UK Space Agency International Partnership Programme

Space for Policy in Developing Countries

July 2020

UK SPACE AGENCY

About the UK Space Agency

https://www.gov.uk/government/organisations/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

International Partnership Programme

https://www.gov.uk/government/collections/international-partnership-programme

The International Partnership Programme (IPP) is a £30 million per year programme run by the UK Space Agency. IPP focuses on using the UK space sector's research and innovation strengths to deliver a sustainable economic, societal or environmental 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. The GCRF is a £1.5 billion fund announced by the UK government to support cutting-edge research and innovation on global issues affecting developing countries.

IPP@ukspaceagency.gov.uk

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.

London Economics has been selected by Caribou Space to support their work for the UK Space Agency's International Partnership Programme, with specialist economic evaluation.

Head Office: London Economics, Somerset House (New Wing), Strand, London, WC2R 1LA, United Kingdom

www.londoneconomics.co.uk/space
t: +44 (0)20 3701 7717
e: info@londoneconomics.co.uk
: @LE_Aerospace

About Caribou Space

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

https://www.caribou.space/

Authors

London Economics: Farooq Sabri, Romain Esteve, Joscelyn Miller, Wesley Jessie
Caribou Space: David Taverner

Image: Sergio Souza

Contents

Executive summary **6**

Study aims 6

Key findings 6

Recommendations 7

1 Introduction **8**

1.1 Context 8

1.2 The International Partnership Programme (IPP) 9

1.3 Scope of study 9

1.4 Audience 10

2 Evidence of space for policy **11**

2.1 Agriculture 11

2.2 Climate change and the environment 22

2.3 Disaster resilience 34

2.4 Forestry 41

2.5 Urban and transport 51

3 Conclusions and recommendations **58**

Index of tables, figures and boxes **60**

Executive summary

Study aims

This study aims to evidence the use of satellite-derived technologies as a tool to support government policy across five areas in developing countries: agriculture, climate change and the environment, disaster resilience, forestry, and urban and transport.

The evidence is intended to showcase the value of satellite technologies, and to support the increased exploitation of space across policy making in developing countries.

The UK Space Agency's International Partnership Programme provides active support for the exploitation of space solutions in developing countries. It provides many of the examples considered in this study.

Key findings

In general terms, this study finds a number of cases where space technologies are being used to support more effective policy, and a further number of instances in which their potential is only just being explored.

Space technologies inherently provide coverage that is automated, repeatable, consistent, objective, analysis-ready and wide-area in scope. A common theme of these findings is that these technologies are well placed to provide intelligence on a range of economic and environmental activities at a lower cost than alternative methods of data collection. This advantage is critical to developing country governments that face budget constraints, increased demand, increasing global pressures and growing public scrutiny.

Specific findings include the following:

- Most applications of space in **agriculture**, such as rural payments and insurance products, aim to stabilise the incomes of farmers at low cost. Space solutions can also assist governments to maintain food security and plan for disasters, by providing early warning information and risk identification to support advance planning and mitigation. Earth observation (EO) can also provide accurate, updated maps of natural resources to support sustainable management.
- Satellite data provide rich information about **climate and environmental** conditions. Satellite data can be used to optimise renewable energy production and to underpin models that predict climate change risks and inform adaptation and mitigation strategies.
- The use of satellite data can enhance **disaster resilience** by informing disaster preparedness, resilience and response. It can increase the survival and recovery rates of populations and economies in developing countries.
- Satellite imagery provides accurate, cost-effective surveillance and monitoring of **forestry resources** at frequent intervals so that changes to land coverage can be monitored and detected quickly. This means that illegal logging, or outbreaks of pests and diseases, can be detected quickly and at lower cost than through other methods of data collection.
- Satellite technologies offer a powerful data source for governments that need to inform **urban** planning and update property databases in the face of rapid urban change. EO is useful for land use and change detection; traffic data can be used to detect hotspots of activity; and location data can support the development of universal geographic reference systems.

This study has also found that space technologies face challenges that limit their uptake by developing world governments. These include government capacity constraints; a gap between solution providers and policy makers; and the reputation of space solutions as being appropriate for donor-funded pilots rather than as sustainable and fully operational solutions.

Recommendations

With these findings in mind, the following recommendations are suggested for consideration:

- Increased co-ordination between developing-country governments to consolidate requirements and points of engagement with industry;
- Further provision of learning and development by the space industry and solution providers to government, aiming to increase the understanding of space capabilities and applications as well as future technology developments;
- Increased interaction and engagement between government entities and industry. This could involve greater communication of requirements by government, and of technology developments by industry. Ongoing engagement through the 'R&D to procurement' phase would enable governments to steer technology developments to meet their future needs. This could help accelerate the adoption and maturity of applications, building on the work of current initiatives such as the UKSA's IPP;
- Greater use of existing tools, including downstream R&D programmes, to enable R&D efforts to be directed at developing-country requirements;
- Consideration of strategic infrastructure which could facilitate access to and use of exploitable satellite data for users and for applications development. This could involve greater integration with other complementary datasets such as geospatial data.
- Coordinated action between international donors to ensure that projects are sustainable, non-duplicative and focused on under-addressed needs in the developing world.
- A search for opportunities to provide capacity building and training to developing world governments on the role of space solutions to support policy in their countries.
- Space agencies to continue the positive initiatives now under way to promote the use of space solutions to address developing world challenges, including NASA SERVIR, Dutch G4AW, ESA Space in Support of International Development Assistance, and UKSA IPP.

1 Introduction

1.1 Context

The United Nations 2030 Agenda outlines 17 Sustainable Development Goals (SDGs), intended to secure economic and social development for all countries.[1] These goals recognise that development is linked to a government's capacity to make more effective decisions, including those that improve the sustainability of food production and the natural environment; the ability of cities to support growing populations, and humanity's resilience to natural disasters and climate change.

The effectiveness of a government's decision-making is defined by the effectiveness of its policy cycle. This policy process has four stages:[2]

1. Problem identification;
2. Policy formulation;
3. Policy implementation; and
4. Policy evaluation.

The effectiveness of this process is determined by a number of things, but the quality of information available to decision-makers at each of its stages is critical. By providing decision-makers with real-time intelligence to support each stage of the policy process, space-based technologies can enhance the capacity of government to achieve its objectives. This is because space-based technologies use satellites whose sensors observe vast and remote areas of the Earth. For example:

- **Earth Observation (EO)** satellites are used to monitor the land, oceans and icecaps of the planet and its atmosphere, and to identify patterns or changes in the natural or man-made environment. EO can be used to provide users with the intelligence needed to target resources to improve development outcomes.
- **Global Navigation Satellite Systems (GNSS)** are used to measure a user's position and time with high accuracy. This data can be used on its own, or be integrated with EO to provide geolocation data, images overlaid with location information.
- **Satellite communications (SatComms)** satellites relay and amplify radio signals between different points on the Earth to support resilient telecommunications in isolated environments that lack access to terrestrial infrastructure. This makes SatComms suitable for communicating intelligence (e.g. from EO) or to provide voice and internet communications for infrastructure planners or emergency responders.

These technologies are often used in combination. The provision of timely information to inform the government's policy process, often more efficiently or cost effectively than alternative data sources, is a common theme for space-based solutions.

However, 'space for policy' is an emerging domain. Little systematic evidence exists on the value of space-based applications for policy, especially in the developing world where alternative sources of data are often too difficult or costly to obtain. Without this evidence, it is difficult to convince governments and funders of the benefits of investing in space-based solutions for policymaking.

This report attempts to close this gap by presenting real-world evidence of space-based applications supporting more effective or efficient policy decisions in the developing world. Five areas of policy are considered in this report: agriculture; forestry; disaster resilience; climate change and the environment, and urban and transport.

---

1. United Nations. 'Sustainable Development Goals'. https://sustainabledevelopment.un.org/sdgs. Accessed April 2020.
2. An elaboration of the policy cycle is presented in HM Treasury. 'The Magenta Book: Central Government guidance on evaluation'. 2020. www.gov.uk/government/publications/the-magenta-book. Accessed April 2020.

1.2 The International Partnership Programme (IPP)

This report was commissioned by the International Partnership Programme (IPP), a £30 million per year programme run by the UK Space Agency. IPP uses the UK Space sector's research and innovation strengths to deliver a sustainable economic, societal or environmental benefit to developing countries. Projects within IPP span a wide range of themes. These include improving agriculture, reducing deforestation, improving disaster response, reducing maritime pollution and illegal fishing, optimising renewable energy, and improving resilience to climate change.

IPP is part of the Department for Business, Energy and Industrial Strategy's (BEIS) Global Challenges Research Fund (GCRF), a £1.5 billion Official Development Assistance (ODA) fund which supports cutting-edge research and innovation on global issues affecting developing countries. ODA-funded activity focuses on outcomes that promote long-term the sustainable development and growth of developing countries on the OECD Development Assistance Committee (DAC) list. IPP is fully ODA compliant, being delivered in alignment with UK aid strategy and the UN's Sustainable Development Goals (SDGs).

1.3 Scope of study

This study set out with the objective of evidencing the use and value of satellite-derived technologies in supporting five policy areas of importance to developing countries. Given the time and resource constraints of the study, the scope of this research is limited by the following:

- **Definition of policy:** this study is focused on the use of space in supporting more effective public policy decisions by national governments in the developing world. Evidence is limited to cases where national government is an end user of space applications. The use of space in supporting other end users, such as citizens, intergovernmental organisations and businesses is beyond the scope of this study. However, such examples are considered in so far as they indicate potential use and value to national governments. In some cases, the use of space-based applications to support policy making in developing countries is nascent. Here the use of space-based applications in developed countries is considered to highlight their potential for developing nations.

- **Definition of use:** the use of space applications has been defined to include cases where space applications and data are used as a tool to support policy formulation and decision-making. The use of space to support operational processes, for example to enforce compliance with existing policy, is not the focus of this study.
- **Scope of government policies:** the use and value of space are identified across five sectors. These were prioritised after a preliminary research phase undertaken to identify space application areas of high current and/or potential use. In order to direct research efforts, we prioritise breadth over depth. While there are clear overlaps between some of the areas, the scope of these policy areas was defined to eliminate duplication, as follows:
  - **Agriculture:** food security; rural payments.
  - **Forestry:** carbon abatement through forestry; sustainable resource use; law enforcement; plant health.
  - **Disaster resilience:** disaster preparedness; disaster mitigation and infrastructure resilience; disaster recovery and response.
  - **Climate change and the environment:** climate change adaptation; renewable energy; carbon abatement; air quality.
  - **Urban and transport planning:** investment and urban planning; transport and critical infrastructure; cadastre and land taxation.
- **Scope of space-based applications:** this study considers applications that use all three categories of space assets: EO, GNSS and SatComms. Despite this breadth, EO accounts for a disproportionate share of the evidence of the use of space-based applications for policy. This study also focuses on the use of space-based applications or solutions, rather than simply on space data. While the provision of 'data' implies simple passive provision of information, 'applications' implies more functionality to support decision-making, for example by providing additional insights and analysis that can guide decisions.

1.4 Audience

This study is aimed at a range of audiences, and contains insights of interest to each.

Governments in the developing world are the primary audience for this study. It sets out to demonstrate how satellite technologies are being leveraged to address key policy challenges facing developing country governments. In doing so, it aims to persuade policy makers of the value of investing in and exploiting space-based solutions.

This study may also be of interest to the downstream sector. Key developing country challenges are presented for each policy area, and a list of existing and potential solutions is identified. This information may provide downstream solution providers with an indication of potential opportunities.

Potential funders for developing world solutions (e.g. international donors) may also benefit from an enhanced understanding of the challenges that space can address, and of the challenges that stand in the way of its increased exploitation which they can help address.

2 Evidence of space for policy

This chapter presents evidence on the use and value of space-enabled solutions in supporting public policy decisions by national governments.

While public policy covers a diverse range of areas, this chapter focuses on five areas of government policy: agriculture, forestry, climate change and the environment, disaster resilience, and urban and transport. These use cases are presented in alphabetical order.

These sub-sections have a common structure, with a short introduction outlining the policy problem that developing country governments face in each area, after which evidence on the current and potential use and value of space in these areas is presented.

2.1 Agriculture

This section presents evidence of the use of satellite applications to support agricultural policies in the developing world. In this report, space applications in agriculture cover activities such as food security and rural payments.

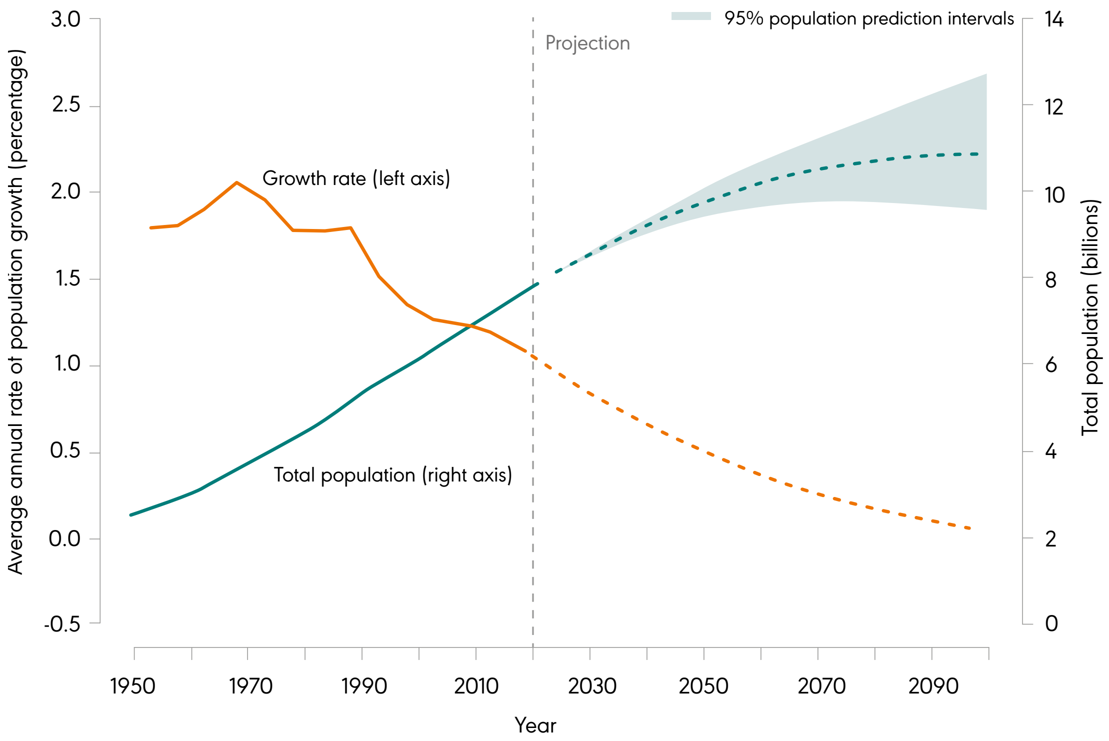
2.1.1 Introduction

The global agriculture sector faces multiple challenges. A combination of population growth, rising incomes, climate change, and the increasing scarcity of agricultural inputs means that the world will have to substantially increase the yield, resilience and efficiency of food production[3] to ensure the nutrition, welfare and stability of developing world populations over the coming decades.

By 2050, the global population is predicted to be over 9 billion (as shown in Figure 1) and food demand will be 60 per cent greater than it is today.[4] The supply of natural resources (e.g. water and land) that underpin agricultural production is also under pressure, with unsustainable practices contributing to food shortages.[5]

3. Food and Agriculture Organisation (FAO). 'How to Feed the World in 2050'. http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf. Accessed April 2020.
4. Breene K. 'Food security and why it matters'. 2016. www.weforum.org/agenda/2016/01/food-security-and-why-it-matters. Accessed April 2020.
5. Caribou Space. 'Space for Agriculture in Developing Countries'. 2018. www.spacefordevelopment.org/library/space-for-agriculture-in-developing-countries. Accessed April 2020.

Figure 1: Global population growth



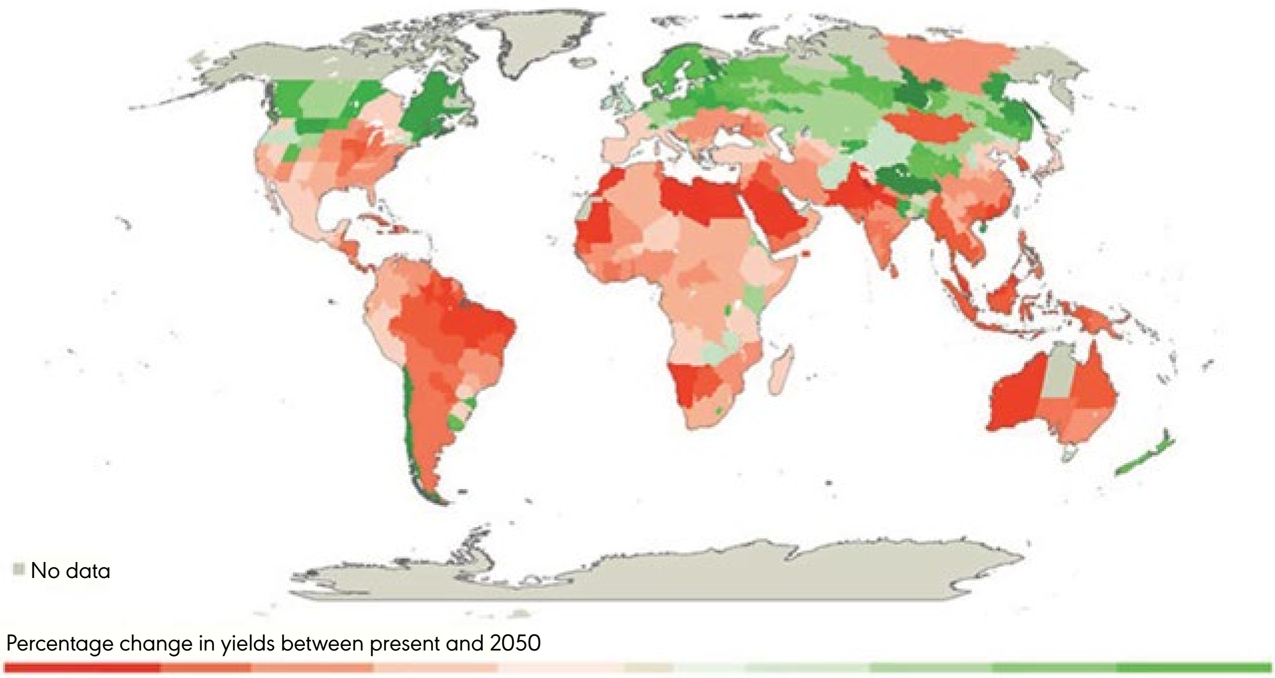
Global population continues to rise, but at a diminishing rate

Source: UN Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019

Agricultural output is highly variable and is dependent on many factors that are difficult to control, such as rainfall and soil quality. This can be particularly damaging for subsistence crop farmers, whose nutrition and incomes are directly tied to their crop yields.

Developing countries are also characterised by fast-growing populations, economies dependent on subsistence agriculture, and heavy exposure to the adverse consequences of climate change. These countries are particularly vulnerable to the agricultural challenges discussed above (see Figure 2).

Figure 2: Change in yields due to climate change



Projections suggest that there will be significant adverse impacts on crop yields due to climate change (for example the 3°C temperature rise illustrated above), particularly affecting developing countries.
Source: World Resources Institute

There is a clear requirement in developing countries for cost-effective solutions to support more efficient and sustainable food production. Most applications of space in agriculture focus on improving the level and stability of farmer incomes, and minimising the damage from disasters for farmers and producers in the agricultural sector. Even so, space can also support intelligence-led solutions that help governments improve the design, implementation and enforcement of specific agricultural policies. These include policies that target food security, the design and monitoring of agricultural subsidies, and land management practices which affect farmers, insurers, agronomists, and big agricultural producers. These policies can be grouped into five areas:

– Decision-support tools for food security: frequent remote monitoring using EO technology supports decision-making across the supply chain, reduces input costs and improves yields.

– Early warning systems for food security: frequent remote monitoring supports early detection and mitigation of adverse events that may compromise agricultural yield.

– Sustainable food production: frequent remote monitoring and mapping of agriculture, natural resources and ecosystems supports optimal and sustainable resource management along the supply chain.

– Monitoring to support rural payments: EO data can be used to provide accurate and timely crop mapping and monitoring of land use at regional and national scales, to underpin the evidence base for the payment and audit of farm subsidies.

– Credit and insurance products: accurate and frequent mapping data provide low-cost land use mapping and vegetation change detection for use by credit or insurance companies offering products to agricultural producers.

6. Caribou Space. 'Space for Agriculture in Developing Countries'. 2018. www.spacefordevelopment.org/library/space-for-agriculture-in-developing-countries. Accessed April 2020.

The following table presents a summary of the evidence on how space is used to support different agricultural policy applications.

Table 1:
Agriculture: space applications for policy making

Application	Evidence of use
Food security	✓
Sustainable food production	✓
Rural payments	✓
Credit and insurance markets	✓

Note: ✓ current evidence; (✓) future applications and/or pilot studies
Source: World Resources Institute

Further details of how space can support agriculture in developing countries can be found in Caribou Space's *'Space for Agriculture in Developing Countries'* report.[7]

2.1.2 Evidence: agriculture

Food security

Food security is defined as resilient access to a food supply that supports adequate nutrition.[8] In 2017, 821 million people were estimated to be undernourished, equivalent to about 1 in 9 people across the globe.[9] As well as having obvious health implications, malnourishment compromises productivity and reduces economic growth. For these reasons, food security is a key aim of the UN Sustainable Development Goal to *"End hunger, achieve food security and improved nutrition and promote sustainable agriculture" (Goal Number 2).*

Space solutions can assist by providing tools that inform policy decisions along the supply chain. These applications can help manage resources and, by underpinning early warning systems, help mitigate the consequences of adverse events that could compromise yields.

Food security: decision support tools

Satellite data can complement existing data sources, for instance on prices, trades, and historic yields, that are used to predict, monitor and manage food supply. EO technologies such as those supported by the IPP (see box below) support intelligence-led solutions that help governments to improve the effectiveness of specific agricultural policies, and which maximise resource efficiency by pinpointing vulnerable hotspots that require specific assistance.

Drought and Flood Mitigation Service (DFMS), Rheatech, Uganda

A consortium led by the RHEA Group, working in cooperation with relevant Ugandan Ministries, Departments and Agencies, has created a suite of information products relevant to drought and flood forecasting and monitoring that are provided as a subscription-based service.

The DFMS platform provides access to robust meteorological, hydrological, and other EO-based information as current observations, future forecasts, and historical archives. This enables informed decisions to be taken, risks and their associated humanitarian and financial losses to be reduced, and the effects of climate change to be mitigated.

For example, better forecasts enable farmers to protect their key assets and implement mitigation strategies to reduce damage to crops, such as by crop diversification, during periods of flooding or droughts. The project is expected to improve response to various environmental conditions and ultimately improve crop yields and livestock conditions.

---

7. Same as above.
8. Global Food Security. 'The challenge'. www.foodsecurity.ac.uk/challenge/. Accessed April 2020.
9. United Nations (UN). 'Sustainable Development Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture'. https://sustainabledevelopment.un.org/sdg2. Accessed April 2020.

In **India**, the *Forecasting Agricultural output using Space-borne, Agro-meteorological and Land observations* (FASAL) system uses EO data to improve decision-making surrounding food security. The project carries out seasonal crop forecasting to support decisions on trade, prices and procurements. The accuracy of EO-based data has enabled the government to better target and improve responses to drought.[10] EO data was also used to identify shortfalls in wheat supply and justify the importation of wheat to mitigate this gap.[11]

In addition, EO has provided evidence for decisions concerning land reclamation. For example, Uttar Pradesh's Sodic Land Reclamation Project used EO to categorise areas by levels of soil quality and identify villages that needed land reclamation for agriculture. The successes of the project were significant. EO increased the soil quality of reclaimed land, thus increasing average cereal yields and family income by 50 per cent and generating net returns of US$16 million from an area of 36,000 hectares.[12]

Food Security: early warning systems

Early warning systems (e.g. for disease or pest outbreaks and extreme weather events) provide an indication of risk, allowing policymakers and other stakeholders to take timely action to mitigate against events and maintain a stable food supply.

IPP's PRISE project (see below) provides a case study of a space-based early warning system for agriculture.

Pest Risk Information SErvice (PRISE), CAB International, Kenya, Zambia, Malawi and Ghana

This project has developed an early warning system to detect the presence of pests and alert farmers when crops are most at risk. The service uses satellite technology (including Meteosat SEVIRI, Terra/Aqua MODIS and Sentinel-3) and other complementary data sources (e.g. ground surveys and risk forecast models), to monitor real time observations of pest risk.

With the provision of a warning system, farmers are given time to contingency-plan and make better decisions regarding their agricultural techniques, such as when to deploy pesticides. This should improve yields and incomes of farmers and, on a wider scale, increase food security. The Ministry of Agriculture, Livestock and Fisheries for Kenya has partnered with the project lead, CAB International, to deliver this project, with further commitments from government ministries in Zambia and Ghana. This project is encouraging these governments to develop policies to strengthen crop protection and demonstrates how an effective pest forecasting service can be scaled to regional and national levels.

---

10. Caribou Space. 'Space for Agriculture in Developing Countries'. 2018. www.spacefordevelopment.org/library/space-for-agriculture-in-developing-countries. Accessed April 2020.
11. Jayaraman et al. 'Rejuvenation of agriculture in India: Cost benefits in using EO products'. 2008. www.sciencedirect.com/science/article/abs/pii/S009457650700358X. Accessed April 2020.
12. Srivastava, S. 'Case study: Harnessing new tools and techniques for making agricultural statistics more efficient and evidence based to support food security policy decisions in India'. 2011. Accessed April 2020.

There are many other examples of early warning systems in existence across the world, as detailed in Table 2 below.[13]

Table 2: Overview of existing early warning systems

Level of implementation	Example
International	Famine Early Warning Systems Network[14]
Regional	Pest Risk Information SErvice (PRISE), Comité permanent Inter-Etats de Lutte contre la Sécheresse in the Sahel region[15]
National	Food Security and Nutrition Analysis Unit in Somalia[16]
Community	Garba Tulla development Office in Northern Kenya[17]

Source: London Economics analysis from identified sources

The addition of EO data to existing meteorological data can significantly improve the accuracy of forecasting. For example, satellite technologies such as the Meteosat Spinning Enhanced Visible and Infrared Imager (SEVIRI), Terra/Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) and Sentinel-3 SLSTR are used to inform pest risk models. These models create an alert when conditions are favourable for a pest outbreak.

These cases show that space can be used to improve forecasting capabilities, increasing the lead time for governments and other stakeholders to implement effective intervention, for example to support crop diversification or the deployment of pesticides, and prevent severe damage to food security.

Just one square km of an adult desert locust swarm can consume the same quantity of food as 35,000 people.[18] In **East Africa**, locust swarms have threatened the food supply and led to famine. The Desert Locust Information System (DLIS) is an early warning system that predicts when locust swarms are likely and identifies the risk to yields. This system uses rainfall estimates from METEOSAT and 250m-resolution vegetation imagery from MODIS to identify areas with suitable environmental conditions for locust breeding and habitat.[19] These are verified with survey results to provide intelligence to the UN Food and Agriculture Organisation (FAO) to inform its mapping of vulnerable areas. Governments can use this advice to guide their own policies. For example, the **Somalian government** used this service to declare a national state of emergency and seek international assistance following a recent locust swarm in East Africa.[20] In **Kenya**, the government used DLIS to guide the aerial spraying of insecticide and depress the spread of locusts.[21]

13. Bailey, R. 'Managing Famine Risk: Linking Early Warning to Early Action'. 2013. www.chathamhouse.org/sites/default/files/public/Research/Energy%2C%20Environment%20and%20Development/0413r_earlywarnings.pdf. Accessed April 2020.
14. Famine Early Warning Systems Network (FEWS NET). 'Acute Food Insecurity: Near Term (May 2020)'. https://fews.net. Accessed April 2020.
15. Le Hub Rural. 'Comité permanent inter-Etats de lutte contre la sécheresse dans le Sahel'. www.hubrural.org/Comite-permanent-inter-Etats-de.html. Accessed April 2020.
16. Food Security and Nutrition Analysis Unit - Somalia. https://fsnau.org/. Accessed April 2020.
17. United Nations Framework Convention on Climate Change (UNFCCC). 'Point-to-point radio in Isiolo, Kenya'. www4.unfccc.int/sites/NWPStaging/Pages/item.aspx?ListItemId=23431&ListUrl=/sites/NWPStaging/Lists/MainDB. Accessed April 2020.
18. Same as above
19. Food and Agricultural Organization of the United Nations (FAO). 'Satellite for locust early warning'. http://www.fao.org/ag/locusts/en/activ/DLIS/satel/index.html. Accessed April 2020.
20. Maruf H. 'Somalia Declares National Emergency over Locust Upsurge'. 2020. www.voanews.com/africa/somalia-declares-national-emergency-over-locust-upsurge. Accessed April 2020.
21. BBC. 'Somalia declares emergency over locust swarms'. www.bbc.co.uk/news/world-africa-51348517. Accessed April 2020.

Famine is a slow-onset disaster. Early warning systems can be particularly effective in their prevention and mitigation, by providing longer lead times which give governments greater opportunity to take action.[22] For example, the Famine Early Warning Systems Network[23] (FEWSNET) is an international early warning system that uses EO agricultural climatology data, Earth Observation and other data aggregates (prices, trade, agricultural production) to provide yield estimates and a risk classification for famine up to 6 or 12 months in advance.[24] This tool is a valuable resource for organisations and national governments, which can use it to plan for extreme famine events and more efficiently manage resources along the supply chain in the early stages of such events. For example, FEWSNET was able to predict droughts in Southern Africa in 2015/16, and national scenario assessments induced countries to issue Drought Emergency Declarations. In addition, and as part of their contingency planning, the governments of South Africa and Zimbabwe increased their grain imports for January 2016 to increase the food supply.[25] Despite this evidence of successful policy making, FEWSNET has been singled out for having a fragmented link to the response stage. The number of available responders to famine crisis is large, including national government, donors, agencies and NGOs, which all have different agendas. This conflict of interests can make it difficult to initiate any response from the space-enabled evidence.[26]

Studies have also found that agricultural productivity can be predicted using MODIS data and other oscillation indices,[27] which could contribute to a global drought early-warning system. The dataset used is from **Chile**, covering a wide range of climates and vegetation types within the sample. Two prediction approaches, optimal linear regression and deep learning models, both had similar prediction accuracies at varying lead times, suggesting that satellite-derived models could be used in future early warning systems.

Sustainable food production

Opening up new land for agriculture brings major environmental costs. This includes pollution of fresh water, erosion and desertification from over-grazing, and deforestation.[28] It is therefore critical that food demands be met from existing agricultural land as much as possible. For example, agriculture is responsible for 80 per cent of tropical deforestation.[29] This negative by-product from agricultural land acquisition contributes to carbon emissions and damage to complex ecosystems.

An increase in production must therefore be met through the sustainable intensification of agriculture. This can be achieved through the promotion of an ecosystem approach to integrate the management of land, water and living resources and that promotes conservation and sustainable management.[30] EO data from space can be used to visualise ecosystem services at local, regional and national scales by identifying land cover, aspect, topography,

22. Bailey, B. 'Managing famine risk: Linking Early Warning to Early Action. A Chatham House Report'. 2013. www.chathamhouse.org/sites/default/files/public/Research/Energy%2C%20Environment%20and%20Development/0413r_earlywarnings.pdf. Accessed April 2020.
23. Famine Early Warning Systems Network (FEWS NET). 'Acute Food Insecurity: Near Term (May 2020)'. fews.net/. Accessed April 2020.
24. Famine Early Warning Systems Network (FEWS NET). 'Evidence-based Analysis for a Food Secure World'. fews.net/sites/default/files/uploads/fews-net-brochure-en.pdf. Accessed April 2020.
25. Magadzire T et al. 'How climate forecasts strengthen food security'. 2017. public.wmo.int/en/resources/bulletin/how-climate-forecasts-strengthen-food-security. Accessed April 2020.
26. Bailey, B. 'Managing famine risk: Linking Early Warning to Early Action. A Chatham House Report'. 2013. www.chathamhouse.org/sites/default/files/public/Research/Energy%2C%20Environment%20and%20Development/0413r_earlywarnings.pdf. Accessed April 2020.
27. Bigiarini F et al. 'Prediction of drought-induced reduction of agricultural productivity in Chile from MODIS, rainfall estimates, and climate oscillation indices'. Remote Sensing of Environment. 2018. www.researchgate.net/publication/328252968_Prediction_of_drought-induced_reduction_of_agricultural_productivity_in_Chile_from_MODIS_rainfall_estimates_and_climate_oscillation_indices. Accessed April 2020.
28. Campbell et al. 'Sustainable intensification: What is its role in climate smart agriculture?'. 2014. www.sciencedirect.com/science/article/pii/S1877343514000359. Accessed April 2020.
29. Rainforest Alliance. 'Livelihoods'. www.rainforest-alliance.org/issues/food. Accessed April 2020.
30. Convention on Biological Diversity. 'Ecosystem Approach'. www.cbd.int/ecosystem. Accessed April 2020.

infrastructure and land management systems. Consistent monitoring of agriculture can therefore support optimal and sustainable management of agriculture in the face of climate change and at reduced costs.[31]

The enforcement of sustainable practices is often led by the demand side (agricultural consumers), as the supply side (the producers) lacks incentives to seek alternative means of production that are more sustainable.

An example is the extraction of palm oil, an environmentally intensive process. More sustainable practices are incentivised on the demand side by organisations like the Roundtable on Sustainable Palm Oil (RSPO), which certifies sustainable production practice.

EO data is used in Land Use Change Analysis (LUCA), and for high-value conservation assessments and greenhouse gas assessments. These determine damage to vegetation and the environmental impact of production processes, and are used to certify whether palm oil production affects primary forests. National commitments from several governments in Europe, including the UK, Sweden and Germany, have promoted certified palm oil suppliers through such schemes.[32] In the UK's case, RSPO certification was used to encourage large importers to switch to more sustainable suppliers. In 2015, UK consumption figures show that substantial progress had been made, with 87 per cent of palm oil imports sustainably sourced, compared to just 50 per cent in 2012.[33]

31. Caribou Space. 'Space for Agriculture in Developing Countries'. 2018. https://www.spacefordevelopment.org/wp-content/uploads/2018/10/6.4502_UKSA_SPACEUK_Solutions-for-Agriculture_web.pdf. Accessed April 2020.
32. Roundtable on Sustainable Palm Oil (RSPO). 'National Commitments'. www.rspo.org/about/national-commitments. Accessed April 2020.
33. Department for Environment, Food and Rural Affairs (Defra). 'UK statement on sustainable palm oil: final progress report'. 2017. assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/590473/palm-oil-final-report.pdf. Accessed April 2020.

Rural payments

Agricultural subsidies and rural payments aim to smooth income for farmers who are dependent on crop yields, and may experience falls in income during adverse periods. Where subsidies or payment schemes exist (through an insurance scheme, for example), EO data can be used to provide accurate and timely crop mapping and monitoring of land use at regional and national scales. When combined with in-situ data sources, this can be used to underpin the evidence base for the payment of farm subsidies and to assist with audit checks.

For example, rural payments agencies of EU member states check whether claimants meet their Common Agricultural Policy (CAP) obligations using EO. CAP's Basic Payment Scheme (BPS) requires member states to inspect at least 5 per cent of applications to ensure they meet the conditions for subsidy claims. EO is used to assess around 75 per cent of the BPS applications, with a very detailed assessment or resolution of 1m or less. The remaining 25 per cent are carried out by inspections on the ground. The addition of satellite monitoring has significantly reduced operational costs and increased efficiency. Evidence from Ireland suggests that the average cost of a physical inspection in 2010 was €1,800 compared to €60-70 for an EO-enabled check.[34]

Credit and insurance markets

Insurance and credit markets in developing countries are plagued with market failures, such as moral hazard[35] and adverse selection.[36] In addition, weather index insurance (where payments are triggered when weather conditions fall below a certain threshold) often suffer from high basis risk where insurance payments do not match an individual's actual losses. This is because these indices are typically characterised by a low level of granularity. This generalises losses even for farmers with notably different conditions.

These problems make it difficult for insurance or credit companies to accurately assess the degree of risk of farmers, resulting in an undersupply of insurance, loans and credit, even if they are demanded, and high premiums so that insurance companies can protect themselves from potential losses. Where private insurance cannot be obtained, there are examples where government have used EO data to provide state-backed subsidies (see the Common Agricultural Policy above).

EO can also provide assistance in the monitoring process by supplying accurate data to insurers. This corrects for market failures in the insurance market in the following ways:[37]

- **Underwriting:** without EO, insurers have to use historic loss data to calculate individual risk. EO data can be combined with meteorological data to determine the relationship between past and future loss rates. This allows for more accurate calculation of risk and premiums than with alternative methods.
- **Contract monitoring:** monitoring costs can be expensive, particularly when clients are geographically dispersed in rural areas. Using EO, insurance companies can check remotely whether contractual conditions are being upheld at relatively low cost.
- **Risk and damage assessment:** EO can verify whether damage has occurred from extreme weather events, at a high degree of granularity and at timely intervals. This can trigger payments accurately (lowering basis risk) and provide assistance to farmers requiring support quickly after an incident has occurred.

Further details on how space can support the provision of financial products in developing countries can be found in Caribou Space's *'Space for Finance in Developing Countries'* report.[38]

34. Allen, M. 'Contextual overview of the use of Remote Sensing data within CAP eligibility inspection and control'. 2015. www.niassembly.gov.uk/globalassets/documents/raise/publications/2015/dard/3115.pdf. Accessed April 2020.
35. Moral hazard occurs when an actor has an incentive to increase their exposure to risk because they do not bear the full costs of that risk. For example, when a person is insured, they may take on higher risk knowing that their insurance will pay the associated costs.
36. Adverse selection is a market situation where buyers and sellers have different information, so that a participant might participate selectively in trades which benefit them the most, at the expense of the other trades. The fear of rigged trade can prompt the worried party to withdraw from the interaction, diminishing the volume of trade in the market.
37. Chatzikostas, G. 'An eye on Earth: satellite Earth Observation for agriculture insurance'. 2017. www.earthobservations.org/geo_blog_obs.php?id=240. Accessed April 2020
38. Caribou Space. 'Space for Finance in Developing Countries'. 2020. www.spacefordevelopment.org/library/space-for-finance-in-developing-countries. Accessed April 2020.

In **Thailand**, there is evidence of satellite technology being used in the delivery of a government supported insurance scheme. The government-owned Bank for Agriculture and Agricultural Co-operatives (BAAC) provides affordable credit to agricultural producers, including the provision of insurance payments to farmers suffering from droughts or floods.[39] SOMPO Thailand is the private provider working alongside the BAAC to provide a weather insurance programme for Longan farmers in Chiang Mai province.

Figure 3: Funding flows for the AgriSompo insurance product

Source: SOMPO holdings "Launch of "Longan parametric weather insurance program" in Thailand" [40]

This project follows an initiative by the Thai government to launch an efficient financial support programme and provide insurance for farmers without a stable income. The Longan crop is particularly significant in its selection since it is a key agricultural export and has been exposed to drought risk in the past. The AgriSompo insurance product, provided through collaboration between the BAAC and SOMPO Thailand, uses satellite mapping of precipitation and EO to develop risk prediction tools[41], allowing the insurers to better calculate and manage risks associated with agriculture. This builds on previous index-based insurance products in this sector where it was expensive to monitor and assess individual farms losses. EO data helps to offer a more accurate dataset at a lower collection cost, and thus provide actuarially fair insurance products to the market. With this level of data, precipitation levels and vegetation coverage can be monitored remotely at a much higher resolution, and payment can be triggered when the yield is deemed to be below a threshold.[42] Monitoring costs are also lowered, as the EO data can remotely track which fields require an additional assessment. This can be particularly effective when customers are geographically dispersed, when the costs of visiting cropland to monitor would be high.

39. Bank for Agriculture and Agricultural Co-operatives (BAAC) 'BAAC's Vision'. www.baac.or.th/baac_en. Accessed April 2020.
40. Sompo Holdings. 'News release: Launch of "Longan parametric weather insurance program" in Thailand'. 2019. www.sompo-asia.com/files/pdf/LAUNCH%20OF%20LONGAN%20PARAMETRIC%20WEATHER%20INSURANCE%20PROGRAM%20IN%20THAILANDN%20(8%20Feb).pdf. Accessed April 2020.
41. Same as above
42. Chantarat, S et al. 'Farmers and Pixels: Toward Sustainable Agricultural Finance with Space Technology'. 2017. www.pier.or.th/wp-content/uploads/2017/10/pier_dp_075.pdf. Accessed April 2020.

2.1.3 Key findings: agriculture

- Climate change and population growth motivate the need for increased and more sustainable food production, particularly in developing countries whose populations are more likely to experience malnutrition and hunger.
- IPP is supporting six agricultural projects and two of those support government policy in the agriculture domain: Drought and Flood Mitigation Service (DFMS) by Rheatech (Uganda), and Pest Risk Information SErvice (PRISE) by CAB International (Kenya, Zambia and Ghana).
- Most applications of space in agriculture, such as for rural payments and insurance products, aim to stabilise the incomes of farmers and agricultural producers at low cost. Governments also have a responsibility to ensure food security, by implementing policies that maintain food security and plan for disasters. Space solutions can assist by providing early warning information and risk identification to support advance planning and mitigation.
- Alongside ground surveys, EO technology provides a regularly updated, accurate map of the land so that natural resources such as water, land space and timber can be more efficiently managed. Governments can promote sustainable food production to encourage these beneficial practices, as illustrated by the UK government's commitment to sustainable palm oil production.
- EO can provide insurers with more accurate, low cost and high-resolution data to improve damage assessment, lower administration costs and lower basis risk.
- IPP projects currently being delivered, and new satellite capabilities, are further developing the scope of satellite technology in agriculture.

2.2 Climate change and the environment

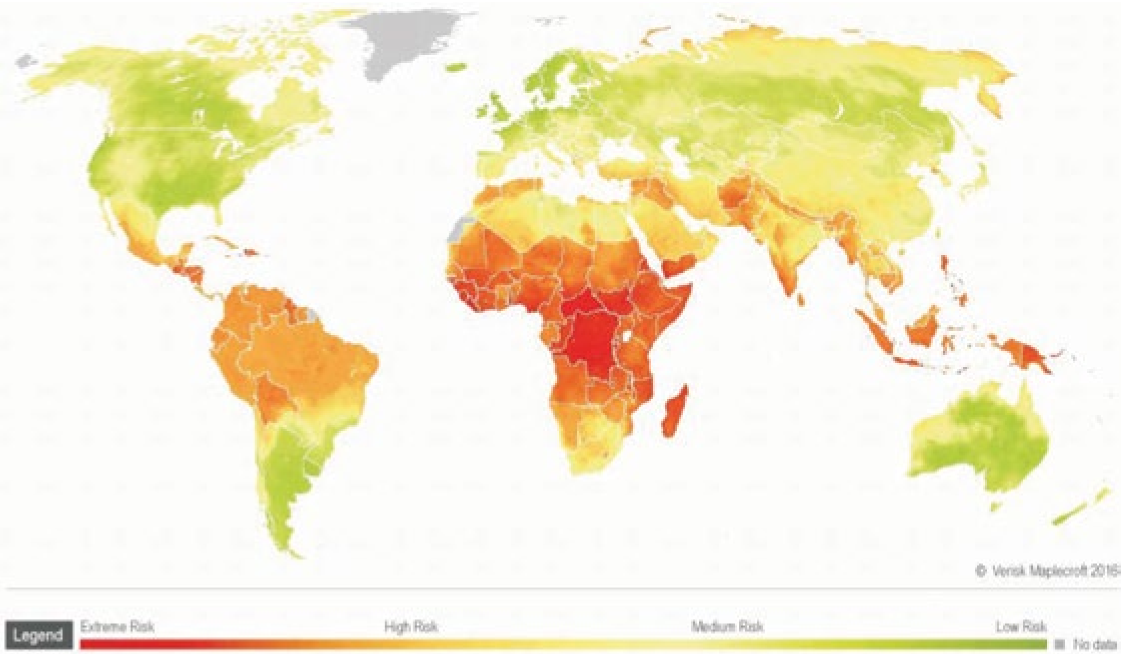
This section examines the evidence for satellite applications supporting the climate change and environment policies of national governments. This policy area covers four policy activities: climate change adaptation, renewable energy, carbon abatement, and air quality.

2.2.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) issued a warning in 2020 that there were now only ten years remaining to take action and avoid irreversible disruption from climate change.[43]

The Climate Change Vulnerability Index (Figure 4) maps the degree to which countries are exposed to climate change risk, with countries in red (the Global South) identified as being most affected by climate risk. These countries often have limited adaptive resources and are already facing issues such as food insecurity. This means that the increased risk of droughts, flooding, extreme weather events and rising temperatures is likely to hit these countries severely.[44]

Figure 4: Climate Change Vulnerability Index 2017



The five **worst performing countries**

Rank	Country	Region	Score	Category
1	Central African Republic	Africa	0.01	Extreme
2	DR Congo	Africa	0.20	Extreme
3	Haiti	Caribbean	0.24	Extreme
4	Liberia	Africa	0.25	Extreme
5	South Sudan	Africa	0.41	Extreme

The five **best performing countries**

Rank	Country	Region	Score	Category
191	Denmark	Europe	10.00	Low
190	United Kingdom	Europe	9.96	Low
189	Uruguay	S.America	9.95	Low
188	Iceland	Europe	9.85	Low
187	Ireland	Europe	9.83	Low

Source: Verisk MapleCroft Climate Change Vulnerability Index 2017,
retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/verisk%20index.pdf

43. United National (UN). 'Only 11 Years Left to Prevent Irreversible Damage from Climate Change, Speakers Warn during General Assembly High-Level Meeting'. 2019. www.un.org/press/en/2019/ga12131.doc.htm. Accessed April 2020.
44. Intergovernmental Panel on Climate Change (IPCC). 'Climate Change and Land'. 2019. www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf. Accessed April 2020.

There is an increasingly urgent need for world governments to put measures in place to decarbonise their economies and mitigate potential climate change risks. Effective action requires detailed information about the climate, and on sources of carbon emissions.

However, ground-based weather and climate monitoring systems only cover about 30 per cent of the Earth's surface.[45] Satellites offer global coverage of our planet and can provide the data that is needed to support informed decarbonation and climate mitigation policies.

EO is a particularly relevant technology in this domain. The combination of optical and synthetic aperture radar (SAR) sensors means that many aspects of the climate and environment can be monitored over time, such as vegetation cover, temperature and air quality. This data allows countries to understand how their environment will change under the pressures of climate change and global warming, and thus allows decision makers to make mitigating and adaptive policies. An example, discussed in this section, is how likely Australian heatwaves are to occur as greenhouse gas emissions and global warming continue to intensify.

In this section, we cover four policy activities which can be supported by space-based applications. A brief overview is given here for each of the four sections.

- **Climate change adaptation:** Climate change is associated with an increasing number of extreme weather events and natural disasters. These put humans, wildlife and natural resources at risk. Satellite data allow policy makers to assess climate and environmental conditions, and help their countries prepare for climate-change related disruptions and changes.
- **Renewable energy:** Renewable energy generation is greatest where renewable resources are most plentiful, and satellite data can help identify these locations. Satellites can also be used to monitor the negative impacts from the construction of renewable energy infrastructure, and to inform plans for mitigation.
- **Carbon abatement:** Mitigation of greenhouse gas emissions requires a good understanding of the levels of gas in the atmosphere (today as well in the past and future). Satellite data estimate this consistently and with wide geographical coverage. Another aspect of carbon abatement discussed in this section is Carbon Capture and Storage, whose integrity and cost-effectiveness can be enhanced by space technologies.
- **Air quality:** Satellites can estimate air quality, providing data that can be used to identify pollutant levels across time and space. This could inform governments about the effectiveness of their air quality policy.

The following table shows application areas where there is evidence for the use of space technologies. The domains of climate change and the environment are vast, and therefore the topics covered here may only represent a subset of all policy applications of space in this area.

Table 3: Climate change and the environment: space applications for policy

Function	Evidence of use
Climate change adaptation policy	✓
Renewable energy policy	✓
Carbon abatement policy	(✓)
Air quality management	(✓)

Note: ✓ current evidence; (✓) future applications and/or pilot studies
Source: London Economics analysis

45. Committee on Earth Observation Satellites (CEOS). 'CEOS EO Handbook – the Important Role of Earth Observations'. http://www.eohandbook.com/eohb2011/climate_satellites.html. Accessed April 2020.

IPP Climate Resilience Call

Part of IPP Call 3 that ran from October 2019 to February 2020 was a specific call on 'Climate Resilience Planning for Developing Countries'. The projects that will join IPP through this call can use any space solutions to support countries to develop plans and policies for building resilient future climate change scenarios.

2.2.2 Evidence: climate change and the environment

Climate change adaptation policy

Climate change adaptation refers to various forms of action that are taken to adjust to actual or expected climate.[46] Climate change impacts vary nationally and regionally, and different countries may engage in different strategies. Examples can range from building flood defences and adopting drought-resistant crops, to redesigning communication systems.[47] This section focuses on adaptation actions that are taken to adapt to the increasing number of climate change-induced severe weather events and natural disasters.

Well-designed policies in this area require data and evidence to understand past, current and potential future climate and environmental conditions. This section illustrates the ways in which EO has provided this data to help guide decision makers, and will likely continue to do so in the future.

The **Australian** heatwaves and bushfires of 2019 are a striking example of the kind of environmental risks that are exacerbated by climate change, and which pose a serious threat to property, wildlife, human life and the natural ecosystem.[48] It is important to understand the likelihood of these events occurring in a world that is projected to continue warming.

The Australian Bureau of Meteorology used climate data from the Copernicus Climate Change Service to estimate future heat wave severity under different emission scenarios. It was found that increasing CO_2 emissions are strongly associated with heat wave severity in the future. The Bureau also learnt that the more severe heatwaves would occur on the east coast and south coast of the country.[49]

These results were passed on to the local stakeholders in the form of an interactive web system to inform decision making.[50] Stakeholders were made aware that in a world of higher carbon emissions, heatwaves are more likely to occur, and of where they are most likely to occur in the country.

Heatwave-related disasters are expected to occur more frequently in the future across all economies, developed or developing. There will likely be an increasing demand for solutions to cope with this risk. This example illustrates the point that space applications can be used to meet this demand.[51]

Climate change may also pose a threat to natural resources, such as water. For example, the Asopos River in Central **Greece** is exposed to a high level of industrial activity because of its proximity to Athens.[52] These industrial activities rely on the river to dispose their effluent, threatening the river as a safe source for water abstraction and irrigation.[53] EO has a role in monitoring the quantity and quality of the water sources against required standards.

46. Intergovernmental Panel on Climate Change (IPCC). 'Annex II: Glossary'. 2018. www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-AnnexII_FINAL.pdf. Accessed April 2020.
47. United Nations Climate Change. 'What do adaptation to climate change and climate resilience mean?'. unfccc.int/topics/adaptation-and-resilience/the-big-picture/what-do-adaptation-to-climate-change-and-climate-resilience-mean. Accessed April 2020.
48. BBC. 'Australia heatwave: All-time temperature broken again'. 2019. www.bbc.co.uk/news/world-australia-50837025. Accessed April 2020.
49. Copernicus Climate Change Service (C3S). 'Heatwaves causing health stress in Australia'. Posted at: climate.copernicus.eu/heat-waves-causing-health-stress-australia Accessed April 2020.
50. Same as above.
51. International Monetary Fund (IMF). 'Climate change will bring more frequent natural disasters & weight on economic growth'. 2017. blogs.imf.org/2017/11/16/climate-change-will-bring-more-frequent-natural-disasters-weigh-on-economic-growth/. Accessed April 2020.
52. Copernicus Climate Change Service (C3S). 'Environmental flows and point source emissions'. https://climate.copernicus.eu/environmental-flows-and-point-source-emissions. Accessed April 2020.
53. Same as above

The Greek Special Secretariat for Water was required to monitor the pressures on the Asopos River and review the effectiveness of current regulatory measures under climate change pressures. This action needed to be informed by evidence, as too strict regulation might stifle the economy, while too loose regulation might compromise the river.

Data on river flow were obtained from the Copernicus Climate Change Service to assess the discharge, and therefore the assimilative capacity of the river, under future climate change scenarios.

While climate change was found to have no discernible impact on the assimilative capacity of the river, it was found that further industrial development could negatively impact the river's water quality.[54] These findings were used to help form a preliminary plan to mitigate river pollution and guide further analysis. This example provides a clear use case for EO data informing both current and future policies to manage natural resources, particularly in the face of climate change.

CommonSensing, United Nations Institute for Training and Research (UNITAR) and Operational Satellite Applications Programme (UNOSAT), Fiji, the Solomon Islands, Vanuatu

CommonSensing aims to use satellite EO for applications that support three island states to improve national resilience to climate change. To do this, the project will provide evidence and data needed for these islands states to apply to the Commonwealth Climate Finance Access Hub[55] with a much higher degree of success than at present. This funding will help protect critical infrastructure and build resilience to climate change, reducing economic losses and fatalities from climate-induced disasters. The evidence will come from a combination of analysis-ready data from optical (Sentinel-2, SPOT and Landsat), radar (Sentinel-1) and elevation (PALSAR) satellite images.

54. Same as above

55. The Commonwealth. 'Climate Finance Access Hub'. thecommonwealth.org/climate-finance-access-hub. Accessed April 2020.

As well as the preservation of human lives and natural resources, the preservation of wildlife is an important area of climate change adaptation. **Costa Rica** has demonstrated that space is a valuable tool in designing a policy for biodiversity preservation. The country is ecologically important, hosting 5 per cent of the Earth's biodiversity, but its vulnerability to climate change puts the ecosystem at risk.[56]

Although the Costa Rican government recently decided to investigate the potential impact of climate change on its environment, good quality country-wide climate data was limited.[57] This data deficit challenged the development of a climate adaptation and ecosystem preservation policy. The Copernicus Climate Change Service adjusted its global scale data to a spatial resolution of 5km^2 or smaller.[58] This data included precipitation and temperature data, which were used to locate vegetation ecosystems and predict the movements of species. In collaboration with local research partners, the Costa Rican government was able to access usable data to identify climate-sensitive areas of the country. This allowed the government to establish biological corridors that allow species to move between protected areas.[59] Since October 2018, a total of 44 biological corridors have been identified, representing about 33 per cent of Costa Rica's of continental territory.[60]

As pressure on natural landscape increases due to urbanisation, increasing demand for agricultural land and climate change, sustainable management of national wildlife and biodiversity becomes increasingly important.[61] This example shows that satellite data can fill data deficits that hold back effective policies to mitigate these threats and support sustainable management.

The **UK** is another country which has recognised the role of space in coping with climate change. The Department of Energy and Climate Change (before it became a part of BEIS in 2016) devised the Earth Observation Strategy to understand how the department could access and use EO data to mitigate the risks associated with climate change, as well as a shortage of safe and affordable energy supplies.[62] The strategy involved several measures. These include expanding the use of atmospheric observations to verify emission estimates for the greenhouse gas emissions inventory, and increasing funding for Earth System Modelling, in order to locate future renewable energy resources and understand the environmental impacts of renewable energy, such as the impact of wind turbines on wildlife.[63]

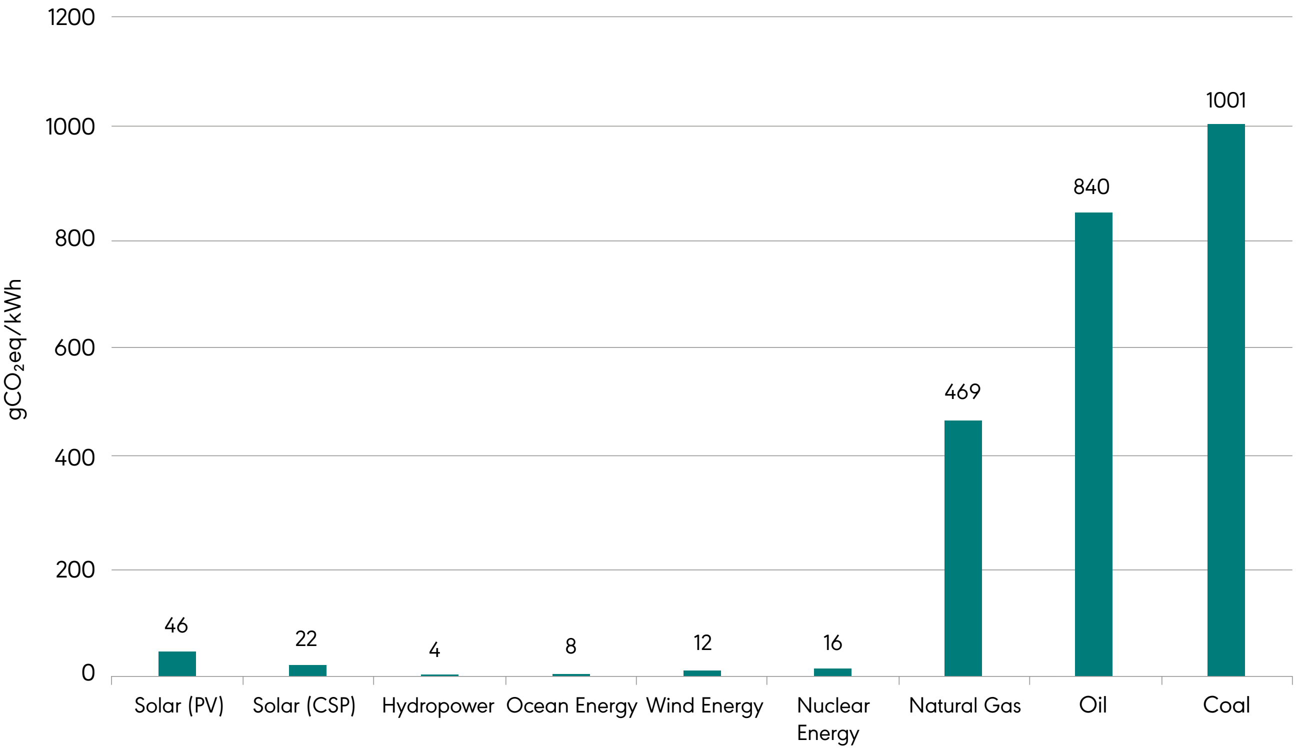
As the strategy outlined, the UK government co-funded a number of EO projects, including the £150,000 each for the Argo and JASON-3 programmes.[64] This was to ensure that the government would have access to the necessary data for climate modelling and climate policy. For example, Argo data has significantly reduced forecast uncertainty in ocean heat content, while JASON-3 has significantly increased the accuracy of sea level measurements.[65] Both improvements have given the government a better prediction of climate change and supported the making of national climate policy. This is an example of a national government making a policy plan which was centred on EO in order to prepare against potential climate change challenges.

56. Copernicus Climate Change Service (C3S). 'Climate change impacts on biodiversity in Costa Rica'. 2018. climate.copernicus.eu/climate-change-impacts-biodiversity-costa-rica. Accessed April 2020.
57. Same as above.
58. Same as above.
59. Mexican Biodiversity. 'Biological corridors'. www.biodiversidad.gob.mx/v_ingles/corridor/biologicalCorridors.html. Accessed April 2020.
60. National System of Conservation Areas (SINAC). 'Biological Corridors'. www.sinac.go.cr/EN-US/correbiolo/Pages/default.aspx. Accessed April 2020.
61. Imperial College London. 'Gratham Institute Briefing paper No 13: Climate change and challenges for conservation'. 2015. www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Climate-change-and-challenges-for-conservation-Briefing-Paper-No-13.pdf. Accessed April 2020.
62. Department of Energy and Climate Change (DECC). 'DECC Earth Observation Strategy'. assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48428/5592-decc-earth-observation-strategy.pdf. Accessed April 2020.
63. Same as above.
64. Same as above.
65. Same as above.

Renewable energy policy

To reduce human reliance on fossil fuels and our influence on global warming, a shift to renewable energy is increasingly seen as essential.[66] As Figure 5 shows, renewable energy is associated with lower greenhouse gas emissions than its fossil fuel counterparts. Furthermore, in poor rural areas and developing countries, electrification in an off-grid model via renewable energy is sometimes more cost-effective than grid extension.[67] But harnessing renewable energy calls for exposure to the sun, wind and water. The construction of power plants can also bring about negative environmental impacts. The section shows how space can provide information to help manage renewable energy and design relevant policy.

Figure 5: Lifecycle assessment of greenhouse gas emissions from electricity generation technologies, gCO2eq/kWh



Note: Each level reported here represents the 50th percentile of the estimates gathered from IPPC's literature review for the generation technology.
PV = Photovoltaic, CSP = Concentrating solar power.
Source: IPPC, retrieved from www.ipcc-wg3.de/report/IPCC_SRREN_Annex_II.pdf

66. Intergovernmental Panel on Climate Change (IPCC). 'Renewable Energy Sources and Climate Change Mitigation'. 2012. www.ipcc.ch/site/assets/uploads/2018/03/SRREN_FD_SPM_final-1.pdf. Accessed April 2020.
67. Chauhan A. 'Renewable energy based off-grid rural electrification in Uttarakhand state of India: Technology options, modelling method, barriers and recommendations'. 2015. www.sciencedirect.com/science/article/abs/pii/S1364032115006152?via%3Dihub. Accessed April 2020.

Renewable energy site selection and monitoring

To optimise renewable energy production (including solar, tidal, wind and hydro), production sites should be located in areas that maximise their energy generation potential. EO can be used to assess potential locations for these attributes.

For example, irradiation is essential for solar panel energy conversion, as are favourable wind conditions for wind turbines and water flow for hydroelectric dams.[68] These parameters could all be assessed via EO data to make hindcasts, nowcasts and forecasts[69] of renewable energy production and inform energy management. **Norway**, where hydropower accounts for over 95 per cent of the country's power production[70], already uses EO to model and predict water flow[71] and energy generation capacity from its 120 reservoirs in high elevation and mountain areas.[72] EO provides an accessible way to monitor snow coverage and thickness. Although the use of EO is operationally limited by clouds, it helps validate in-situ measurements. The addition of radar to penetrate cloud cover would increase the potential of this data and ultimately reduce labour costs from in-situ measurement.[73]

Renewable energy sources are key to the transition to a low-carbon economy. However, the development of renewable energy sources still comes with some environmental impacts.

In the case of hydro energy, construction of a dam can cause disruption to the area's landscape and to water flow upstream and downstream. In **Colombia**, satellite imagery has been used to assess the changes in vegetation cover associated with the Miel I Hydroelectric Power Plant development. These vegetation measurements were used to indicate the local communities' adaptation to the reconstructed habitat following the development of the project. Here, satellite data has helped monitor energy production and to guide the mitigation of negative environmental impacts that may result from its use.

Renewable Energy Space Analytics Tool (RE-SAT), Institute for Environmental Analytics, Seychelles, Mauritius, Montserrat, St Lucia, Palau, Tonga and Vanuatu

The RE-SAT project is developing a software platform with associated data products and modelling tools to support Small Island Developing States (SIDS) to transition from fossil fuel electricity generation to renewables. Despite the enormous potential of SIDS for renewable energy generation, many SIDS lack the environmental data to plan their renewable energy strategy. As a result, the budgets of many SIDS are exposed to rises in fossil fuel import prices.

To address this data gap and support SIDS to improve strategic planning on renewables, RE-SAT uses freely available EO datasets to augment limited ground-based observations and validate renewable energy models. In this way, RE-SAT uses space data to improve the effectiveness of renewable energy planning and development and to support the case for climate change adaptation funds.

To date, RE-SAT's renewable energy applications has provided value to several users in the developing world. For example, RE-SAT made it easy for Seychelles officials to assess different scenarios for potential RE installations, the results from which informed the decision that solar power alone will not achieve the long-term target of generating all energy from renewable sources.

RE-SAT has also supported projects in Palau and Montserrat to estimate the renewable energy potential of solar panels and windfarms respectively. In both cases, RE-SAT has provided the evidence to support each island's renewable energy targets.

---

68. PwC. 'Copernicus Market report - February 2019'. 2019. www.copernicus.eu/sites/default/files/2019-02/PwC_Copernicus_Market_Report_2019_PDF_version.pdf. Accessed April 2020.
69. Hindcast, nowcast, and forecast are scientific predictions about the past, present, and future states.
70. International Hydropower Association (IHA). 'Norway'. www.hydropower.org/country-profiles/norway. Accessed April 2020.
71. European Space Agency (ESA). 'Space shows way to Europe's renewable energy future'. www.esa.int/Applications/Observing_the_Earth/Space_shows_way_to_Europe_s_renewable_energy_future. Accessed April 2020.
72. Same as above.
73. Same as above.

In addition, building the components necessary for renewable energy infrastructure requires a mix of metals, including copper, cobalt, nickel, rare earth metals, silver and lithium.[74] The growing scale of demand for these minerals has sometimes led to mining in biodiversity-rich locations that were previously undisturbed.[75] For example, the Atacama Salt Flat in **Chile** is an important habitat and breeding ground for Andean flamingos,[76] but is also the site of the largest lithium reserves in the world. The growing demand for lithium from electric car manufacturers is a direct threat to this important ecosystem if not properly managed.

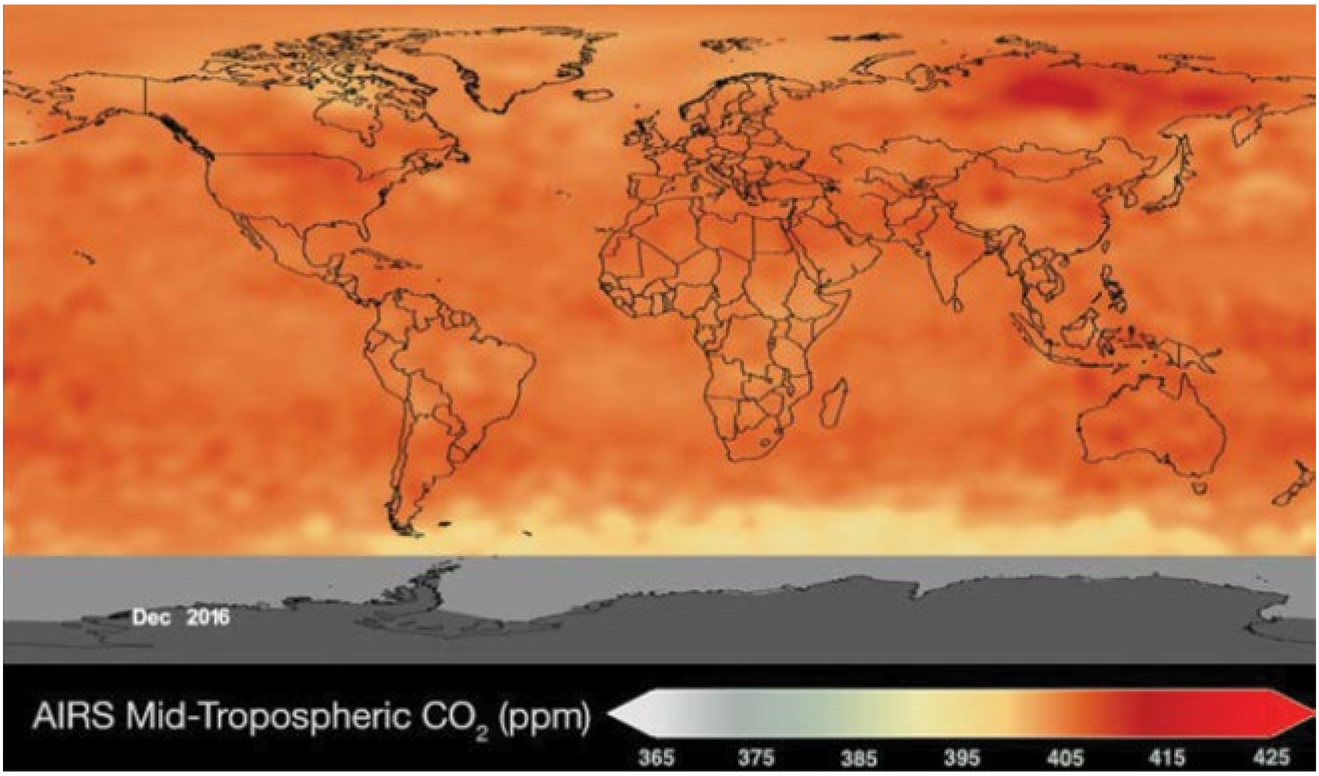
For this reason, Liu et al (2019)[77] used NASA satellite data to estimate the average growth rate of the Salt Flat mining area in the past two decades and the associated environmental degradation. It was found that the impact area extended beyond wildlife habitats to human settlements, resulting in degrading vegetation cover, hotter local climates and dryer conditions.[78] As this example demonstrates, satellite data is a valuable asset for policy makers who need to evaluate the costs and benefits of mining activities and enforce sustainable mining practices within carefully defined concessions. With the growing need for renewable energy, there is an increasing need for evidence of its impact. Policy makers can use space data to meet this need.

Carbon abatement policy - Greenhouse gas (GHG) emissions inventory

The Paris Agreement aims to limit global warming to 2 degrees Celsius, and ideally 1.5 degrees, above pre-industrial levels. Countries can only monitor their progress and be held accountable if their greenhouse gas emissions levels are recorded. Satellites can measure atmospheric concentrations of gases and offer global coverage, which is a key advantage over ground-based measurement of emissions.[79]

74. Earth Works. 'Report: Clean Energy Must Not Rely on Dirty Mining'. 2019. earthworks.org/media-releases/report-clean-energy-must-not-rely-on-dirty-mining/. Accessed April 2020.
75. Same as above.
76. Stumvoll A. 'Shift to renewable energy could have biodiversity cost, researchers caution'. 2019. news.mongabay.com/2019/06/shift-to-renewable-energy-could-have-biodiversity-cost-researchers-caution/. Accessed April 2020.
77. Liu W et al. 'Spatiotemporal patterns of lithium mining and environmental degradation in the Atacama Salt Flat, Chile'. 2019. www.sciencedirect.com/science/article/abs/pii/S0303243419300996. Accessed April 2020.
78. Same as above.
79. Imperial College London. 'Grantham Institute Briefing paper No 16. 'Satellite observations to support monitoring of greenhouse gas emissions'. www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Satellite-observations-to-support-monitoring-of-greenhouse-gas-emissions-Grantham-BP-16.pdf. Accessed April 2020.

Figure 6: Mid-Tropospheric CO_2 parts per million (ppm), mapped by NASA Atmospheric Infrared Sounder (AIRS)



Source: NASA, retrieved from https://climate.nasa.gov/vital-signs/carbon-dioxide/

The use of satellite data to measure GHG emissions in a given country depends on its national reporting standards. Some countries have already been exploiting satellite data to improve their GHG emissions reporting. For example, the UK has trialled using satellite data to fulfil its reporting requirements for the National Atmospheric Emissions Inventory.[80] The data were tested for measuring emissions at a sector level. This meant greater clarity about the sectoral distribution of emissions, and contributed to the design of more targeted mitigation policies.

The global coverage of satellite instruments for GHG measurements also offers a cost advantage. International requirements for GHG reporting by developing countries tend to be less rigorous, and these countries may also face limited resources in building ground-based infrastructure for emissions monitoring.[81] Satellite data can be used to construct a GHG inventory dataset at a global level, and a country breakdown. European researchers are already developing an instrument that could measure GHG emissions around the world at a level of precision that could trace back to cities and plantations.[82] If this European project is successful, this kind of data would become available at a higher resolution and developing countries could use it to inform their carbon abatement policies.

80. London Economics. 'Value of satellite-derived Earth Observation capabilities to the UK Government today and by 2020'. 2018. londoneconomics.co.uk/wp-content/uploads/2018/07/LE-IUK-Value-of-EO-to-UK-Government-FINAL-forWeb.pdf. Accessed April 2020.
81. The National Academies Press. 'National Inventories of Greenhouse Gas Emissions'. 2010. www.nap.edu/read/12883/chapter/4. Accessed April 2020.
82. Witze A. 'Europe eyes fleet of tiny CO_2 monitoring satellites to track global emissions'. 2018. www.nature.com/articles/d41586-018-06963-4. Accessed April 2020.

Carbon abatement policy - Carbon capture and storage (CCS)

Carbon capture and storage (CCS) is a technology which captures and stores carbon dioxide from production processes and prevents it from entering the atmosphere. Public opinion is divided on this technology's potential to tackle climate change.[83]

Some of the main concerns about CCS are whether it can be trusted, and whether it will be cost-effective in the near future.[84] Researchers at ESA suggest that satellite observations could become a cost-effective way to monitor CCS facilities.[85] EO data can give important tectonic and terrain information about the site, which could help avoid the risks associated with underground reservoirs of potentially hazardous gases. EO (and GNSS) can also help navigate the terrain for carbon transportation and pipeline routing. For instance, the identification of landslides can inform the construction and rerouting of pipelines. In addition, satellite data can monitor CO_2 movements and spot potential CO_2 leakages. This could enhance the integrity of the CCS site.

Given the public scepticism over CCS and its potential risks, governments implementing it would need to adopt stringent monitoring requirements. Space could become a cost-effective way of supporting compliance with these requirements.

Air quality policy

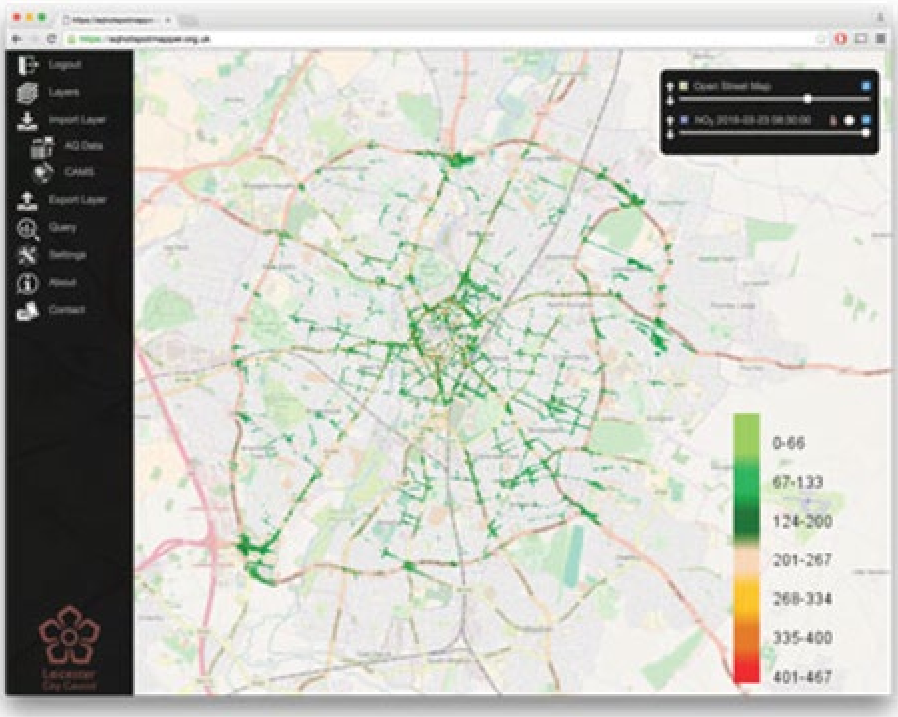
Air pollution is a major public health threat.[86] Air pollutants from diesel engines have also been shown recently to circulate around the globe and land on ice and snow in remote areas such as the Arctic, reducing sunlight reflection and ultimately contributing to climate change.[87] Improving air quality can therefore have positive outcomes for both public health and climate change.

An important first step to improving air quality is to measure it and understand where the pollutants originate. Satellite data can validate ground-based data inputs by triangulation of top-down with bottom-up, and estimate pollution movement across borders. By reducing uncertainty and improving forecast accuracy, satellite-derived EO data can support more effective pollution mitigation.

In the **UK**, Leicester City Council and Rotherham Metropolitan Borough Council have demonstrated the feasibility of using satellite data to map out air quality hotspots.[88] The system was shown to be able to measure air quality in a city in near-real time, and identify the sources and impacts of pollution (see Figure 7). UK local authorities have a statutory duty to assess and improve air quality, and this case showed that satellite data has the potential to help them fulfil this duty. It also illustrated the point that the UK government, and governments around the world, could make use of these data to design and implement air quality policy and early warning systems.

83. Reiner D. 'Perspectives on carbon capture and storage'. www.cisl.cam.ac.uk/resources/publication-pdfs/david-reiner-perspectives-on-carbon-capture-and-st.pdf. Accessed April 2020.
84. Same as above.
85. European Association of Remote Sensing Companies (EARSC). 'The Role of Earth Observation in Carbon Capture and Storage'. 2011. http://earsc.org/news/the-role-of-earth-observation-in-carbon-capture-and-storage. Accessed April 2020.
86. World Health Organisation (WHO). 'Ambient air pollution: Health impacts'. www.who.int/airpollution/ambient/health-impacts/en/. Accessed April 2020.
87. United Nations Environment Programme. 'Taller plants in warming Arctic could speed up climate change'. 2018. www.unenvironment.org/news-and-stories/story/taller-plants-warming-arctic-could-speed-climate-change. Accessed April 2020.
88. UK Space Agency. 'Case study: University of Leicester – Air Quality Hotspot Mapper'. spaceforsmartergovernment.uk/case-study/university-of-leicester-air-quality-hotspot-mapper-aqhsm/. Accessed April 2020.

Figure 7: Illustration of Leicester City Council and Rotherham Metropolitan Borough Council's air quality hot spot mapper



Source: UKSA, retrieved from https://spaceforsmartergovernment.uk/case-study/university-of-leicester-air-quality-hotspot-mapper-aqhsm/

Indeed, some researchers have shown that satellite data can be used to monitor air quality and evaluate the effectiveness of a country's air quality policy. For instance, Chen et al 2018[89] used satellite data to study the effects of the 2013 Chinese air quality policy, which introduced the monitoring and control of coal use, vehicle emissions standards and pollutant discharge permits for industries.[90] The study monitored trace gas pollutants to estimate anthropogenic emissions in China and showed that these emissions had declined since 2013. Another example is Laugher and Cohen (2019)[91] which used satellite data to measure nitrogen oxides in North American cities between 2005 and 2014. It was found that the levels were decreasing there, which suggested that US pollution regulations had been working.[92]

The ability of satellites to provide wide-area coverage can give governments an overview of their country's air quality as well as data at high granularity for local-level monitoring. As with greenhouse gas reporting, satellite data could be a cost-effective air quality monitoring tool in areas where ground-based measurement devices are limited.

89. Chen L et al. 'Satellite record of transition of air quality over China'. 2018. www.tandfonline.com/doi/full/10.1080/20964471.2018.1514818. Accessed April 2020.
90. Library of Congress. 'Regulation of Air Pollution: China'. www.loc.gov/law/help/air-pollution/china.php. Accessed April 2020.
91. Laughner et al. 'Direct observation of changing NOX lifetime in North American cities'. 2019. science.sciencemag.org/content/366/6466/723. Accessed April 2020.
92. Pullano N. 'Satellite Data Shows US Air Pollution Policies Actually Work'. www.inverse.com/article/60758-satellite-data-greenhouse-gas-pollution. Accessed April 2020.

2.2.3 Key findings: climate change and the environment

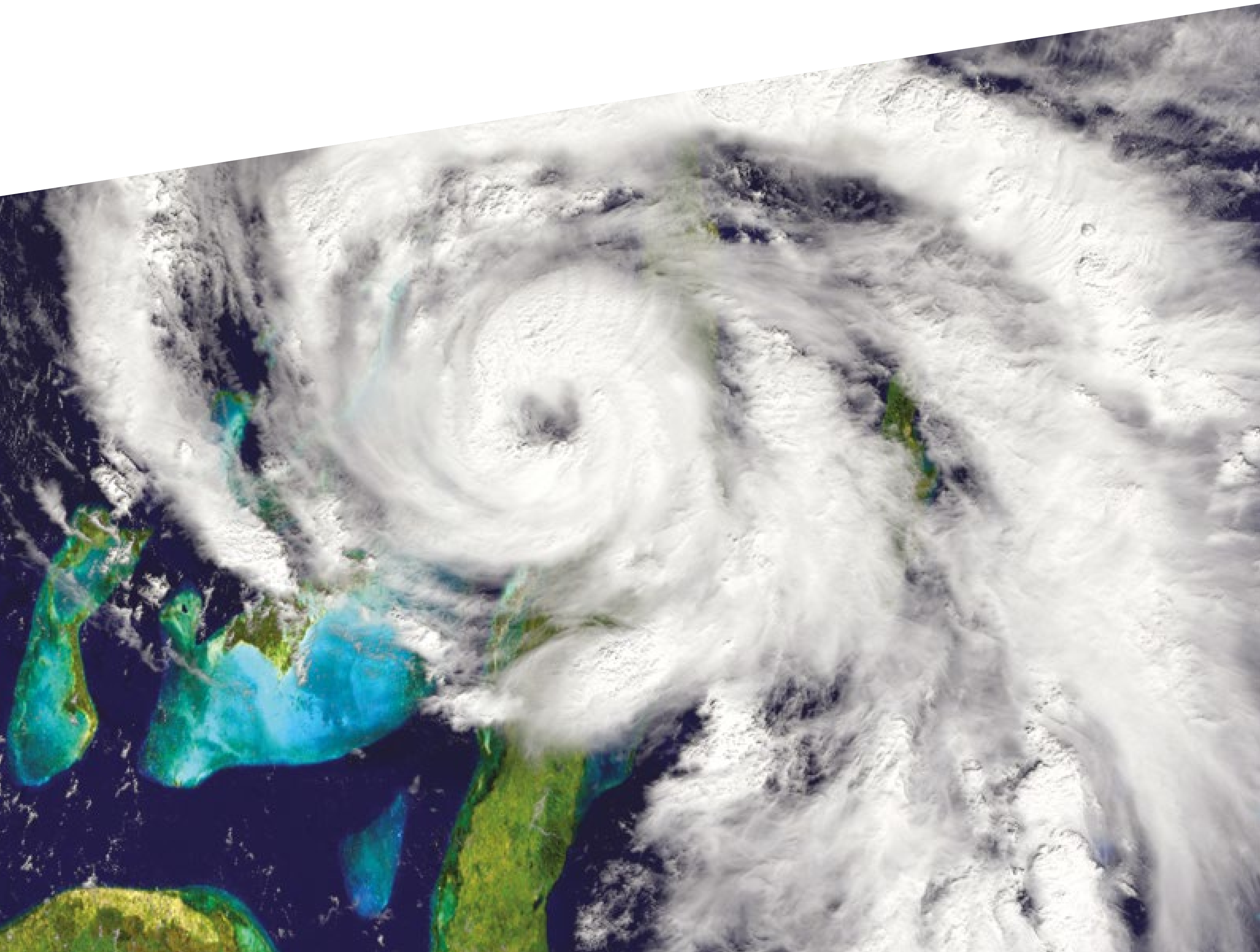
- Satellite data provide rich information about future climate and environmental conditions, and thus allow policy to mitigate risks that are predicted to increase in the future due to climate change.

- IPP is supporting two climate change projects that support governments to make more effective decisions concerning climate change policy: Renewable Energy Space Analytics Tool (RE-SAT), (Seychelles, Mauritius, Montserrat, St Lucia, Palau, Tonga and Vanuatu) by the Institute for Environmental Analytics, and CommonSensing (Fiji, the Solomon Islands, Vanuatu) by the United Nations Institute for Training and Research (UNITAR) and Operational Satellite Applications Programme (UNOSAT).

- Renewable energy production can be optimised by using satellite data to improve understanding of favourable conditions for the required natural resource. EO can also monitor the potential adverse environmental impacts of renewable energy.

- Satellite data provide a database on greenhouse gas emissions consistent on a global basis, even for locations which lack ground-based measurements. EO could also enhance the integrity of Carbon Capture and Storage technology, which is needed to convince the public of its viability.

- Air quality can be measured at a high level of detail using satellites. This allows policy makers to map out locations which require policy mitigation and to monitor progress.



2.3 Disaster resilience

This section presents evidence of the use of satellite applications to support disaster resilience policies in the developing world. Pilot studies may indicate future applications of space technologies and so are also presented for reference.

2.3.1 Introduction

Natural hazards, such as floods, droughts and earthquakes, have a large negative impact on affected countries in both the short and long term. Natural disasters destroy both physical assets (infrastructure, housing, crops, livestock) and human capital, deteriorating the productive capacity of countries long after the disaster has occurred.[93] During the 1980-2015 period, such natural disasters have affected an average of 169 million people per year, resulting in the loss of 50,000 lives per year and US$2.6 trillion in total economic damage over the period.[94]

Natural disasters such as earthquakes and other geological events are regular occurrences, but climatic and weather-related events are expected to increase over time because of humanity's carbon footprint and its impact on climate change.

The global bushfires from summer 2019 are a good illustration of this. A combination of heatwaves and droughts contributed to an increase in recorded wildfires registered by the Sentinel-3 satellite from 17,000 in 2018 to 79,000 in 2018 – an unprecedented increase in wildfires since the ASTR World Fire Atlas was created in 1995.[95] Potential losses due to disasters could increase without more effective mitigation.

Developing countries are particularly vulnerable. Their populations are eight times more likely to be affected by disasters, suffer five times as much direct damage as a share of GDP, and have much lower levels of insurance against such losses when compared to developed countries. Between 1991 and 2005, nearly 90 per cent of disaster-related fatalities and 98 per cent of people affected by disaster were in developing countries.[96] For example, ten of the deadliest disaster events in the past 20 years (out of 7,300), have occurred in developing countries and took more than 890,000 lives. These catastrophes include Haiti's earthquake in 2010 (220,000 reported deaths[97]), the 2004 Indian Ocean earthquake followed by Tsunami (where more than 200,000 perished[98]) and a 2008 tropical cyclone in Myanmar (nearly 140,000 reported casualties[99]). In addition, the aftermath of disasters in developing countries is characterised by significant social problems, such as famine, homelessness, uncontrolled migration, criminality, and disease.[100,101]

The difference in vulnerability between developed and developing countries is largely due to developing countries' lack of preparedness, poor investment in resilient infrastructure and housing, and slow emergency response.[102] At the government level, early warning systems, if they exist, are underdeveloped and response times are usually greater than in developed economies because of poorer emergency procedures. Developing countries are therefore unable to limit the number of casualties per disaster event compared to developed countries.

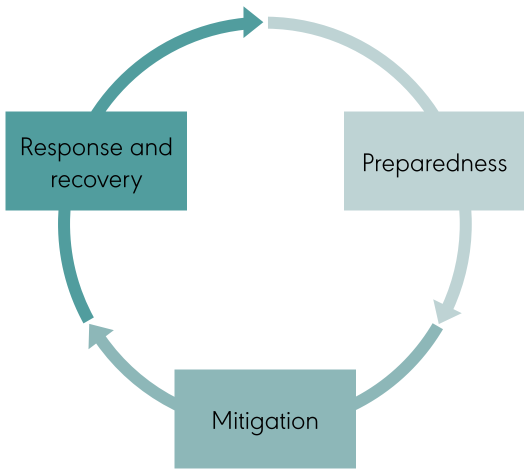
93. Botzen, W et al. 'The Economic Impacts of Natural Disasters: A Review of Models and Empirical Studies'. 2019. academic.oup.com/reep/article/13/2/167/5522921. Accessed April 2020.
94. Moody's Investor Services. 'Understanding the Impact of Natural Disasters: Exposure to Direct Damages Across Countries'. 2018. www.eenews.net/assets/2016/11/30/document_cw_01.pdf. Accessed April 2020.
95. European Space Agency (ESA). 'Is Earth on fire?'. 2019. www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-3/Is_Earth_on_fire. Accessed April 2020.
96. Zorn M. 'Natural Disasters and Less Developed Countries'. 2018. www.researchgate.net/publication/318862730_Natural_Disasters_and_Less_Developed_Countries. Accessed April 2020.
97. Ritchie H and Roser M. 'Natural Disasters'. 2019. ourworldindata.org/natural-disasters. Accessed April 2020.
98. BBC. 'Indian Ocean tsunami anniversary: Memorial events held'. 2015. www.bbc.co.uk/news/world-asia-30602159. Accessed April 2020.
99. The International Federation of Red Cross and Red Crescent Societies (IFRC). 'Myanmar: Cyclone Nagris 2008 Facts and Figures'. 2011. https://www.ifrc.org/en/news-and-media/news-stories/asia-pacific/myanmar/myanmar-cyclone-nargis-2008-facts-and-figures/. Accessed April 2020.
100. Centers for Disease Control and Prevention (CDC). 'Cholera in Haiti'. www.cdc.gov/cholera/haiti/index.html. Accessed April 2020.
101. CBS. 'Red Cross: 3M Haitians Affected by Quake'. 2010. www.cbsnews.com/news/red-cross-3m-haitians-affected-by-quake/. Accessed April 2020.
102. Padli et al. 'The impact of human development on natural disaster fatalities and damage: panel data evidence'. 2018. www.tandfonline.com/doi/pdf/10.1080/1331677X.2018.1504689?needAccess=true. Accessed April 2020.

It is critical for developing world governments to mitigate these issues by developing their capacity for effective disaster preparedness, resilience, response, and recovery. Space solutions can enhance this capacity by providing intelligence to focus efforts and public spending on the areas that face the greatest risks. For example, the wide coverage of EO can be used to assess the vulnerability of populations and assets to natural disasters. This intelligence can help authorities to plan, predict, and observe natural disasters and their aftermath. Space-enabled solutions for disaster resilience can be mapped onto the stages of the disaster management cycle:

- **Disaster preparedness:** preparedness refers to measures taken to prepare for, and where possible avoid, disasters.[103] Preparedness encompasses measures and policies taken before events occur, such as event forecasting (through improved environmental and meteorological measurement), alert systems, early warnings and spatial planning.
- **Disaster mitigation:** mitigation is the means to reduce the severity of human and material damage caused by disasters. EO and GNSS data can provide authorities with near real-time intelligence on disaster exposure. This allows them to plan mitigation and prioritise response, reducing potential deaths and loss.
- **Disaster recovery and response:** the management and response time post-disaster are crucial for the affected region to return to its normal economic activity and ensure the safety of affected people. The recovery section focusses on the use of space technologies to reduce emergency response time and improve the efficiency of aid in devastated areas.

Preparedness and mitigation are ex-ante measures (taken in advance of disasters) while recovery and response are ex-post (after disasters occur). Preparedness and mitigation measures can also be improved after a disaster takes place, since post-disaster analysis can be used to assess the effectiveness of decisions and inform actions that reduce the impact of the next event. The process of disaster resilience applications can be seen a "dynamic cycle" (Figure 8).

Figure 8: Disaster resilience virtuous cycle



Source: European GNSS Agency

Table 4: Disaster resilience: space applications for policy making

Function	Evidence of use
Disaster preparedness	✓
Disaster mitigation	✓
Disaster recovery and response	✓

Note: ✓ current evidences; (✓) future applications and/or pilot studies
Source: London Economics analysis

103. Disasters are a consequence of hazards where economic and life costs are accountable for it.

2.3.2 Evidence: disaster resilience

Disaster preparedness

Effective disaster anticipation and preparedness by government require a lot of precise intelligence on the spatial distribution and concentration of populations and infrastructure (the level of exposure) and on the likelihood of a disaster occurring (the hazard risk). Accurate and up-to-date intelligence can be costly to obtain in developing economies with limited funds. Developing nations often have rapidly changing populations and fast-moving urban development.

The evidence in this section details how satellite technologies can address this issue by providing high-frequency, high-resolution imagery of any point on Earth and at relatively low cost.

Flood and Drought Resilience, Airbus Defence & Space, Ethiopia and Kenya

Ethiopia and Kenya both suffer from floods and droughts with significant social costs and economic losses, in part caused by lower agricultural yields. This project aims to increase resilience towards these events. EO data will be used from Sentinel 2, DMC2 and KAZSTSAT satellites to develop a drought indexing mechanism to trigger payments. All information (maps, reports, statistics, risk measures) will be displayed on an integrated online platform to support farmers. In Kenya, the data is being used at a local and county level to improve the efficiency of allocating government subsidies and micro-insurance payouts from private providers. In Ethiopia, focus is towards the sustainable management of resources, providing intelligence to the Ministry of Finance and Economic Cooperation to plan for food shortages and adopt measures to mitigate climate change.

Earth and Sea Observation, Satellite Applications Catapult, Malaysia

In Malaysia, the Earth and Sea Observation System is addressing challenges posed by flooding, marine pollution and illegal logging, priorities identified by the Malaysian government.[104] In 2014, the country experienced particularly severe flooding, resulting in 21 deaths and the displacement of 250,000 people.[105] This had significant costs for economic activity including agriculture.

The Earth and Sea Observation System aims to: reduce the degradation to the mangrove coastline in Malaysia by reducing marine pollution in the Malacca Straits; reduce the social and environmental impact of illegal logging and increase the economic benefit from legal logging for Malaysia; and reduce the economic and social cost of floods.

Using EO, the programme provides high-value decision support for tackling these problems. The system assesses areas most in need of solutions to these three challenges and encourages government departments to share information through coordinated decision-making, using an integrated dashboard to monitor progress. The EASOS Flood Watch system incorporates satellite data to monitor real-time and forecast rainfall. This is combined with telemetry data, catchment state conditions and forecasting simulations. High-precision flood maps estimate multiple sources of flooding on a range of timescales. These maps form the foundation for further risk analysis using catastrophe modelling. This will enable better understanding of the flood risk landscape and support more effective decision-making before, during and after a flood.

---

104. UK Space Agency. 'Case study: Satellite Applications Catapult (Malaysia) Environmental Monitoring'. 2017. www.gov.uk/government/case-studies/satellite-applications-catapult-malaysia-environmental-monitoring. Accessed April 2020.
105. Ambiental. 'Government of Malaysia – Developing flood risk analysis and forecasting systems for Malaysia'. www.ambientalrisk.com/uk-space-agency-asia/. Accessed April 2020.

Satellite Earth observation data is a critical tool for preparedness

After 20 tropical storms within 10 years (1998-2008), the **Cuban** government established disaster risk reduction as a priority. The Cuban Civil Defence created the Risk Reduction Management Centre Strategy (RRMCS). By using EO data, the Cuban government assessed vulnerabilities and established a risk map. It then carried out a multi-hazard risk assessment, based on historical data, to map hazards, vulnerable areas, and buildings & populations at risk. These maps later served as a tool to determine priorities to reduce vulnerability to disasters.

Preparedness and capacity building enabled by the RRMCS at the local level has proven to be very effective in the protection of human life in Cuba.[106]

In both **Bangladesh** and **Myanmar**, GIS analysis mixed with EO data was used to assess earthquake risks. The project, led by the Asian Disaster Preparedness Centre (ADPC), contributed to the definition of urban growth patterns and the identification of high-risk areas. It also helped forecast future risks in order to help define the appropriate measures to take if a natural hazard occurred.[107]

In the city of Mandalay (Myanmar), the ADPC studied seismic characteristics and risks by using geospatial information, in particular EO data, to assess vulnerable buildings and geological features prone to earthquake damage. This intelligence that was acquired was used in the guidelines for integrated disaster risk information in urban land use and planning.

The city of Mymensingh (Bangladesh) benefited from being equipped with geospatial earthquake risk information, and applied that knowledge into its formal urban planning procedure. This was achieved in close relationship with decision makers and relevant stakeholders.

In cooperation with ESA and the **Indonesian** Government, a Canadian company has carried out a project to develop EO-based information products that could be used to prepare flood risk management plans, flood forecasting and early-warning systems in support of integrated flood risk management.[108] The product that was developed used EO data (images and elevation) to identify the critical areas where flooding was more likely to occur. Pleiades and RapidEye satellite images were used to assess areas at risk. This information was wrapped into a flood forecasting tool, now available to the Government of Indonesia.

The increase of climate-related catastrophes in **Tanzania** has pushed the government to revise its strategy for natural hazard preparation. The urban resilience programme reports that between 2019 and 2020, US$7.3m[109] is expected to be spent on disaster resilience management.

Of that investment, 11.5 per cent will be shared between satellite data access, use and management for risk identification, with the objective of building hydrological forecasting tools to mitigate flooding. In addition to building the technical tools, the report emphasises the importance of training and capacity building for relevant staff to develop and manage these tools.

Within the SERVIR programme, NASA has developed a susceptibility map for landslide prediction. The Landslide Hazard Assessment Situational Awareness (LHASA) tool utilises rainfall intensity measurement and a binary decision model to identify the regions that are the most at risk of landslides.[110]

The application provides information of landslides over 700,000km^2 and is applied mostly to **Central America** and the **Caribbean**, with pilot studies in Nepal and Peru.

106. Guerra J. 'Cuba risk reduction management centres, best practice in risk reduction'. 2010. www.preventionweb.net/publications/view/14963. Accessed April 2020.
107. Hossain F. 'Earth Science Satellite Applications: Current and Future Prospects'. 2016. www.springer.com/gp/book/9783319334363. Accessed April 2020.
108. European Space Agency (ESA). 'Earth Observation for a Transforming Asia and Pacific'. 2017. www.adb.org/publications/earth-observation-transforming-asia-pacific. Accessed April 2020.
109. Coward et al. '2019 Annual Report Tanzania Urban Resilience Program'. 2019. Accessed April 2020. documents.worldbank.org/curated/en/132061570739508217/pdf/Tanzania-Urban-Resilience-Program-Annual-Report-2019.pdf. Accessed May 2020.
110. NASA. 'Landslide Hazard Assessment for Situational Awareness (LHASA) Model'. gpm.nasa.gov/landslides/projects.html. Accessed April 2020.

The ultimate objective of LHASA is to provide a set of tools at the regional level to characterise areas of potential landslide hazard and improve situational awareness. The eventual aim is to improve emergency response and focus attention on the most affected areas.

The NASA SERVIR programme also developed applications for flood prevention in the **Hindu-Kush-Himalaya** region (HKH).[111] The database and spatial delineation of flood risk zones have been prepared for the region to support planning efforts but is not yet used operationally.

Disaster mitigation and infrastructure resilience

The mitigation of disastrous natural hazards is central to the protection of populations and infrastructure prior to an event. Decision makers and urban planners require solid information on the areas that are the most exposed to a given natural hazard. Although predicting a natural catastrophe is not always possible, the vulnerability of infrastructure and the location of populations is a known factor which governments can identify with geospatial data.

Satellite data can provide intelligence to mitigation measures

The southern provinces of **Laos** were hit by a severe typhoon in 2009, with more than 190,000 people affected. Two years later the country was hit in the north by two subsequent typhoons, which impacted ground stability and induced flooding and landslides. A project led by the United Nation Development Programme helped the government of Laos to generate a geospatial inventory of vulnerabilities and risks to infrastructure and populations. This intelligence leveraged decision-making for infrastructure resilience, mostly for transport infrastructure, in a timely and cost-effective manner to help mitigate future disaster events.[112]

In Nepal, vulnerability and flood hazard maps were developed to support urban planning and reduce losses of life and infrastructure. The maps include historical data on flood events, inundation maps, land cover and river networks.

While the practicality of the product from this earlier effort was limited by the cost of data, calibration and technical expertise[113], a further collaborative effort between the Nepalese government and the NASA-SERVIR team was undertaken in 2016 with more success. This effort established an online platform for disaster information and risk assessment, to inform decision making and investments for disaster mitigation and infrastructure resilience.

SIBELIUs: Improved resilience for Mongolian herding communities, eOsphere Limited, Mongolia

Approximately 30 per cent of Mongolia's population is dependent on livestock herding. However, extreme weather events (called dzuds), involving dry summers and very cold winters, are damaging the economy and farmers' livelihoods, as their livestock are killed in the extreme weather. These natural disasters, unique to Mongolia, have been increasing, exacerbated by climate change. The SIBELIUs project aims to support herding communities by increasing their resilience to dzuds. It is expected to reduce the number of herders affected and the economic losses from the disaster. While a large part of this project is looking at private insurance for herders in the face of disasters, it is also supporting the Mongolian Ministry of Food, Agriculture and Light Industry to better manage grazing reserves for the event of a disaster, by giving the government better information about the quality and location of pasture lands. Satellite information on environmental conditions will be used to examine grazing capacity, snow depth and the quality of the pastureland, thus creating a dzud risk map.

111. Kansakar P and Hossain F. 'A review of applications of satellite earth observation data for global societal benefit and stewardship of planet Earth'. www.sciencedirect.com/science/article/abs/pii/S0265964616300133'. 2016. Accessed April 2020.
112. Hossain et al. 'Earth Science Satellite Applications'. 2016. www.springer.com/gp/book/9783319334363. Accessed April 2020.
113. Same as above.

Disaster recovery and response

Information is a key resource in disaster recovery and response. Knowledge of the location, timing and extent of disasters gives emergency planners the intelligence necessary to allocate their resources, which are often limited in developing countries.

Space-based data have demonstrated significant potential to fill the gaps in information gathering after disasters. Local data acquisition on the ground is nearly impossible after a disaster because of critical damage to communications and transport infrastructure. Satellites orbiting overhead, on the other hand, are unaffected by such events and are the perfect source of resilient and ubiquitous data on disaster-hit areas. This intelligence can improve response times and optimise the allocation of resources, saving lives and reducing economic loss.

The International Charter Space and Major Disasters, a worldwide collaboration between space agencies, is one mechanism which provides satellite-derived data and products for disaster response. This unique initiative mobilises space agencies to support more efficient coordination of resources and expertise for rapid response in major disaster situations through a single access point, and at no cost to the user.[114] As of 26th March 2020, the Charter supported 646 activations across 126 countries, using data from 61 satellites.[115]

SatComms for natural disasters, Inmarsat, Philippines

The Philippines suffers over 20 cyclones annually, as well as frequent volcanic eruptions and earthquakes. It is highly experienced at responding to rapid onset disasters, but a key lesson from Typhoon Yolanda in 2013 was the ineffective deployment of crisis communications. This project transforms disaster responses by prepositioning powerful but easily deployable communications equipment in-situ, including Inmarsat's new Global Xpress (GX) satellite equipment. Rapid deployment at the disaster area will provide the national coordinating authority with the infrastructure to run national and local disaster response communications, at scale. This capability will reduce the adverse impacts of disasters and their adverse secondary effects, improve survivorship and lessen economic damage through reinstatement of basic facilities as rapidly as possible.

Satellite data can enable a better emergency response by providing data from above

In **Haiti** a location-based service (LBS) was deployed for survivors of a natural disaster. Through their mobile phones, survivors were able to send text messages to request help or report issues. NGO Ushahidi provided software to local authorities so that they could map these distress messages by location in real time and inform more effective emergency response.[116]

GNSS-enabled LBS data used in this way can increase the efficiency of search and rescue by providing the precise location of the caller or sender. This emergency system can also use data on the density and frequency of messages to help in allocating resources across the disaster area. Such improvement in the distribution of resources can be critical within the hours following a disaster: available resources are limited, so optimised allocation reduces fatalities and economic losses and aids speedier recovery.

---

114. The International Charter Space and Major Disasters. disasterscharter.org/web/guest/home. Accessed April 2020.
115. International Charter Space and Major Disasters. 'About the Charter'. disasterscharter.org/web/guest/about-the-charter. Accessed April 2020.
116. Parliamentary Office of Science and Technology. 'Resilience to Natural Hazard in Developing Nations'. 2012. http://researchbriefings.files.parliament.uk/documents/POST-PN-402/POST-PN-402.pdf. Accessed April 2020.

Another programme, SERVIR, created an international network of scientists and decision makers to collaborate on the use of EO data for disaster response. This network hub supports scientists to communicate and share data and technologies (including space applications) to support natural disaster mitigation and response. This network proved critical after a magnitude 7.3 earthquake struck **Nepal** in 2015[117], triggering a series of landslides and avalanches. A consortium of agencies and more than 80 volunteers collaborated to provide bespoke analysis for the earthquake response. Products included maps of the extent and magnitude of the impact, which were delivered to decision makers to support their disaster relief actions.

SatComms and other communications data can be valuable in identifying priorities after a natural hazard. A team of Chinese scientists has studied the pattern of mobile communications and location pings before and after an earthquake in **China**.[118] By assessing the extent of change in the volume of mobile data before and after the earthquake, they were able to identify the worst hit areas for communications, and those areas which had been rendered inaccessible. Moreover, areas with an increased volume of transmissions can be used to indicate an accumulation of people and therefore the need for creation of shelters and safe zones.

2.3.3 Key points: disaster resilience

- During the 1980-2015 period, natural disasters have affected an average of 169 million people per year, resulting in the loss of 50,000 lives per year and US$2.6 trillion in total economic damage over the period.
- Developing countries are more affected by disasters, due to their lack of preparedness, weak infrastructure and poor emergency response capability.
- IPP is supporting ten disaster resilience projects, and three of these support government policy decisions: Earth and Sea Observation System (Malaysia) by the Satellite Applications Catapult; Drought and Flood Mitigation Service (Ethiopia and Kenya) by Rheatech Group, and SIBELIUs: Improved resilience for Mongolian herding communities (Mongolia) by eOsphere Limited.
- The use of satellite data can enable greater preparedness, resilience and response, thereby increasing the survival and recovery rates of populations and economies in affected nations.
- Evidence shows that the use of EO in modelling for landslides, flooding and meteorology is effective at predicting events with great accuracy. In addition, SatComms are key in the trigger of alerts in remote areas.
- Mitigation and infrastructure resilience can benefit greatly from satellite applications, because of the wide range of applications in urban management that can support the identification of vulnerable buildings and populations.
- Finally, SatComms and EO can be used in unison to provide information on the location of affected populations and on roads that are unsafe for navigation. These data can be used to optimise response efforts.

117. Hossain et al. 'Earth Science Satellite Applications'. 2016. www.springer.com/gp/book/9783319334363. Accessed April 2020.
118. Chaoxu et al. 'Research on the application of mobile phone signal data in earthquake emergency work: A case study of Jiuzhaigou earthquake'. 2019. journals.plos.org/plosone/article?id=10.1371/journal.pone.0215361. Accessed April 2020.

2.4 Forestry

This section examines the evidence for satellite applications supporting the forestry policies of national governments.

Existing applications of space technology monitor the extent of forest loss, providing intelligence for policies that reduce deforestation and degradation. In this way, space-based data can help reduce carbon emissions, promote sustainable resource use, and maintain plant health.

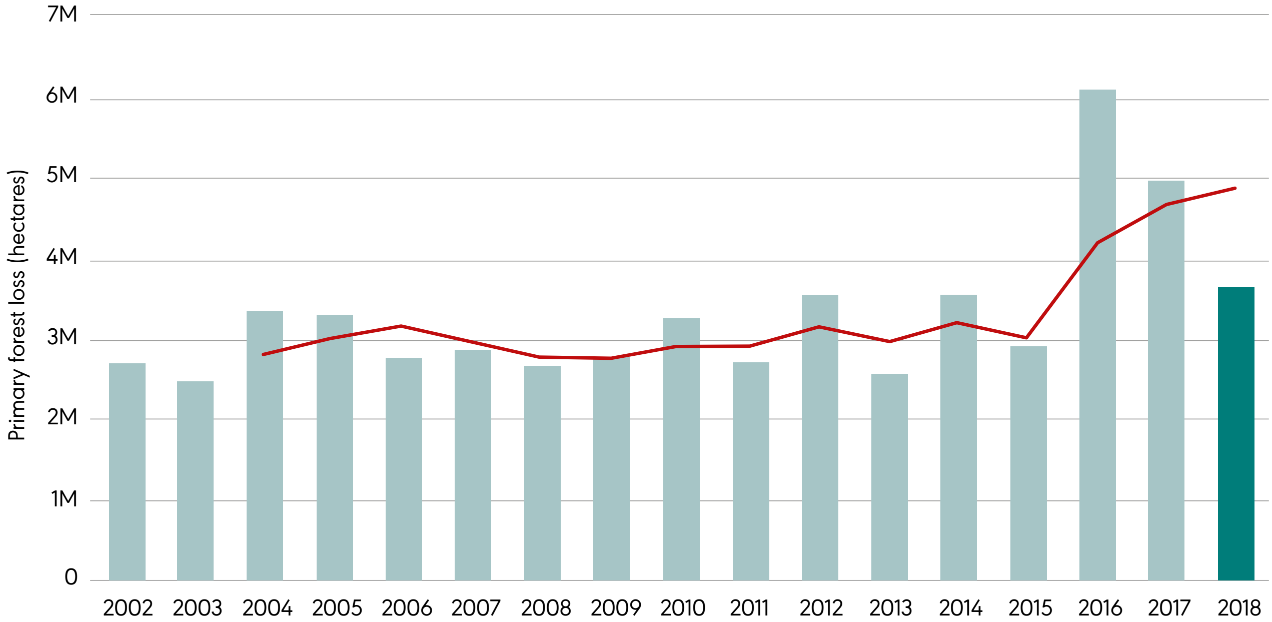
2.4.1 Introduction

Forests are valuable ecosystems that provide the air we breathe, timber for fuel and building material, and the raw material used in medicinal products. Forests are also important as a carbon sink[119] - 80 per cent of the Earth's above-ground terrestrial carbon and 40 per cent of below-ground terrestrial carbon is contained in forests.[120] Protection of the carbon sink is therefore important for climate change mitigation.

Despite their value, forests are increasingly under threat from encroachment due to increased economic development. This forest loss (as shown in Figure 9) has large implications for the environment, since it reduces the size of the carbon store. In order to sustainably utilise forest resources, a balance must be sought between the need for development and the maintenance of natural ecosystems.[121] Deforestation, degradation and logging for agricultural land, urban development and the production of commodities (like palm oil and timber) represent the main man-made threat to forests. Forest fires are also an increasing contributor to forest lost as climate change exacerbates the prevalence of extreme dry-weather spells.

119. World Wide Fund for Nature (WWF). 'The importance of forests cannot be underestimated'. wwf.panda.org/our_work/forests/importance_forests/. Accessed April 2020.
120. Forest Carbon Partnership Facility. 'What is REDD+'. www.forestcarbonpartnership.org/what-redd. Accessed April 2020.
121. Caribou Space. 'Space for Forestry in Developing Countries'. 2018. www.spacefordevelopment.org/wp-content/uploads/2018/11/6.4918_UKSA_Forestry-Report_WEB.pdf. Accessed April 2020.

Figure 9: Tropical primary forest loss, 2002-2018



Note: The red line marks the three-year moving average.
This may represent a more accurate picture of the data due to uncertainty in year-to-year comparisons.
Source: World Resources Institute

Given that forests have high value and are increasingly under threat, many international organisations, NGOs, forest agencies and governments are mandated to promote sustainable management of forests through reforestation programmes. These initiatives help maintain carbon sinks and mitigate climate change. The effectiveness of these interventions requires governments to understand the condition of existing forest resources.

Space solutions can inform intelligence-led policy to reduce forest loss, by providing cost-effective remote monitoring and mapping facilities to governments and forest authorities. Space solutions for the forestry sector have three main capabilities:[122]

- **Monitoring systems:** ensuring licensed forest stakeholders operate within defined boundaries, and using EO to monitor the rate of deforestation and degradation.
- **Mapping systems:** informing land use planning and mapping natural resources.
- **Decision support tools:** providing intelligence to governments to inform decisions on national reforestation and forest protection strategies. Understanding the trade-off between agricultural production and ecosystem conservation and finding the right balance.

122. Same as above.

Most evidence of existing applications of space technology demonstrate all three capabilities. Satellites can complement ground monitoring by offering increased capability to map conditions remotely, at regular intervals, and across large geographical areas. They can be used to pinpoint changes in forest cover and ecosystems so that ground monitoring can be more cost-effectively focused on areas of visible change ('hot spotting') or to provide monitoring of remote or inaccessible areas. For example, Sentinel 1 has a Synthetic Aperture Radar (SAR) sensor which can penetrate clouds and measure the height, shape and roughness of the surface. It can therefore be used to detect changes in forest cover and support decisions for policy makers. These capabilities can be used to support a number of impacts[123], including:

- **Detecting loss** of trees from storm damage or diseases. These events can be costly to tree stocks but if losses can be identified quickly, the timber resource can be recovered and utilised, reducing the value of losses.
- **Detecting illegal tree removal** such as logging. Enforcement of the rules can then be assisted by monitoring.
- **Enforcing afforestation (replanting) grants:** afforestation grants are sometimes subject to inspections to check that recipients have met requirements. Inspections could be performed remotely using satellite data, reducing the cost of inspections.

The following table presents the functions of space technology and evidence of use.

Table 5: Forestry: space applications for policy making

Application	Evidence of use
Reduce carbon emission	✓
Sustainable resource use	✓
Law enforcement	✓
Plant health	✓

Note: ✓ current evidences; (✓) future applications and/or pilot studies
Source: London Economics analysis

2.4.2 Evidence: forestry

Monitoring systems to reduce forest loss and carbon emissions

Deforestation and forest degradation are responsible for 11 per cent of global greenhouse gas emissions.[124] Mitigation of forest loss is therefore a key objective for climate change mitigation policy as well as ecosystem management, natural resource management and biodiversity policy. The evidence below concentrates on projects delivered through the UN's Reducing Emissions for Deforestation and Degradation (REDD) scheme, which focuses on reducing carbon emissions from forest loss and maintaining carbon stores.

123. Janusz S and Wilkinson S. 'The satellites that safeguards our forests'. 2017. defradigital.blog.gov.uk/2017/03/21/the-satellites-that-safeguard-our-forests/. Accessed April 2020.

124. UN-REDD. 'About Redd+'. www.unredd.net/about/what-is-redd-plus.html. Accessed April 2020.

Reducing Emissions for Deforestation and Forest Degradation (REDD)

The **UN Reducing Emission for Deforestation and [Forest] Degradation (UN-REDD)** is an international programme which supports projects to protect forests from deforestation and degradation. The programme is critical to the achievement of UN SDG 15 *"Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"*.[125] In the 10 years of the REDD programme, many projects have been implemented with broad impacts. Some are facilitated by the use of EO to map forests and support governments' intelligence-led solutions. It is recognised that robust and objective Measuring, Reporting and Verification (MRV) systems are needed in this field, and that satellite technology is the only way to regularly monitor forests given the geographical and time scales required.

A selection of projects which utilised space technology and were delivered through the REDD programme, are detailed below:

In **Indonesia**, peat mapping and monitoring was performed using satellite measurements.[126] As the largest natural carbon store, peatlands are valuable forestry ecosystems for global efforts to mitigate the effects of global warming. In 2015, large peat and forest fires in Indonesia emitted 16 million tonnes of CO_2 per day[127] and caused US$16 billion in economic losses. Since then, the Indonesian government has implemented numerous policies, informed by EO technology, to restore the level of peat. This includes enforcing new regulations, strengthening enforcement of illegal activity, and training citizens through the UN-REDD programme to improve decisions at the first response stage. In January 2016, Indonesia's national Peatland Restoration Agency was established to restore 2.4 million hectares of damaged peatland by 2020. It is supported by the UN Food and Agriculture Organisation (FAO), which provides satellite imagery and ground measurements of the peatlands to support emissions monitoring and management of the land.

The Mabira forest in **Uganda** is home to many endangered species and important resources which are threatened by forest loss. In particular, there is high demand for charcoal and firewood, and encroachment of agricultural land use for sugar cane plantations.[128] These pressures have contributed to one of the fastest rates of deforestation in the world. Forest cover was down to 9 per cent in 2019 compared to 24 percent in 1990. In response, the government launched a national REDD+ strategy in 2017 to maintain this valuable ecosystem and reduce carbon emissions. The FAO provides support for this strategy by providing open access software, SEPAL, which is a cloud-based EO platform to process and maintain geospatial forestry data. This allows the government to rapidly understand the extent of forest cover change and carbon stock of the forest, based on measurements of the height, diameter and density of forest cover. By replacing ground surveys and manual mapping, space solutions have improved the cost-effectiveness of monitoring and provided more accurate evidence for afforestation policies.

In **Panama**, tribes have been trained in the use of geospatial and EO technologies[129] to support management of forest resources, fires, and water sources, and to mitigate encroachment from logging or mining in indigenous areas. Surveillance occurs in areas where there is deforestation and degradation to the forests. It ensures mapping even during monsoon seasons where ground surveys are impossible. This data has informed decision making in the community and at the national level, and contributed to the achievement of a 10 per cent increase in carbon absorption by forests.[130]

---

125. United Nations (UN). 'Sustainable Development Goal 15'. sustainabledevelopment.un.org/sdg15. Accessed April 2020.
126. UN-REDD Programme. www.10year.un-redd.org/indonesia-peatlands. Accessed April 2020.
127. The International Union for Conservation of Nature (ICUN). 'Peatlands and climate change'. www.iucn.org/resources/issues-briefs/peatlands-and-climate-change. Accessed April 2020.
128. UN-REDD Programme. www.10year.un-redd.org/ugandamappingforests. Accessed April 2020.
129. UN-REDD Programme. www.10year.un-redd.org/panamas-indigenous-techs. Accessed April 2020.
130. Same as above.

In **Kenya**, REDD+, the Kenyan government and University of Leicester (UK) have collaborated to launch a mobile application, ForestSENTINEL[131] to map real time forest cover change using Sentinel satellite data[132], regardless of cloud cover. This application will be used by national and local bodies in Kenya to meet targets specified in the national REDD+ strategy. Specifically, the app sends a message to registered users to enable early intervention against illegal logging and promote afforestation.

In **DR Congo**, the Ministry of Environment has used EO maps of forest cover from the Satellite Observatory for the Forests of Central Africa (OSFAC) to inform the national REDD+ Strategy. For example, the Moabi Democratic Republic of the Congo[133] is a mapping initiative overseen by OSFAC which supports forest communities to conduct monitoring. It identifies activities which may encroach on forest ecosystems, such as oil and gas exploration, copper and iron mining and industrial agriculture.[134]

Forests 2020, Ecometrica, Brazil, Indonesia, Mexico, Colombia, Kenya, Ghana and Belize

This is a global project operating in seven developing countries. While EO is acknowledged as an effective data source for the monitoring and mapping of forests, this project develops methodologies to improve change detection, risk modelling and digital infrastructure to disseminate information more effectively. It is intended that new methods will improve forest monitoring at a national level and help to protect and restore up to 300 million hectares of tropical forest.

Peatland Assessment in SE Asia by Satellite, CGI IT UK Ltd, Indonesia and Malaysia

Peatland fires are extremely damaging. They cause degradation to an important ecosystem and large amounts of emissions, leading to deterioration of public health and climate change. In the absence of intervention, peat fire frequency is increasing, and efforts are required to maintain natural water levels in the peat and prioritise restoration of particularly damaged areas. It is recognised that satellite data can offer a cost-effective way to monitor peat conditions remotely. Sentinel (S-1, S-2 and S-3) data is useful for this project. A time series of S-1 data is incorporated into the inSAR technique, which can observe vertical displacement of peatland, a key indicator of how drained and degraded the peat is. These improved metrics, alongside other data on vegetation, hydrology and fire risk, allow for a complete characterisation and monitoring of the peat.

131. Copernicus masters. 'Forest Sentinel - App-Based Deforestation Alerts'. https://copernicus-masters.com/winner/forest-sentinel-app-based-deforestation-alerts/#. Accessed April 2020.
132. UK Research and Innovation. 'REDD+ Monitoring Services with Satellite Earth Observation - Community Forest Monitoring Pilot'. gtr.ukri.org/projects?ref=NE%2FN017021%2F1. Accessed April 2020.
133. Observations Satellite des Forests d'Afrique Centrale (OCFAC). 'Moabi DR Congo'. www.osfac.net/moabi-dr-congo. Accessed April 2020.
134. Moabi DRC. 'Competition for resources threatens REDD+ in DRC'. http://rdc.moabi.org/redd_risk/en/#9/0.3996/23.9502&layers=moabi_redd_projects,moabi_palm. Accessed April 2020.

Monitoring for sustainable resource management

Reducing the level of deforestation is crucial to ensuring sustainable supplies of timber for fuelwood, paper and building materials. However, communities near the forest are also dependent on many other forest resources, including water and biodiversity, which are key to the present and future needs of these communities. Sustainability of these resources can be achieved with an ecosystem approach that integrates the management of land, water and living resources and promotes conservation and sustainable management.[135] EO data can be used to visualise forest ecosystem services at local, regional and national scales by identifying tree coverage, infrastructure and land management practices, and can support optimal and sustainable management of forest resources across the supply chain by improving audits and verification at reduced cost.[136]

In **Liberia**, authorities have struggled to get an accurate assessment of the country's forest base.[137] In 2004, most of the existing forest maps were outdated or fragmented and could not provide a complete picture of the current forest inventory. A solution delivered by eoworld used Landsat imagery to provide comprehensive land use mapping and change detection for the whole forest area. As a result, the Liberian government now has an accurate assessment of deforestation trends.[138] By combining information from satellite imagery with population data, the scheme can identify the location of key natural resources relative to communities, supporting authorities to improve forest management and identify options for national land use reform.

Land use interventions, Vivid Economics, Peru

Peru has high rates of deforestation – 250,000 hectares per year - and three million people in rural poverty. Satellite tools are being used to help the government understand linkages and trade-offs between these two challenges. The main use for space is for high-resolution images from Copernicus Sentinel data, RapidEYE and SPOT satellites to be integrated into a land use inventory to classify and differentiate physical surfaces. In addition, economic information will be incorporated into the land use inventory to map land value and calculate the risk of exploitation. For example, Vivid has provided econometric analysis to price the value of a hectare of deforestation in terms of the impact it has on water turbidity and sediment levels in the water supply, and thus the costs of cleaning the water. They are hopeful that the Peruvian Ministry of Water will use this information to help price payment for environmental services and so slow deforestation. They have also helped to plot out land titles of (officially) landless farmers, to recognise their claims to land formally and issue legal land contracts. In this way, they have provided an actual tool to support the land registration law. 14 such contracts have been issued so far, and the process is anticipated to be expanded regionally and eventually nationally.

135. Convention on Biological Diversity. 'Ecosystem Approach'. www.cbd.int/ecosystem. Accessed April 2020.
136. Caribou Space. 'Space for Agriculture in Developing Countries'. 2018. www.spacefordevelopment.org/library/space-for-agriculture-in-developing-countries/. Accessed April 2020.
137. World Bank. 'High Above Earth, Satellites Help Direct Ground-Breaking Development Work'. 2013. www.worldbank.org/en/news/feature/2013/08/20/earth-observation-for-development-success-stories. Accessed April 2020.
138. World Bank. 'Liberia Forest Sector Project'. projects.worldbank.org/en/projects-operations/project-detail/P154114. Accessed April 2020.

The Satellite Monitoring for Forest Management[139] project (SMFM) is an international scheme directed by the World Bank that aims to develop EO solutions to mitigate challenges faced by forest ecosystems. It has an emphasis on tropical dry forest ecosystems, where the application of this technology is less studied and more challenging than for moist tropical forests[140] due to greater cloud cover and variability in rainfall. New EO methods will be developed for mapping and monitoring tools and facilities, and there will be knowledge exchange between key global stakeholders. Participants in the scheme include representatives from **Mozambique**, **Zambia** and **Kenyan** government agencies. Four tools have been developed to improve mapping and monitoring of forest ecosystems from the SMFM project:

- **Land cover and use mapping**[141]: Sentinel-2 data offers increased resolution, frequent revisit times and guaranteed data continuity, which makes it an attractive data source for future land cover monitoring.
- **Biomass estimation**[142]: Uses Advanced Land Observation Satellite[143] data to generate forest maps determining the level of coverage, vegetation class and changes, and estimation of biomass.
- **Deforestation and degradation mapping**[144]: Use Sentinel 1 and 2 data to map tropical dry forests, with more accurate identification of deforestation and degradation and therefore enforcement against illegal activities.
- **Deforestation and degradation type mapping**[145]: As well as identifying changes in land cover, this tool identifies causes and drivers behind land use cover.

Palm oil mapping in **Indonesia** and **Malaysia** uses optical and radar (including Sentinel) satellite data via the map service, Airbus Starling.[146] The service provides intelligence along the supply chain for companies to verify their commitments and improve sustainable production practices. For example, Nestlé used this data to verify that 77 per cent of its agricultural commodities are deforestation-free.[147]

---

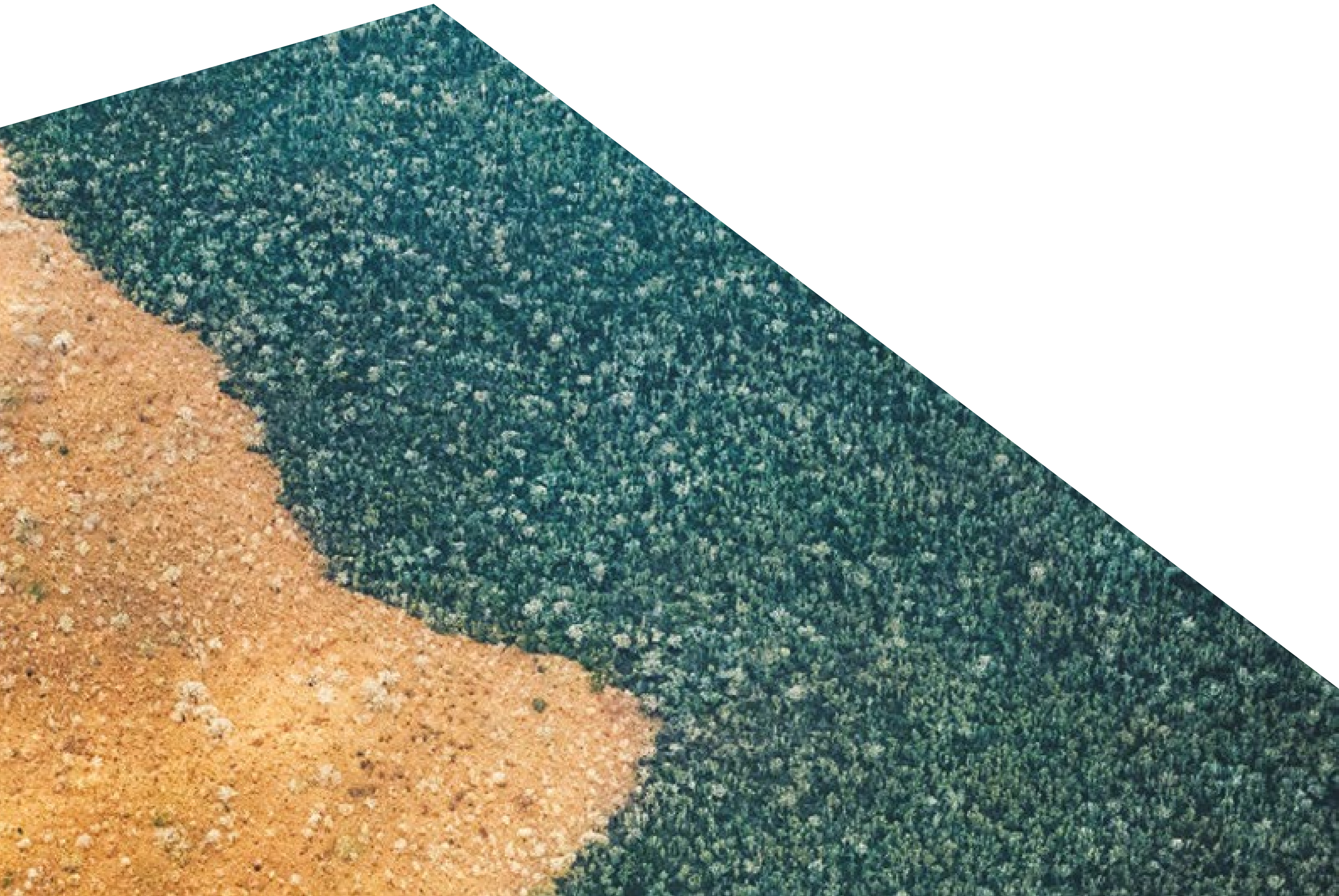
139. Satellite Monitoring for Forest Management (SMFM). 'About SMFM'. www.smfm-project.com/. Accessed April 2020.
140. LTS International. 'Satellite EO Design Report – Draft'. 2018. docs.wixstatic.com/ugd/6b4651_93baf6614a2142aba1dd45f9025a0def.pdf. Accessed April 2020.
141. Satellite Monitoring for Forest Management (SMFM). 'Activities for Land Cover/Use Mapping'. www.smfm-project.com/tool1ab. Accessed April 2020.
142. Satellite Monitoring for Forest Management (SMFM). 'Above-Ground Biomass Estimation'. www.smfm-project.com/tool2. Accessed April 2020.
143. Advanced Land Observing Satellite (ALOS), also called Daichi, is a 4-tonne Japanese satellite launched in 2006. After five years of service, the satellite lost power and ceased communication with Earth, but remains in orbit.
144. Satellite Monitoring for Forest Management (SMFM). 'Deforestation & Degradation Mapping'. www.smfm-project.com/tool3. Accessed April 2020.
145. Same as above.
146. European Space Agency (ESA). 'Copernicus Sentinel-2 helps put a halt to deforestation'. 2018. https://earth.esa.int/web/sentinel/news/-/article/copernicus-sentinel-2-helps-put-a-halt-to-deforestation. Accessed April 2020.
147. Nestlé. 'Nestlé verifies three-quarters of its supply chain as deforestation-free'. 2019. www.nestle.com/media/pressreleases/allpressreleases/nestle-three-quarters-supply-chain-deforestation-free. Accessed April 2020.

Deforestation Prevention, Vivid Economics, Côte d'Ivoire

Cote d'Ivoire has very high levels of rural poverty affecting more than half of the rural population, and high levels of deforestation as economic development increases. 80 per cent of the country's forests have been lost to degradation and deforestation. There is a clear need for better monitoring and sustainable use of forest resources to prevent total loss.

Three tools have been developed from the project: land use inventory, natural capital valuation (combining the land use survey with economic activity and value of production) and a forest disturbance early warning system. The project uses Copernicus Sentinel satellite data, offering high resolution images at regular frequency, and SPOT satellite data for particularly high-resolution images to inform these tools. The early warning systems will use a technique of rapid detection of forest disturbances, using time series from satellites.

The project is expected to have two main outcomes for policy. Firstly, improved monitoring and evaluation will prioritise afforestation and forest restoration. This will contribute to achieving 20 per cent national forest cover by 2030. In addition, more integrated support will be directed toward local economic development to help improve supply chain sustainability. This includes creating new markets that commercialise preservation activities, and developing deforestation-free production processes.



Monitoring for law enforcement

Forests cover large areas, and forest land ownership is often divided between areas with different deeds and stakeholders. Satellite imagery is a useful tool for authorities to monitor activities (such as logging and mining) across all boundaries, and assess where activities occur relative to ownership boundaries. Satellite imagery can complement ground surveys to verify whether enforcement action is required. If an activity is deemed to be illegal, the satellite data provides a robust evidence base to enforce legal requirements.

In **Brazil**, the Amazon Deforestation Satellite Monitoring Project generates yearly deforestation rates using high-resolution images from EO.[148] The Brazilian authorities use these images to assess deforestation levels and work with local authorities to prohibit illegal activities. Enforcement is also assisted by space technology from the Brazilian National Institute of Space Research (INPE).[149] This institution tracks the rate of deforestation in the Amazon and an alert is generated when more than three hectares of cleared land is detected, guiding law enforcement to the forestry activities taking place and their location.

In **Finland**, Terramonitor, partially funded by the Finnish government, is a map service that uses AI and EO to provide forest resource management and law enforcement support for the government.[150] Copernicus Sentinel 2 satellite data is used to detect and monitor forest activity, such as logging and infrastructure changes, as well as the status of vegetation. It gives updated information on logging in Finland's forests, so optimising resource use and the efficiency of the forestry sector. The project has also been developed within the Finnish Government's 'logging detection' remit, and will also support effective law enforcement in this area. In the absence of the tool, the government relied on forest declarations and field inspections from a sample. However, the implementation of satellite data means that law enforcement can be performed remotely for the whole area as opposed to select samples, with accurate evidence.

Monitoring for plant health

Alongside preventing forest loss, satellite data can also identify changes in the quality of forest ecosystems using measures of tree height and count, area coverage and wood volume. Change detection through space technology can also help detect signs of deteriorating plant health. Early detection provides time for early action to contain degradation and limit loss.

In **Portugal**, 'MAPP.it' is a service provided by Portuguese company Spinworks to improve resource management in forestry and agriculture, and to provide early detection of disease and pests.[151] It has been used to monitor disease transmission in cork oak forests.[152] Early detection of diseases provides time to implement early action policies that can reduce the impact of a crisis. High temporal and spatial resolution are achieved by combining five-day Sentinel 2 data with 5cm drone data. Other insights this service provides include the creation of management zones based on intra-plot variability, detecting and locating crop gaps, and guiding treatments for diseases or pests. These insights improve the efficient use of inputs including herbicides and pesticides, as well as reducing loss and increasing yields.[153]

---

148. Escobar H. 'Deforestation in the Amazon is shooting up, but Brazil's president calls the data 'a lie'. 2019. www.sciencemag.org/news/2019/07/deforestation-amazon-shooting-brazil-s-president-calls-data-lie. Accessed April 2020.
149. Same as above.
150. European Space Agency (ESA). 'Copernicus Sentinel-2 helps put a halt to deforestation'. 2018. https://earth.esa.int/web/sentinel/news/-/article/copernicus-sentinel-2-helps-put-a-halt-to-deforestation. Accessed April 2020.
151. Same as above.
152. MAPP. 'Cork Oak'. mapp.it/cork-oak/. Accessed April 2020.
153. Spinworks. 'How to improve resource efficiency in agriculture by early detection of diseases and pests using Copernicus data'. www.slideshare.net/EU_GNSS/spinworks-how-to-improve-resource-efficiency-in-agriculture-by-early-detection-of-diseases-and-pests-using-copernicus-data-joo-arajo-spinworks. Accessed April 2020.

2.4.3 Key points: forestry

- Humanity depends on forest resources and peatland ecosystems. As the largest natural carbon store, they are crucial for climate change mitigation.
- Despite their importance, degradation and deforestation are threatening forest ecosystems, and increasing carbon emissions. These activities are predicted to increase as a result of economic development and the encroachment of agricultural land.
- Reducing the level of forest loss is an important aim for policy to mitigate climate change, manage the limited supply of forest resources and maintain plant health. Afforestation, training first responders to fight fires, and increasing the level of enforcement are some examples of policies that are achieving this aim.
- IPP is supporting five forestry projects, each of which support more effective action by government and forestry authorities: EASOS by Satellite Applications Catapult (Malaysia); Forests 2020 (Brazil, Indonesia, Mexico, Colombia, Kenya, Ghana and Belize) by Ecometrica; Peatland Assessment in SE Asia by Satellite (Indonesia and Malaysia) by CGI IT UK Ltd; Land use interventions (Peru) by Vivid Economics, and Deforestation Prevention (Ivory Coast) by Vivid Economics.
- Satellite imagery provides accurate, cost-effective surveillance and monitoring. This technology is especially effective in geographically isolated, covered areas or areas facing extreme weather, where ground surveys are difficult or expensive to perform. Additionally, the imagery is produced at frequent intervals so that changes to land coverage can be monitored and detected quickly. Forests cover large areas, sometimes across national borders. This means that ground surveys can result in fragmented mapping. EO data and specific methodologies developed for its use can mosaic maps together so that the whole forest area can be mapped cost-effectively.
- Evidence shows that satellite imagery is being used to inform a range of national policies. The REDD initiative, overseen by the UN, is developing national strategies to mitigate carbon emissions from deforestation and degradation of the forests. To sustainably manage resources throughout the supply chain, satellite imagery performs mapping which informs policymakers of the priority areas to be targeted in reforestation policies. To reduce illegal activity in the forests, strict enforcement is required. Satellite imagery supports this by providing change detection and an accurate evidence base to legitimise any prosecutions. Moreover, the early detection of pests can prevent wide-scale reduction in plant health.

2.5 Urban and transport

This chapter presents evidence of how satellite technologies are used to support urban and transport policy. Pilot studies for future applications are also detailed in the second half of this chapter.

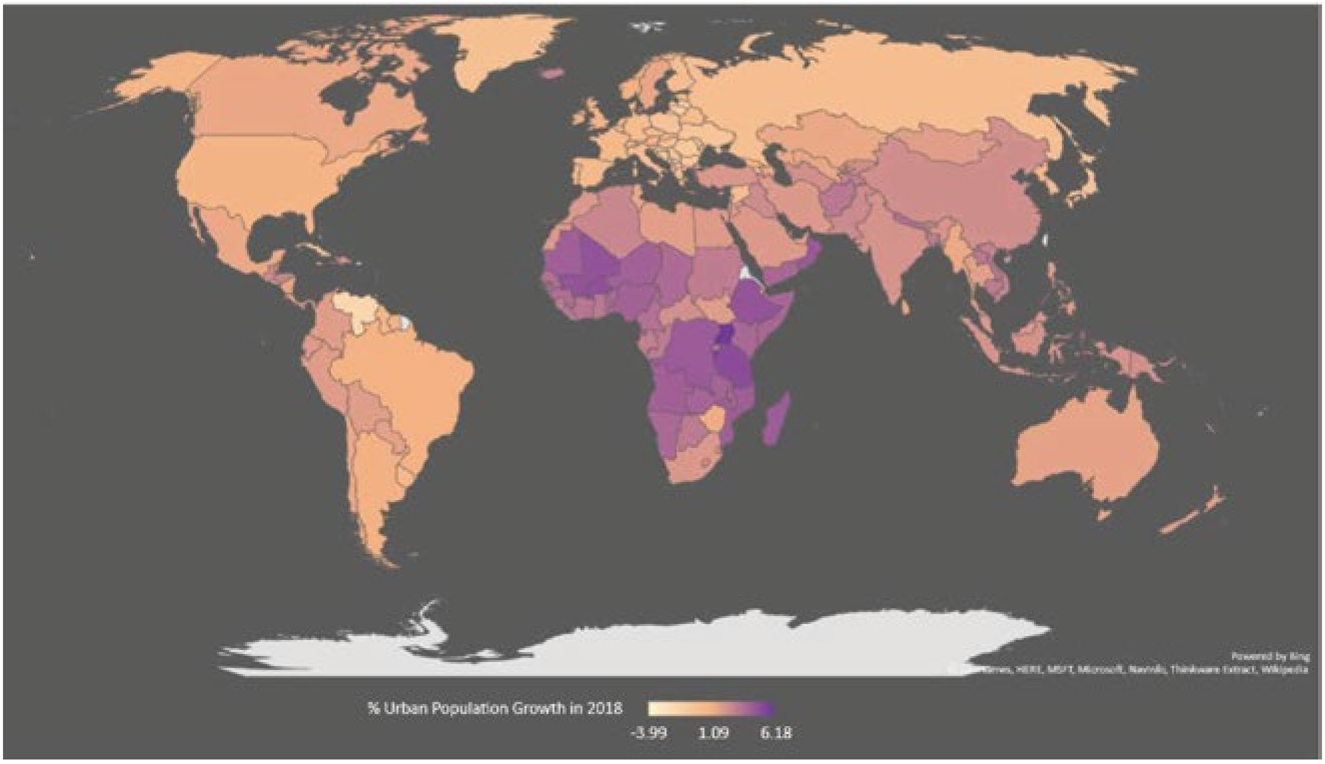
2.5.1 Introduction

Urbanisation is at the heart of many socio-economic challenges of the coming decades. Whilst the growth rate of the urban population is globally decreasing over time (+2.6 per cent in 1968 as against +1.9 per cent 50 years later)[154], it is unevenly distributed around the world, and most developing countries still face strong urban population growth. Data from 2018 shows that the strongest growth will happen in Africa, the Middle East and Asia (See Figure 10).

The growth of urban population comes with numerous challenges to the organisation and management of cities. The concentration of people in unplanned or undeveloped sprawls results in slums where there is a deficit of security, health, power generation and access to clean water.

By 2050, the UN estimates that the urban population will reach nearly 70 per cent of global population.[155] Such a transformation will exacerbate the challenges for city councils and governments. It can only be managed with land use and land cover policies that account for the growing and future demand for urbanisation. To achieve this, policy makers must have accurate access to data on land use and land cover change, as well as accurate predictions for how these might change over time.

Figure 10: World's urban population growth (2018)



Source: World Resources Institute

154. World Bank. 'Urban population growth'. 2018. data.worldbank.org/indicator/SP.URB.GROW. Accessed April 2020.
155. United Nations (UN). '68% of the world population projected to live in urban areas by 2050, says UN'. 2018. www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html. Accessed April 2020.

Data collection in the developing world is costly and usually inconsistent.[156] For example, addresses do not always exist, rendering data harmonisation and traceability difficult and expensive. Ownership often relies on tacit knowledge and agreements, and dedicated teams in government do not always have access to affordable tools. This makes urban planning costly and inefficient.

Satellite technologies can play a pivotal role in data collection and modelling to inform urban development and transportation policy in the developing world. They provide timely, accurate and continuous spatial data that is affordable and scalable to developing countries.[157] For instance, EO data and applications can accurately identify housing and urban growth over time.[158] These applications help us understand how cities develop, and can provide decision makers with precise information on the accessibility, size, ownership and distribution of the urban landscape.[159]

Nevertheless, EO technologies are also associated with technical challenges. The transformation of data into information is a critical step and requires advanced computing skills. Technical experts must understand needs, and be able to deliver a solution that policymakers can use with limited knowledge.

In addition, there is often a gap between research projects and the direct applications that governments and companies involved in a project need to address.[100] This gap must be filled by bridging the needs of policy makers to the skills of service providers. Capacity building, education and training are therefore critical to the use of space-based applications in government.

Analysis of the literature provides evidence on how space applications can support urban and transport policy in the developing world. The literature also presents pilot studies which indicate potential future applications. At a high level, these applications can be classified under three categories:

- **Investment and urban planning:** the development of urban areas requires strategic planning and investment. Ex-ante analysis at the planning stage needs information about the landscape and urban growth in order to optimise resource allocation. This information can be provided by converting data from Sentinel or Landsat satellites into urban information. For example, modern cities have developed models to prioritise areas for development such as housing and preservation (green and public spaces).[160] Such applications could be transferred to developing countries.
- **Transport and critical infrastructures:** with the expansion of urban centres and the growth of the urban population comes the need for optimised transport networks and distribution of critical infrastructure. Knowledge of the expansion of a city and the location of existing assets and infrastructures are key to the identification of gaps. Spatial analyses can be used to support decisions on the location of public services and other infrastructure, energy grids and safety for instance, in response to projected demand.
- **Cadastre inventories and land taxation:** urban planning and land-based taxation (often a key source of revenues for governments in developing countries) require an understanding of the location, dimensions and ownership of land parcels and property in a city. These records help identify the rights, restrictions and responsibilities

156. Musakwa and van Nikerk. 'Earth Observation for Sustainable Urban Planning in Developing Countries: Needs, Trends, and Future Directions'. 2014. journals.sagepub.com/doi/abs/10.1177/0885412214557817. Accessed April 2020.
157. Netzband et al. 'Applied Remote Sensing for Urban Planning, Governance and Sustainability'. 2007. www.springer.com/gp/book/9783540255468. Accessed April 2020.
158. Almazouri et al. 'Application of Landsat Data for Urban Growth Monitoring in Jeddah'. 2017. www.researchgate.net/publication/321396724_Application_of_Landsat_Data_for_Urban_Growth_Monitoring_in_Jeddah. Accessed April 2020.
159. NASA. 'Urban Growth Archive'. landsat.gsfc.nasa.gov/category/news/urban_growth/. Accessed April 2020.
160. Cook. 'Landscape structure indices for assessing urban ecological networks'. 2002. www.sciencedirect.com/science/article/abs/pii/S0169204601002262. Accessed April 2020.

of landowners. They can also be used to inform dispute resolutions between land users and city authorities and to underpin decisions on urban planning. This type of land and property information is often inaccurate, out of date and poorly maintained in rapidly developing environments, such as in developing world cities that face increasing urbanisation. Accurate and up-to-date cadastre information can enhance the revenue collection and development capacity of governments in the developing world.

To implement socio-economic reforms and address urbanisation challenges faced by the developing world, it is necessary to feed governments and NGOs with the tools and data for geospatial analytics. Public investment and the planning of the urban landscape rely on extended knowledge of cities and their urban composition (including population characteristics and geospatial distribution). Traditional, often more manual, forms of data collection (e.g. population and housing censuses) are expensive and time-consuming to undertake. The large time interval between data points makes it harder for city authorities to respond to rapid changes in urbanisation and development. Satellites can provide urban intelligence that is both cheaper and more readily obtainable. For example:

– **Satellite-derived imagery (EO)** can be used to classify the urban landscape and detect change;

– **SatComms data on broadband** usage can be used to identify population activity and infrastructure needs;

– **Location data (GNSS)** can be combined with both of these sources of data (imagery and SatComms) to pinpoint where this activity or change is occurring.

Space applications can therefore support proactive urban management and enable better decision making for urban policies on transportation, resource efficiency, public services, building applications and land-based taxation.

The table below summarises the key policy segments that could benefit from satellite technology in the developing world.

Table 6: Urban and transport: space applications for policy making

Function	Evidence of use
Investment and urban planning	✓
Transport and critical infrastructure planning and resilience	✓
Cadastre inventory and land taxation	✓

Note: ✓ current evidence; (✓) future applications and/or pilot studies
Source: London Economics analysis

2.5.2 Evidence: urban and transport

Investment and urban planning

Uncontrolled growth in cities has several implications for citizens. The provision of quality housing is unequal, and public services such as water and sanitation are not always available in the unplanned and informal settlements that result from rapid urbanisation.[161] The socio-economic impacts of uncontrolled urban development are negative and include physical disorder, inefficient land utilisation, environmental degradation, pollution risks and poorer living standards for households.[162]

These negative impacts can be mitigated with resilient urban and financial planning that is informed by satellite data.[163,164]

Satellite data supports investments and urban planning

In **Ghana**, local authorities supported by the World Bank have developed **a street naming and property addressing system** for Accra, using satellite data.[165] A formal address system was previously non-existent. Addresses instead relied on the knowledge of locals, resulting in system failures such as inefficient delivery and navigation, and unreliable public services.

Together with the planning department and local citizens, the World Bank used satellite imagery to produce up-to-date maps of the city of Accra and (re)name all the streets. As a result, more than 3,700 streets signs have been erected to facilitate navigation and planning.

This newly available reference system allows for improved navigation and emergency response, better-informed urban planning and increased revenue generation.

In **Uzbekistan**, GAF AG has developed an EO-based service which aims at supporting the **development of residential construction**.[166] The project contributed to the Housing for Integrated Rural Development Improvement programme by analysing the suitability of construction sites, progress monitoring of housing construction projects, and facilitating ex-post impact assessments of wellbeing and economic activity in new residential projects.

The project team developed two types of products: classification (for identifying suitable sites for construction) and change maps (for monitoring construction activity and the impact of new residential areas). The classification maps were based on Pleiades and SPOT satellite data, and were used to design a historical baseline of land use

161. Jason W. 'Sustainable Development: Slums, Informal Settlements, and the Role of Land Policy'. 2018. www.lincolninst.edu/publications/articles/sustainable-development. Accessed April 2020.
162. Hitayezu et al. 'The dynamics of unplanned settlements in the City of Kigali'. 2018. www.theigc.org/wp-content/uploads/2019/02/Hitayezu-et-al-2018-final-report-v2.pdf. Accessed April 2020.
163. World Bank. 'Geospatial Technology and Information for Development'. 2019. www.worldbank.org/en/topic/land/brief/geospatial-technology-and-information-for-development. Accessed April 2020.
164. Hossain et al. 'Earth Science Satellite Applications'. 2016. www.springer.com/gp/book/9783319334363. Accessed April 2020.
165. Pott. 'A road by any other name: street naming and property addressing system in Accra, Ghana'. 2017. blogs.worldbank.org/sustainablecities/road-any-other-name-street-naming-and-property-addressing-system-accra-ghana. Accessed April 2020.
166. European Space Agency (ESA). 'Earth Observation for a Transforming Asia and Pacific'. 2017. www.adb.org/publications/earth-observation-transforming-asia-pacific. Accessed April 2020.

in the Tashkent area. The change maps result from comparison of the classification maps and highlight change over time. The changes detected serve as a basis for focusing investment for future residential construction sites.

In **Armenia**, Starlab Space developed tools and maps to create a **priority list of urban investment projects** as part of a collaboration between the Asian Development Bank (ADB) and the European Space Agency (ESA).[167] They too include classification and change maps. They are supplied to local municipalities to give them additional information to help them prioritise funding for urbanisation projects. Such tools will ensure that funding is targeted at projects that maximise socio-economic and sustainable development outcomes.

The analysis was provided to four cities in Armenia, and allowed comparative analysis between them. The pace and direction of urbanisation and the degree of land consumption were compared, and the identified similarities and differences helped characterise different forms of urban development. Ultimately, this data can be used to mitigate uncontrolled urban sprawl in fast-developing cities.

The city of **Johannesburg**, South Africa, launched the **Spatial Development Framework 2040**[168](SDF) in 2016. Its objectives were to fight spatial inequalities and address the challenges posed by rapid urban development - pressure on the natural environment, urban sprawl, spatial inequalities, exclusion and disconnection, and inefficient residential densities and land use - by targeting urban investment.

The SDF policy document identified challenges and opportunities for Johannesburg. For example, EO data and GIS analysis identified multiple spatial inequalities, including place-based poverty, job-housing mismatch, spatial disconnection, pedestrian accessibility, and land use. This data informed city planners and helped officials prepare targeted development options for the future.

In **Indonesia**, the World Bank helps the government to design its urban development strategy with the help of EO data. With the **MIT City Form Lab**[169], the World Bank is setting up City Plan Labs (CPL) in four major Indonesian cities. The focus is on supporting customised strategies for **urban development and real-estate resilience** to help cities achieve sustainable and inclusive economic growth.[170] This project focused on building the capacity of city governments to use evidenced-based spatial planning in decision-making. After raising awareness at the government level and developing geospatial analytics skills, the CPL developed an online platform for GIS data and analysis in Indonesia. Pilot studies are now being undertaken with this data, and housing has been selected as a priority topic.

The use of EO data for urban development and planning is growing in the developing world more broadly through support by foreign aid and international agency programmes (e.g. ESA EO4SD[171] and EO4SD-Urban Development[172] and NASA SERVIR[173]). The AfricaGEOSS[174] framework, for instance, is led by the Group on Earth Observation and comprises 27 countries and 10 regional institutions in Africa. The global objective is to develop the uptake of EO technologies in African countries to improve their socio-economic development.[175]

167. Starlab Space. 'Space Applications in Support of Future urban development in Armenia'. 2015. https://www.unece.org/fileadmin/DAM/hlm/prgm/urbandevt/Measuring_Progress__Achieving_Smarter_Cities_/Presentations/Star2Earth_Lisboa_2015_V2.pdf. Accessed May 2020.
168. City of Johannesburg. 'Spatial Development Framework 2040'. 2016. www.joburg.org.za/documents_/Pages/Key%20Documents/policies/Development%20Planning%20%EF%BC%86%20Urban%20Management/Citywide%20Spatial%20Policies/Spatial-Development-Framework-2040.aspx. Accessed April 2020.
169. MIT Department of Urban Studies and Planning. 'City Form Lab'. 2019. dusp.mit.edu/project/city-form-lab. Accessed April 2020.
170. City Form Lab. 'Indonesia City Planning Labs'. http://cityform.mit.edu/projects/city-planning-labs. Accessed April 2020.
171. The Committee on Earth Observation Satellites (CEOS). 'The Earth Observation Handbook'. 2018. http://eohandbook.com/sdg/part2_8.html. Accessed April 2020.
172. EO4SD. 'Earth Observation for Sustainable Development'. d568aaed-1259-40b9-b155-6b90f843ebdb.filesusr.com/ugd/3b0000_a7a31c0fa5b74a2d91dec8a74ff2feb2.pdf. Accessed April 2020.
173. NASA. 'SERVIR'. www.nasa.gov/mission_pages/servir/index.html. Accessed April 2020.
174. Group on Earth Observation (GEO). 'Strengthening the use of Earth Observations and bringing GEOSS to Africa'. 2017. www.earthobservations.org/documents/publications/201705_AfriGEOSS_brochure.pdf. Accessed April 2020.
175. Group on Earth Observation (GEO). 'AfriGEOSS: Reinforcing Regional African Engagement'. www.earthobservations.org/activity.php?id=106. Accessed April 2020.

Transport and critical infrastructure planning and resilience

In most large cities in the developing world, congestion poses a range of threats to society. Disorganised services and the uncontrollable growth of needs for transport create chaos in highly populated cities.[176]

This congestion reduces the mobility of workers, decreases economic productivity, and increases the commuting time of citizens, with negative implications for physical and mental health and for climate change.

Heavy rains and temperatures directly affect the state of the roads in some environments, while earthquakes and landslides can contribute to the deterioration of this infrastructure. This creates added expense for low-income countries.

Earth Observation and GNSS data can revolutionise transport networks and infrastructures in developing cities

In four Asian countries **(Azerbaijan, Pakistan, Federal State of Micronesia and Fiji)**, information from satellite imagery was provided as a key enabler of the Global Transport Intelligence project, whose objective is to develop a reliable and sustainable transportation network in Asian cities. With remotely sensed data, decision makers have access to better information on the distribution of transport infrastructure and its limitations.

Very high-resolution (0.5m) data was used to detect roads, railways, ports and airports. Historical data from 2005 and 2012 was used to monitor the impact of public investment on transport networks and to study urban transformation. In addition, population growth was estimated using satellite imagery. This information is valuable for urban planners, in particular when designing public transport networks and allocating funding. Finally, GNSS-enabled AIS (ship tracking) data was used to identify coastal approach patterns.

In **Papua New Guinea** satellite imagery was used to assess the resilience of transport infrastructure as the government launched a national strategy plan to boost the development of transport connectivity on land, water and in the air. The objective of the ESA-supported project[109] was to identify transport networks vulnerable to climate change. Intensification of rainfall and temperature have an impact on the resilience of roads, and their deterioration is a threat to safety and economic activity.

Cell phone data records (CDRs) have been tested as a basis for transport network planning. The mapping of cell phone use and their location data (provided through GNSS, for example) can be used to determine traffic patterns in cities. In **Haiti** for instance, CDR and machine learning techniques were used to identify the most common traffic patterns as well as the transport network's vulnerability to flooding. This information was used to plan the city's transport infrastructure.[177]

A study carried out by the World Bank successfully identified traffic patterns and congestion hotspots, and revealed that 42 per cent of workers in Port-au-Prince travelled for more than one hour per day on average. Although no actions have been reported so far, the decision makers now have the intelligence to improve traffic in city centres.

A similar study conducted in **Sri Lanka**[178] shows how CDR data from mobile operators, and real-time GNSS traces from mobile phones, can identify traffic patterns and activity hubs in city centres. The study showed that this information could help city planners revolutionise the transport networks and infrastructures of the developing world. CDR data have strategic advantages compared to traditional methods of traffic data collection. They are easy to access, are much more affordable than other data, and they enable tracking of agents for a given period of time.

---

176. Masood et al. 'Transportation Problems in Developing Countries Pakistan: A Case-in-Point'. 2011. https://www.researchgate.net/publication/266469087_Transportation_Problems_in_Developing_Countries_Pakistan_A_Case-in-Point. Accessed April 2020.
177. Gorham and Sethi. 'Mobility constraints undermine the potential of Haitian cities'. 2018. blogs.worldbank.org/transport/mobility-constraints-undermine-potential-haitian-cities. Accessed April 2020.
178. Lokanathan et al. 'The Potential of Mobile Network Big Data as a Tool in Colombo's Transportation and Urban Planning'. 2016. itidjournal.org/index.php/itid/article/view/1506. Accessed April 2020.

Cadastre inventory and land taxation

It is essential for governments to maintain an up-to-date and accurate registry to support effective land administration.[179] But in developing countries, cadastral registries are outdated and inconsistent, resulting in inefficient tax collection, imperfect credit systems and uncontrolled urban sprawl.

Identifying cadastre and land ownership with satellites can increase the wealth of cities and optimise tax collection.

Property database for Dakar City, Airbus Defence and Space, Senegal

Many cities in the developing world lack the resources to collect and maintain the information they need to calculate property taxes. Within the UK Space Agency's IPP, Airbus UK has developed a solution that could **map areas of property change** in Dakar, Senegal.

Airbus Defence and Space has developed a solution using high-resolution Pleiades satellite data to detect changes in land and building characteristics and produce a parcel reference map. The application allowed local authorities to detect new buildings and changes in existing structures, and to build a database that is updated on a regular basis to monitor future changes and address land property issues. This database was later used to assign property rights and valuation methods, and helped improve tax collection in Dakar. Analysis by Airbus suggests that the new system has the potential to support generation of around €73 million in annual **tax revenue** for Dakar.

In **Kosovo**, the World Bank-funded Real Estate and Geospatial Infrastructure Project[180] was initiated to **increase the quality and availability of land administration data** in the country. The project helped the relevant government agency to modernise the cadastre system and secure property rights and improve the business environment in the entire country.

Resulting products included a systematic update of the cadastral and registration record, the development of the Kosovo Cadastre Land Information System and the development of the national spatial data infrastructure.

In addition, Kosovo's Geoportal was established to consolidate the information on land and property. It has since made publicly available and has helped improve the efficiency of the property market. Access to land property information for all citizens has eased the property transaction process and consequently improved access to credit.[181]

The availability and quality of data is increasing worldwide, and new space missions generate near real time data. This enables an increasing number of opportunities for land use and cadastre inventories, and for land value applications derived from them. The application of data in the urban environment is still evolving. But pilot projects have already proven the capabilities of space applications for land administration and governance in the developing world.[182]

179. Ali et al. 'Using satellite imagery to revolutionize creation of tax maps and local revenue collection'. 2018. http://documents.worldbank.org/curated/en/347231526042692012/Using-satellite-imagery-to-revolutionize-creation-of-tax-maps-and-local-revenue-collection. Accessed April 2020.

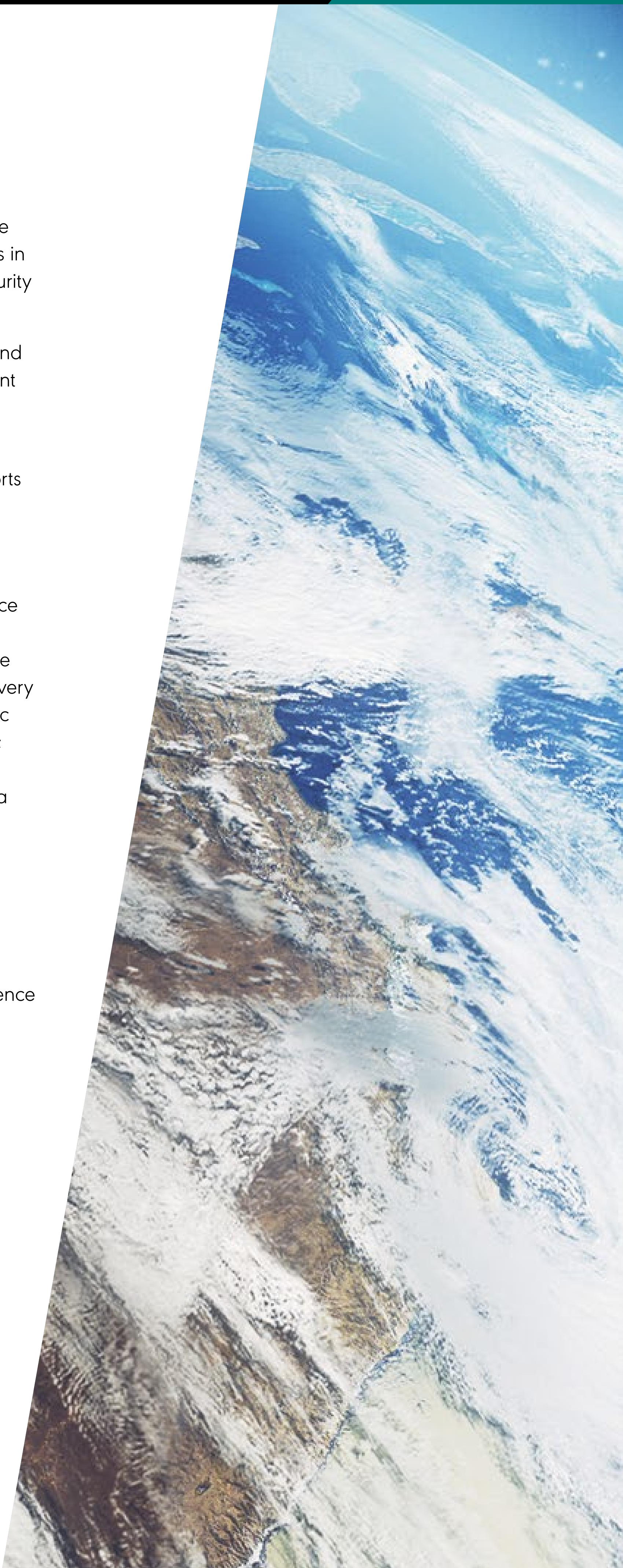
180. World Bank. 'World Bank Supports Improvement of Cadastre Data and Services in Kosovo'. 2018. www.worldbank.org/en/news/press-release/2018/12/18/kosovo-cadaster-data-and-services-to-improve-with-world-bank-support. Accessed April 2020.

181. World Bank. 'Implementation Completion and Results Report'. 2018. http://documents.worldbank.org/curated/en/492691546544351443/pdf/icr00004393-12282018-636818041783772397.pdf. Accessed April 2020.

182. Deininger et al. 'Innovations in Land Rights Recognition, Administration and Governance'. 2010. ideas.repec.org/b/wbk/wbpubs/2519.html. Accessed April 2020.

2.5.3 Key findings: urban and transport

- The rapid growth of the urban population in the developing world comes with major challenges in the management of urban sprawl and the security and safety of the population.
- In these fast-expanding cities, census records and other socio-economic data are often inconsistent and outdated. Traditional methods of data collection are costly and take a long time.
- IPP supports one urban project that also supports decision-making by government and urban authorities: Property database for Dakar City (Senegal) by Airbus Defence and Space.
- Satellite technologies are a powerful data source for governments that need to inform urban planning and update property databases in the face of rapid urban change. EO technology is very useful for land use and change detection; traffic data can be used to detect hotspots of activity; and location data enables intelligence to be derived from other types of data by providing a universal geographic reference system.
- Satellite data supports investment and urban planning, via land use change monitoring and priority mapping.
- Superimposing geographic imagery from EO and traffic density from GNSS provides intelligence for traffic management and infrastructure planning. This is invaluable as cities undergo rapid urbanisation
- Identifying cadastre and land ownership with satellite data can optimise tax collection and therefore the development capacity of city authorities.



3 Conclusions and recommendations

This study has assessed the use of space technologies as a tool for supporting government policy decisions in the developing world. The findings of this report relate to the specific scope of the five areas of government policy studied. Other potential uses of value in other areas of government policy are not considered in this study.

In general, this study finds a number of cases where space technologies are used to support a more effective policy process – from problem identification to formulation, implementation and evaluation – and a number of other instances where their potential is only now being explored.

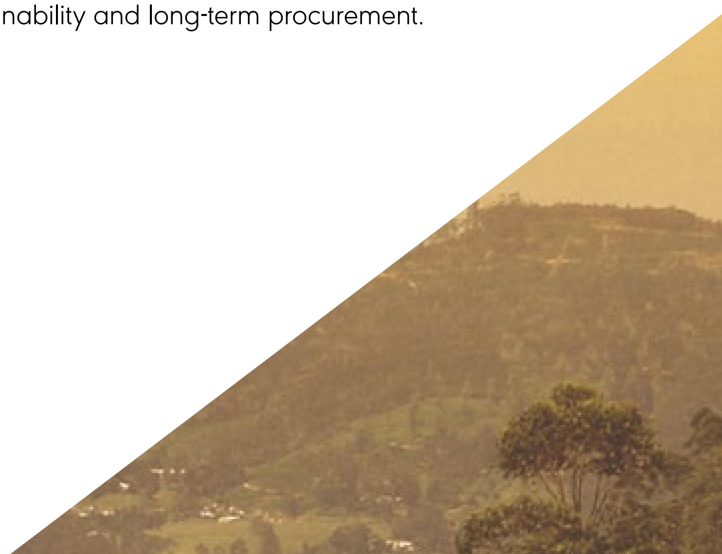
A common theme is that the automated, repeatable, consistent, objective, analysis-ready and wide-area coverage of space technologies means that they are well placed to provide intelligence on a range of economic and environmental activities. Changes, patterns and concentrations of activity can be monitored at a distance, and at lower cost than with more manual or terrestrial methods of data collection. These advantages are critical to developing country governments in the context of significant budget constraints, higher levels of demand, increasing global pressures and growing public scrutiny.

Nevertheless, this study has also found that space technologies face challenges that limit their uptake by developing world governments.

The first set of challenges concerns government capacity. At a fundamental level, governments in the developed and developing world alike often lack the expertise to understand the value of space technologies. Where it is understood, funding pressures make it difficult for officials to produce space solutions and access paid-for products and services from industry. The combination of these budgetary constraints and skills shortages makes it difficult for government departments and agencies to extract value from space data.

While these technical capabilities exist within industry, technical experts must be able to understand user needs and deliver a procurable solution that policy makers can use with limited knowledge. This gap can be filled by bridging the needs of policy makers to the skills of service providers through engagement, capacity building, education and training. User-led, rather than technology-push, solutions are inevitably more successful.

Another observation is the wide gap between the large number of donor-funded solutions that have been piloted, and the much smaller number of long-term solutions that are used on a fully operational basis. The test and fail-fast nature of pilots means that most projects will not reach this stage. But more needs to be done to avoid duplication and ensure that projects achieve sustainability and long-term procurement.



With these findings in mind, the following recommendations are suggested for consideration:

– Increased co-ordination between developing-country governments to consolidate requirements and points of engagement with industry;

– Raise awareness and provide effective support to governments in order to increase the understanding of space capabilities and applications;

– Increased interaction and engagement between government entities and industry. This could involve greater communication of requirements by government and of technology development by industry. Ongoing engagement through the R&D to procurement phase would enable governments to steer technology developments to meet future needs. This could help accelerate the adoption and maturity of applications, building on the work of current initiatives such as the UKSA's IPP;

– Greater use of existing tools, including downstream R&D programmes, to enable R&D efforts to be directed at developing-country requirements;

– Consideration of strategic infrastructure to facilitate the access to and use of exploitable satellite data for users and for applications development. This could enable greater integration with geospatial and other complementary datasets;

– Coordinated action between international donors to ensure that new projects are sustainable, non-duplicative and focused on under-addressed needs in the developing world.

– Seek opportunities to provide capacity building and training to developing world governments on the role of space solutions to support policy in their countries.

– For space agencies to continue the positive initiatives under way to promote the use of space solutions to address developing world challenges, including NASA SERVIR, Dutch G4AW, ESA Space in Support of International Development Assistance, and UKSA IPP.

Index of tables, figures and boxes

Tables

Table 1	Agriculture: space applications for policy making	14
Table 2	Overview of existing early warning systems	16
Table 3	Climate change and the environment: space applications for policy	23
Table 4	Disaster resilience: space applications for policy making	35
Table 5	Forestry: space applications for policy making	43
Table 6	Urban and transport: space applications for policy making	53

Figures

Figure 1	Global population growth	12
Figure 2	Change in yields due to climate change	13
Figure 3	Funding flows for the AgriSompo insurance product	20
Figure 4	Climate Change Vulnerability Index 2017	22
Figure 5	(Lifecycle assessments) Greenhouse gas emissions from electricity generation technologies, gCO2eq/kWh	27
Figure 6	Mid-Tropospheric CO_2 parts per millions (ppm), mapped by NASA Atmospheric Infrared Sounder (AIRS)	30
Figure 7	Illustration of Leicester City Council and Rotherham Metropolitan Borough Council's air quality hot spot mapper	32
Figure 8	Disaster resilience virtuous cycle	35
Figure 9	Tropical Primary Forest Loss, 2002-2018	42
Figure 10	World's urban population growth (2018)	51

UK SPACE AGENCY