can only be accomplished with dedicated staff resource to coordinate programme-level evaluations;
5. **Standardisation is difficult** to achieve across diverse contexts – some nuance between projects may be lost when attempting to do so;
6. **Impacts are complex to identify, isolate, measure and forecast**; and
7. **Alternatives are both complex to define and estimate**. This is because the impact of some solutions cannot be perfectly replicated through other means. Alternatives are also hypothetical so obtaining evidence for their cost or impact may be challenging.

4.4 Next steps

This programme-level CEA uses the CEAs from individual projects that are still implementing their solution at the time of writing this report. These results are therefore forward-looking, using projects of costs and impacts beyond late-2018. **The results of this report should be considered indicative and will be updated in 2021 once projects have implemented their solutions and impacts been both realised and measured.**

Index of Tables and Figures

Tables

Figures

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