GREEN DOSSIER 2023

THE EUROPEAN SPACE AGENCY

ABOUT THIS REPORT

Climate change affects every region on Earth. Its consequences are significant, impacting businesses and the natural world – with phenomena like wildfires and rising sea levels – as well as human, animal and plant health.

Tackling climate change through sustainable development is a priority for the European Space Agency (ESA); space-based solutions have an imperative role to play in the transition to a net-zero world and, simultaneously, the space sector has a responsibility to advance in a sustainable way.

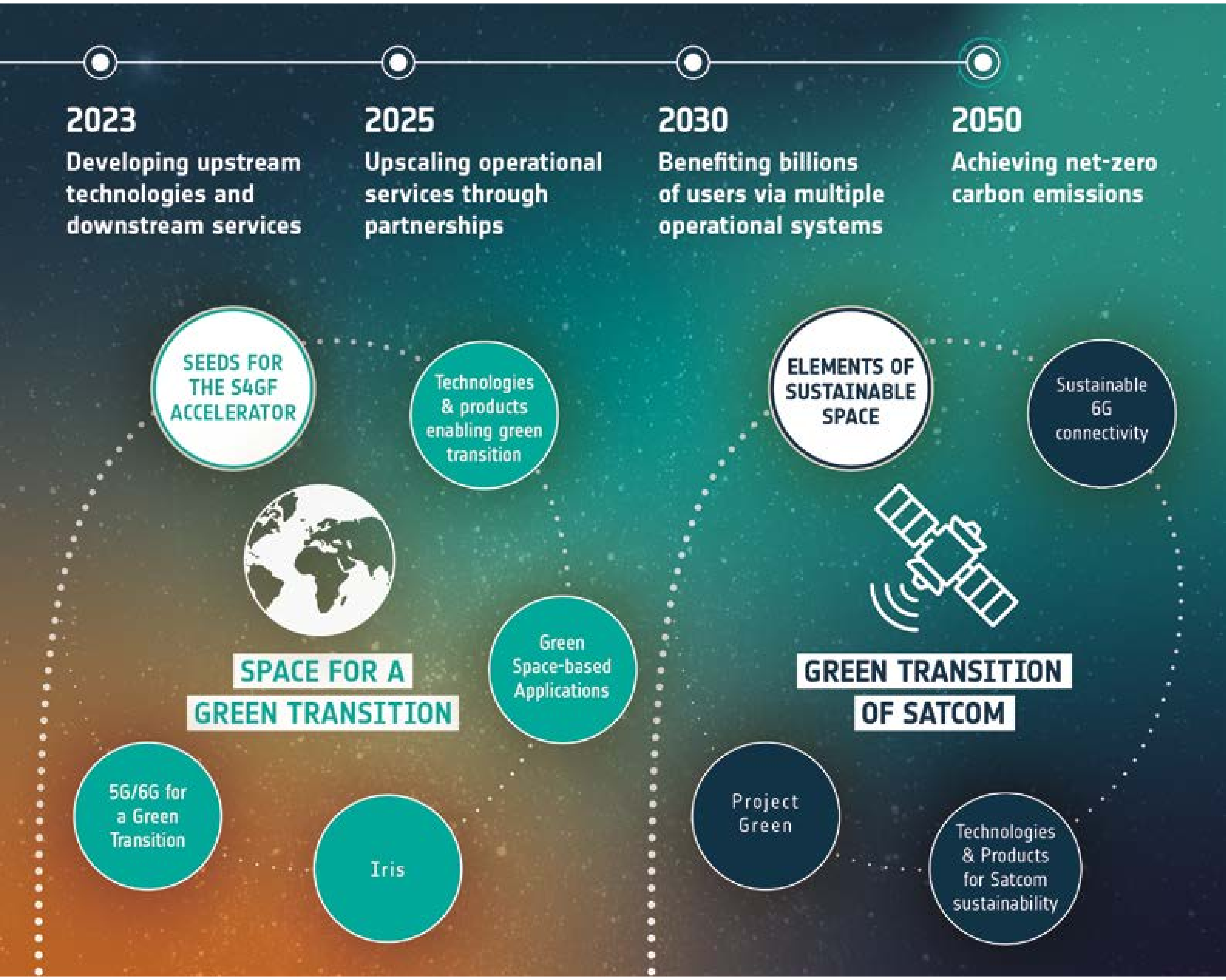
This report presents the ways in which sustainable space and satellite applications can contribute to green objectives, future-proofing the space industry and unlocking its trilliondollar potential.

CONTENTS

GREEN TOPICS IN THIS REPORT

PART 1 forms the main part of this report and presents 'Space for a Green Transition', covering the space applications, technologies and products that are supporting industrial sectors to become greener.

PART 2 presents the 'Green Transition of Satcom', covering technologies and products helping the satcom industry to develop sustainably.



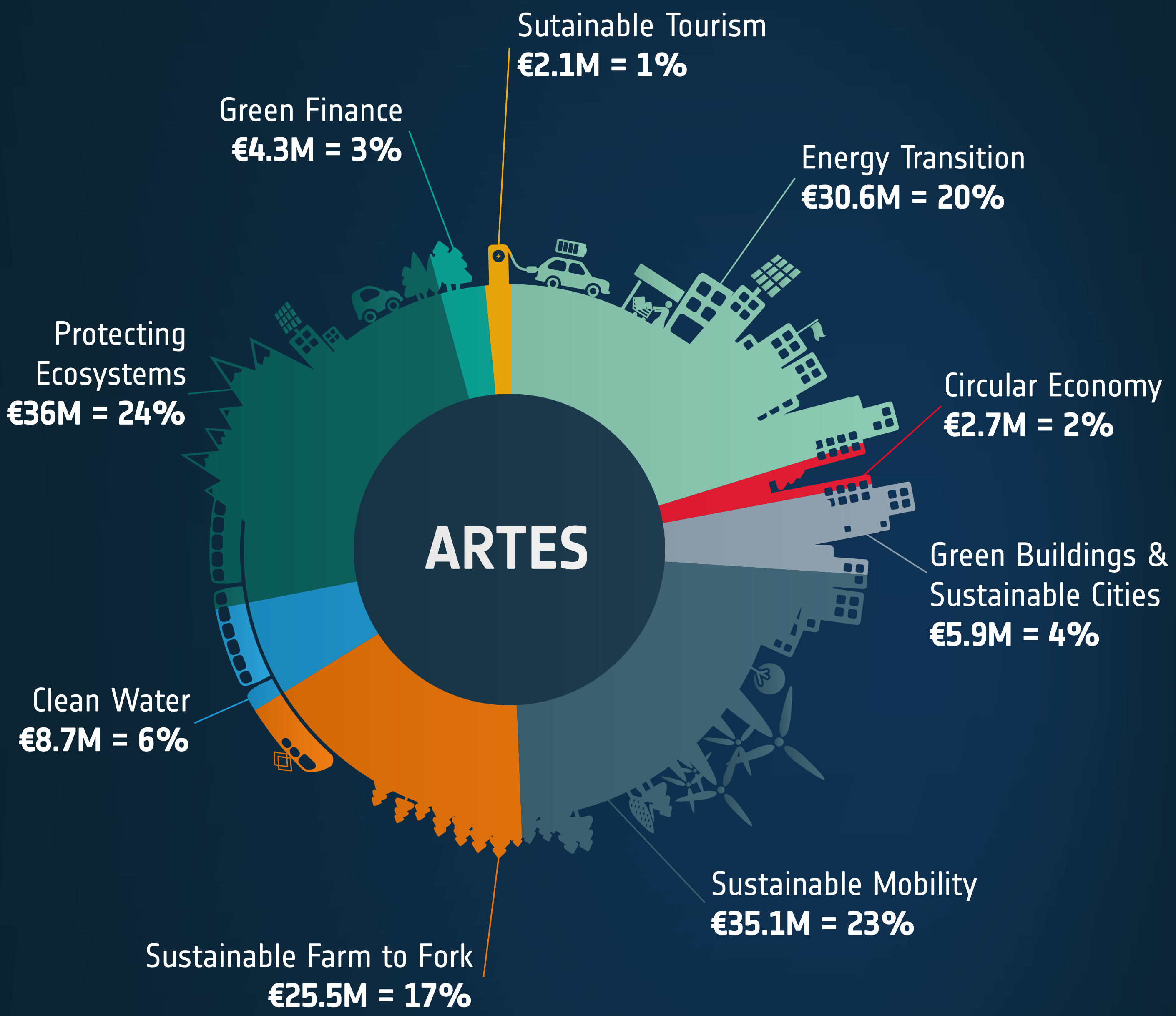
1. A diagram showing the two nuclei of green ARTES 4.0 activities: 'Space for a Green Transition' and 'Green Transition of SatCom'

PART 1: SPACE FOR A GREEN TRANSITION

GREEN SPACE-BASED APPLICATIONS

Satellite applications can help to tackle environmental challenges and support sustainable development in every industrial sector. This report draws upon data from 140 studies and projects, which represent 68 million Euros in investment from public and private sources between 2020 and 2022.

Total investment in green studies and projects from National Delegations and Industry amounts to 150 million euros since 2010.



2. Total cost of feasibility studies and demonstration projects for green applications since 2010 per topic

This report covers the following priority topics:

- **Energy Transition**
- **Clean Water**
- **Circular Economy**
- **Protecting Ecosystems**
- **Green Buildings and Sustainable Cities**
- **Green Finance**
- **Sustainable Mobility**
- **Sustainable Tourism**
- **Sustainable Farm to Fork**

ENERGY TRANSITION

The Energy sector is the highest contributor to greenhouse gas emissions [1] . It has started undergoing decarbonisation processes in several countries around the world, requiring a massive transformation in the way energy is provided, transported, and used. The traditional centralised organisation of the energy system is now facing a paradigm shift to distributed and renewable generation. Satellite applications can be used to help plan, monitor, predict and improve renewable energy production.

KEY CHALLENGES

1. **Countries around the world continue to rely on fossil fuels. Decarbonisation is not just a matter of replacing fossil fuels, but finding scalable, reliable, ecologically viable and affordable ways to meet an increase in demand for electricity.**

2. **Renewables require significant investment, innovation, and planning. Logistical challenges and insufficient infrastructure can impede the development of a renewable powered economy.**

3. **Western countries have become increasingly reliant on imported energy, making them vulnerable to geopolitical impacts. The need to become more self sufficient could offer the perfect opportunity to transition towards more ecologically viable power systems that depend on a less globalised network.**

1. https://www.un.org/en/actnow/facts-and-figures

HOW CAN SPACE SUPPORT THE ENERGY TRANSITION?

- Satellite communication (satcom) can accelerate grid modernisation towards smart(er) grids by helping to implement real-time monitoring and control of the grid and its nodes, which are often in remote locations.
- Satellite Earth Observation (satEO) data and non-space data can provide comprehensive, accurate and actionable information to decision makers for decarbonisation. This enables enhanced insight based on next generation "what-if" analyses on both a global and local scale.
- Satellite navigation (satnav) can be used to locate emissions measurements and to pinpoint sources of greatest emission generation. Positioning information also provides geo-tagging services for data collection.

SHOWCASE: SULMARA SUBSEA

Large, crewed vessels are needed to perform offshore energy decommissioning, subsea inspection, repair and maintenance, and site surveying tasks. These vessels can burn large quantities of fuel. Sulmara Subsea is a feasibility study seeking to introduce an alternative solution, which is based on uncrewed maritime systems controlled from a remote operations centre on land. Satcom and satnav are used for command, control and data transfer. The impact of Sulmara Subsea could be huge with an estimated 85% carbon footprint reduction.

CIRCULAR ECONOMY

In a linear economy, society extracts resources, manufactures products, uses them and then throws them away. The linear economy is based on mass production and disposable products. However, in a circular economy, resources are circulated for as long as possible; resources are used, reused, repaired, and recycled, with minimal waste being generated.

KEY CHALLENGES

1. **The growing world population currently generates over 2 billion tonnes of waste per year [2] – more than society can properly process or recycle.**

2. **At least one third of generated waste is not handled in an environmentally safe way[3], leading to environmental tragedies, like ocean pollution, and geopolitical tensions as wealthier nations ship waste overseas to developing countries.**

3. **Since so much is wasted, society extracts unsustainable quantities of natural resources to keep pace with growing consumption.**

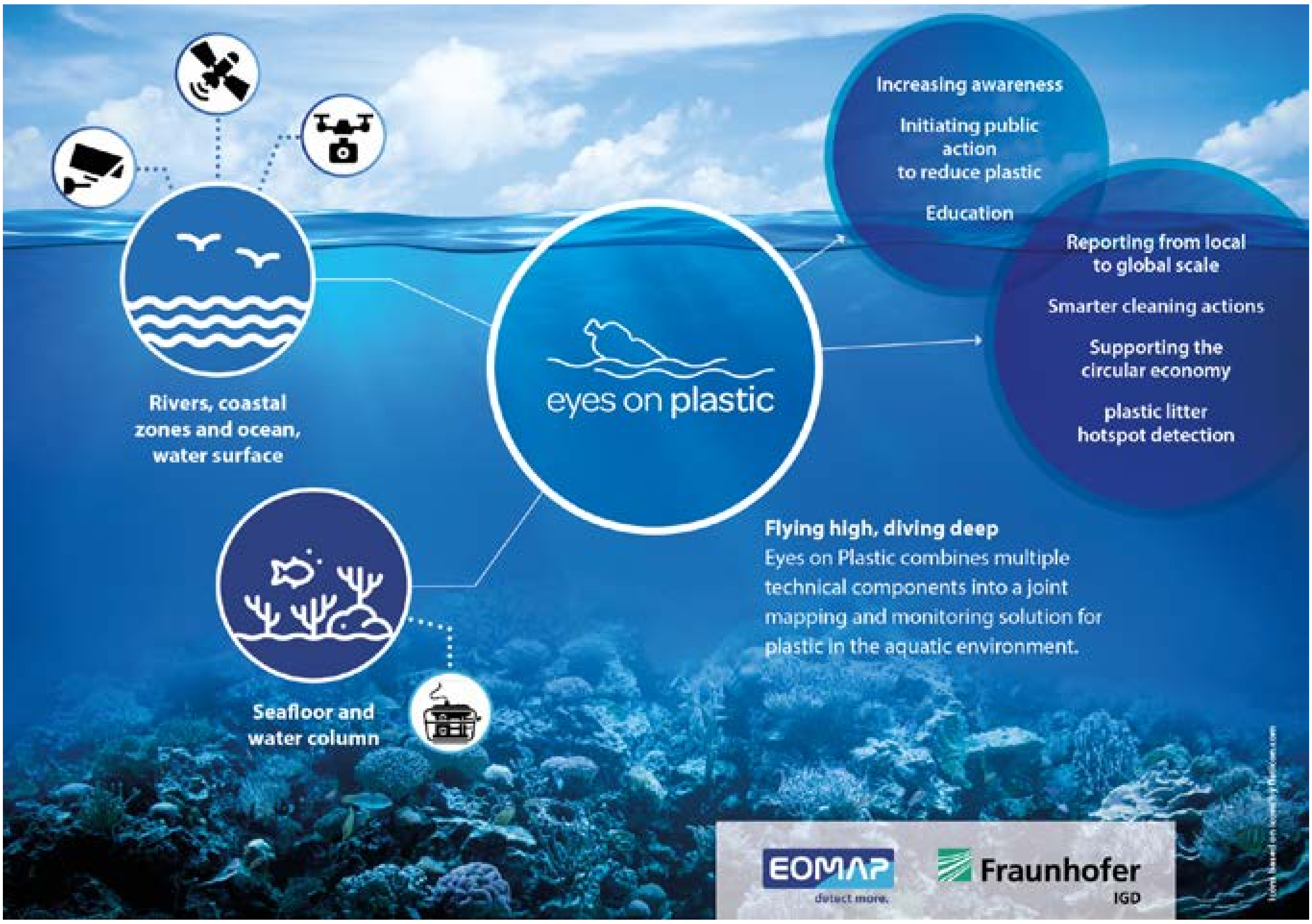
2. *https://datatopics.worldbank.org/what-a-waste/*
3. *https://datatopics.worldbank.org/what-a-waste/*

HOW CAN SPACE SUPPORT A CIRCULAR ECONOMY?

- Satcom enables communication between central hubs and isolated locations, where little or no terrestrial network is available; this is key in supply chain operations and in the collection and processing of materials in remote places.

- Satnav can track and trace goods along the supply chain, helping to optimise efficiency and match supply to demand more accurately. This minimises the risk of goods – like food and pharmaceutical items – expiring. Satnav could enable lifetime monitoring of a product from manufacture to disassembly, ensuring that re-usable and recyclable elements are not wasted. Improved mapping and tracking services could improve household waste collection systems so that recycling is maximised.

- SatEO helps to monitor environmental changes; this is key to reducing the amount of water and chemicals needed during production of certain goods (e.g., in agriculture and in the textiles industry). It helps to establish environmental labelling standards, as well as monitoring and forecasting air quality and emissions along supply chains.



SHOWCASE: EYES ON PLASTIC

Eyes on Plastic is a project aiming to help remove up to 60 tonnes of plastic per day from bodies of water by modelling and geolocalising waste slicks to determine their drift and providing this information to waste collectors. The service is being developed by EOMAP in Germany and will be trialled in Brazil, Indonesia and Italy, in collaboration with environmental agency One Earth – One Ocean, energy company ENEL, the municipality of Genoa and The SeaCleaners.

GREEN BUILDINGS AND SUSTAINABLE CITIES

Urban Sustainability encourages the revitalisation and transition of built-up areas to improve liveability, promote innovation and reduce environmental impacts while maximising economic and social co-benefits[4].

KEY CHALLENGES

1. **Around the world, urban areas are expanding in place of agricultural and semi-natural areas. This creates challenges for cities relating to increasing emissions, air and noise pollution, energy, water and material consumption, land scarcity, waste management, road congestion and habitat/biodiversity loss.**

2. **Despite air pollutant emissions declining in recent years, approximately 20% of the EU's urban population live in regions where air pollutant concentrations exceed at least one EU air quality standards.**

3. **Urban areas are also responsible for at least 70% of global carbon emissions. Cities are a core contributor to future environmental challenges, and thus there is a clear need for European cities to shift towards a more integrated approach to addressing persistent, systemic environmental challenges.**

4. *https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-sustainability#:~:text=Urban%20environmental%20sustainability%20encourages%20revitalisation,Urban%20systems%20are%20inherently%20complex*

HOW CAN SPACE SUPPORT GREEN BUILDINGS AND SUSTAINABLE CITIES?

- Satcom enables IoT-like smart grid applications, which can help to save energy use within buildings and cities. It enables machine health applications at construction sites. Satcom and terrestrial 5G infrastructure are considered essential mainly for smart cities where IoT and sensors are connected to vehicles, watches, power grids, hospitals, tunnels, roads, water systems, buildings, gas and oil pipelines to provide seamless uninterrupted information and monitoring services. Finally, satcom ensures reliable connectivity between different players in a supply chain; for reuse and recycling to become economically attractive, a broad, constant, and comprehensive overview of the supply and demand of relevant resources that are in circulation is necessary, alongside distribution of this information to appropriate stakeholders.

- Satnav provides geo-tagging services for data collected by smartphones and IoT sensors, such as those measuring pollutants in the air. Satnav can locate emission measurements, pinpointing the source of generation, and can support the collection of crowd-sourced data that require geo-referencing. It can guide UAVs taking images of thermal efficiency. Satellite navigation allows transport operators within cities to plan, reroute and avoid traffic jams. It also gives a clearer picture of infrastructure use for planning purposes. Finally, satnav enables both tracking and timing services, which are fundamental in tracing the location of people and assets.

- SatEO provides information on geological, hydrological, ecological and anthropological characteristics of a region prior to developing new services or infrastructure, and during the life of a building. It can monitor and manage natural resources to assist in the site selection, design and operation of green buildings. Examples include mapping vulnerabilities like land deformation and landslides, identifying brownfields to build on, and positioning buildings to maximise natural ventilation. SatEO can map thermally inefficient buildings for renovation, monitor air quality in neighbourhoods and forecast energy production of renewable sources. SatEO data are also used by insurers to validate claims.

Combining space technology with dynamic models, digital twins and rapidly accessible data of cities is paramount in enabling the development of many smart city services. Digital twins are also key for operations and maintenance to facilitate timely intervention when problems arise, or upgrades are required.

SHOWCASE: EO4BELMAP

Belgian company GIM developed a 3D digital twin of the built environment in Belgium and its neighbouring countries. EO4Belmap has a multitude of linked data variables. It leverages satellite earth observation to provide the most accurate, complete, and up-to-date location-related insights on buildings and addresses for the Benelux area. The EO4Belmap modules aid the energy transition to renewables in prospecting for suitable locations and the design and planning of solar panels, shallow geothermal energy, energy communities and urban heat networks.

SUSTAINABLE MOBILITY

Countries around the world are trying to improve transport by reducing congestion, commuting times, traffic accidents and pollution. In 2019, transport accounted for 15% of overall emissions; road transport and freight were responsible for most of these emissions (70%), while aviation, shipping, and rail contributed 12%, 11% and 1% respectively. Sustainable mobility addresses a plethora of challenges related to transport. It involves boosting the uptake of clean vehicles and alternative fuels across all modes of transport, and increasing shared, on-demand, connected and autonomous mobility.

KEY CHALLENGES

ROAD: Continuing innovation is needed to reduce the environmental impacts of road transport. Increased uptake in electric vehicles, alternative fuels, traffic flow management solutions, smart charging schemes and new mobility options like e-scooter sharing are needed.

AVIATION: Aircraft that use less fuel and emit fewer greenhouse gases are needed; hybrid propulsion, electric engines, vertical take-off and landing, and alternative fuels (hydrogen, algae, animal fats, cooking oils) could all help to reduce air travel emissions significantly, while optimising flight routes could improve air traffic.

MARITIME: Vessels can cause air pollution in ports, underwater noise and oil pollution.

RAIL: Rail is more environmentally friendly than many other modes of transport but undergoes change slowly due to heavy regulatory framework and multi-decadal innovation cycles.

HOW CAN SPACE SUPPORT SUSTAINABLE MOBILITY?

- For road transport, satcom ensures communication network robustness and resilience, which is ofprime importance for autonomous vehicles and other road transport services requiring highreliability. Satnav provides accurate tracking and tracing capabilities for automated vehicles and iskey in guiding them to target locations. Satnav can also enable location-based services like carsharing applications, parking assistance and fare payment. SatEO supports the planning oftransport infrastructure in a sustainable manner, respectful of the environment and of biodiversity.Satellite imagery can be used to provide the maps required by traffic management, as well as toevaluate the conditions on the ground, assess changes and provide key data for monitoring andforecasting air pollution and other important parameters.

- In aviation, space technologies can help to optimise routes and flight paths, via accurateweather forecasting and use of Iris. They can also help to implement autonomous airsideoperations – like maintenance robots – for greener airports and environmental monitoring ofairport surroundings.

- For maritime transport, 5G integrated satcom terrestrial networks provide connectivity to vesselsat sea and act as a back-up to terrestrial communications. Advanced positioning, navigation andtiming technologies provide locating, routing and tracking capabilities to vessels, cargo and relevantmachinery used in ports. This means that ships can take greener routes and prevents delays atports. SatEO detects and monitors environmental impacts – such as coastal erosion, effects ofdredging and water quality – as well as enabling surveys of protected areas.

In the railway domain, satnav and satcom can help to reduce infrastructure on the ground through innovative signalling applications and future railway mobile communication systems. Satellite technologies may also help in monitoring the railway infrastructure, improving predictive maintenance and managing logistics. They can help to optimise rail maintenance and operations to foster the capacity of rail as the greenest means of transport.

SHOWCASE: DARWIN

Darwin aims to develop a new technology for seamless and ubiquitous connectivity for the automotive sector, including 5G and satellite communications, with an objective to create a new connected and autonomous vehicle industry vertical. Darwin technology implements a 5G/satellite switch that allows telematics data from the vehicle to be collected and sent both via terrestrial and satellite channels. The Telefonica O2 network is used to send the data via 5G, and Hispasat is used to send the data via the satellite channels. The activity is currently implementing a demo on the Harwell Campus, UK.

SUSTAINABLE FARM TO FORK

The issue of food security is becoming more challenging with a growing global population. Agriculture is extremely vulnerable to climate change while also being a major contributor to the climate problem. It currently generates 19–29% of total greenhouse gas emissions.

KEY CHALLENGES

1. **Production is struggling to keep up with demand as crop yields are levelling off in many parts of the world, ocean health is declining and natural resources – including soils, water, and biodiversity – are stretched dangerously thin.**

2. **Increasing temperatures, weather variability, shifting agroecosystem boundaries, invasive crops and pests, and more frequent extreme weather events can all lead to reduced crop yields, nutritional quality of major cereals, and livestock productivity.**

3. **It can be difficult to implement agricultural policies. For example, in June 2022 Dutch farmers protested against the policy for mandatory nitrogen fertiliser reduction.**

HOW CAN SPACE SUPPORT SUSTAINABLE FARM TO FORK?

- SatEO can help to monitor carbon sequestration, forecast the availability of food supply, and manage water scarcity on farms. Satnav has great potential to support agricultural applications, by tracking herds and flocks, navigating autonomous harvesting machines and improving performance of delicate tasks (like fruit picking) thanks to precise point positioning and other new techniques.

- The role of narrowband data collection from local sensors, known as Satellite IoT, is well acknowledged in the food production industry, especially for remote fields. It is expected to grow significantly because of increasing needs from precision agriculture and the availability of new satellite-based services. Unlike narrowband IoT, the use of broadband satellite communications food production remains limited. In some areas, it is the only way to provide access to farming applications, such as farm management systems and specialised online services.

SHOWCASE: SIITAG

The SIITAG project by German company Spacenus enables farmers to make better and faster fertilisation decisions by providing actionable information related to compliance with existing fertilisation regulations. Satellite data and ground observations coming eg, from smartphone cameras are fused to produce a plant needs-based fertilisation map, showing the current nutrient uptake and the recommended nutrient demand, expressed in kg/ha, which can then be applied as fertiliser by the farmer. The trials conducted during the project demonstrate that the service saves between 15% and 30% of nitrogen fertiliser thus reducing costs and the impact on the environment.

CLEAN WATER

While substantial progress has been made in increasing access to clean drinking water and sanitation, billions of people worldwide — mostly in rural areas — still lack these basic services. The facts surrounding clean water are shocking — over 80% of wastewater from human activity is currently discharged untreated into rivers or seas, water scarcity affects more than 40% of the global population and the rising world population could push society towards a global water crisis[5].

KEY CHALLENGES

1. **All industries rely on water in some way. Access to clean water is therefore vitally important for businesses, with industry using approximately 19% of freshwater worldwide[6]. Any impact of clean water supply to industry would have a knock-on impact on four key areas of a business' value chain: access to raw materials, supply, direct operations, and product use.**

2. **Information on water basins, water quality and water pollution needs updating and constant monitoring as it can be incomplete, inconsistent, dispersed, and outdated.**

3. **Drought and flood prediction and management systems are needed in order to ensure resilience and timely response, especially in case of extreme weather events and natural disasters.**

5. https://www.un.org/sustainabledevelopment/water-and-sanitation/

HOW CAN SPACE SUPPORT CLEAN WATER?

Space has a significant role to play in the development of clean water services. Solutions are especially needed to progress conventional water and wastewater systems into instrumented, interconnected and intelligent systems.

- Satcom will connect data being captured in basins to decision-makers more efficiently; 5G-SatCom connectivity and nanosat networks could enable IoT water monitoring applications for water. Additionally, satcom could be used as a primary or reserve means for operating autonomous vehicles Beyond Visual Line of Sight.

- SatEO can provide geospatial, environmental, and weather data, giving insight on water quality and concentration of pollutants. SatEO data – including next generation nanosatellite and CubeSat networks – could monitor water security and resilience of water basins.

- Satnav can provide positioning navigation and timing information for in-situ data, as well as navigation and tracking of autonomous vehicles.

6. https://www.mckinsey.com/business-functions/sustainability/our-insights/water-a-human-and-business-priority

Other technologies could be combined with satellite technologies and data to provide these services. For instance:

- Artificial intelligence, Machine Learning and digital twins offer significant opportunities to collect, process and better present data, helping to improve water quantity and quality, as well as water sanitation, hygiene, and access systems.

- High-altitude platform systems (HAPS) can provide an information layer complementing in-situ and satEO data to offer a complete picture of water conditions. HAPS could also provide connectivity for autonomous vehicles (including command and control links, broadband payload data communications and inter-vehicle links to swarms of unmanned vehicles) and sensors in remote locations.

- Drones and other autonomous vehicles such as unmanned surface and underwater vehicles equipped with bespoke water monitoring payloads can provide very high-resolution data for detailed analysis of specific areas of interest.

SHOWCASE: OWASIS

Water managers around the world are confronted with huge challenges related to climate change like floods and drought and lack proper information on water demand (how much water does each stakeholder/sector need) and water availability (how much water is available where). OWASIS tackles these challenges by providing real-time water availability information and forecasts of future water availability, focusing specifically on reducing flood and drought-related damages. This service has led to more efficient and improved water allocation and reduced flood and drought-related risks. As a result, contracts have already been signed with the Dutch Water Authorities for continued use of OWASIS and the system is also having a significant impact in South Africa and Colombia.

PROTECTING ECOSYSTEMS

Biodiversity describes the variety of ecosystems, species and genes in the world or in a particular habitat[7]. It is essential to human wellbeing, as it delivers services that sustain our economies and societies. Biodiversity is also crucial to ecosystem services – the services that nature supplies – such as pollination, climate regulation, flood protection, soil fertility and the production of food, fuel, fibre and medicines.

KEY CHALLENGES

1. **Improper agricultural practices are the largest contributor to biodiversity loss - with expanding impacts due to growing populations – and the biggest driver of deforestation. It can destroy biodiversity by converting natural habitats to intensely managed systems, and releasing pollutants, including greenhouses gases.**

2. **In recent decades, new technologies have allowed humans to remove fish from the ocean on a massive scale. Overfishing, by-catch and ghost fishing and habitat destruction are all key causes of ecosystem collapse in many aquatic systems. Furthermore, people lose the valuable ecosystem services provided by coral reefs, such as coastal protection and revenue through tourism.**

3. **Transportation networks can also harm biodiversity. Some areas, including mountainous regions, coastal zones and seas, can be particularly vulnerable to pollution from transport. Transport corridors through Alpine valleys are essential for the European economy, but also exert pressure on unique ecosystems. Certain pollutants, such as ground-level ozone, are known to lower crop yields, affect tree growth and cause acidification in lakes.**

7. https://www.eea.europa.eu/themes/biodiversity/intro#:~:text=Biodiversity%20is%20the%20name%20given,sustain%20our%20economies%20and%20societies

HOW CAN SPACE PROTECT ECOSYSTEMS?

Satcom offers reliable connectivity to remote farms, open ocean, and other regions with insufficient terrestrial coverage. Satcom remote sensors can be placed in water to detect pollution levels, or in soil to determine its status in terms of carbon through collection of real-time data; they can also be used to collect biophysical and biochemical vegetation data for large geographic areas over long periods of time, which fused with other data can help to provide more sustainable natural capital management.

SatEO can be used for:

- Water management and drought monitoring on farms – high spatial resolution satellite images are well suited to monitor the crop development and conserve water use, thereby reducing the costs of irrigation.
- Landscape protection – by monitoring the water, soil, and natural resources of fragile ecosystems, it is possible to decide on the best place to develop the land.
- Tracking changes in plant species diversity and using remote sensing to infer species richness.
- Mapping land cover disturbance from fire, insect infestation, drought or resource development.

Satnav can be used for:

- Tracking livestock movement and behaviour, as well as virtual fencing.
- Routing of vehicles and ships along green corridors.
- Supporting geophysical and hydrographic surveys for monitoring bodies of water while reducing the associated carbon footprint.

SHOWCASE: SPACEWHALE

Monitoring whales in vast, remote oceans can be extremely difficult using traditional boat or aerial survey methods. BioConsult, an ecological research and consulting firm based in Germany, developed SPACEWHALE, a service that uses artificial intelligence to identify and count whales in satellite imagery. It was initially developed to identify large species of whale but was so successful that it can also identify whale calves, smaller whale species and other wildlife species.

GREEN FINANCE

Climate change has driven several policies put in place by governments worldwide[8], with Finance being recognised as part of the solution towards a transition to a low-carbon, more resource-efficient and sustainable economy[9].

KEY CHALLENGES

1. **As different industries plan their transition to more sustainable business models and more resilient asset bases and supply chains, they will need capital to deliver on these objectives. Solutions are needed that can help companies attract capital and investment for their transition plans and investment needs. These could support different internal processes from prioritising internal investment needs to efficient planning and reporting of progress and impact on their sustainable transition to their investors and stakeholders.**

2. **Services are needed to support the growing interest in environmental, social and governance themed products. For example corporate disclosure of climate-related information has made green finance relevant to a much wider market than the financial sector, from energy to manufacturing, transport, logistics, agriculture and food production.**

3. **For investors, such as asset managers or banks, understanding and avoiding physical risks exposure are amongst the important challenges, which can relate to real estate values, non-performing loans and credit losses, or the volatility of financial instruments. The key data needs in physical risk assessment are location of counterparty assets, resiliency plans, expected impacts, regional climate data, vulnerability to physical risks, granular forward-looking location maps for flood, hurricane and wildfire hazards, and vulnerabilities for droughts.**

HOW CAN SPACE SUPPORT GREEN FINANCE?

The collection and integration of in-situ data with remote Earth observation data underlies integrated data platforms supporting data analytics that address the most complex challenges, such as monitoring of greenhouse gas emissions, understanding the extent of oil spills, deforestation, flooding and other climate-related impacts, and enabling the extraction of actionable insights.

8. Climate change laws around the world
9. COP 26 goals - mobilise finance

Ubiquitous connectivity enabled by integrated terrestrial and satellite communications is a key enabler for many data-driven products and services, for example by relaying the data collected by in-situ sensors particularly from remote areas. 5G integrated satellite and terrestrial communication networks can connect, for instance, local sensors and weather stations to the data analysis servers.

Satnav enabled by global navigation satellite systems can provide precise positioning and timing information, eg, to locate assets, geo-tag data collected by in-situ sensors, such as IoT devices, or to timestamp information. For example, geo-located information collected from IoT sensors measuring levels of pollutants in the air is processed through data analytics allowing the identification of the source of the emissions.

SatEO data can add value to products and services by:

- Enabling the tracking of the performance for different green finance products, and to conclude on the environmental impact of borrowers enabling comparison with set targets.
- Facilitating the transition of companies towards a net-zero economy by supporting their effort to attract the necessary capital and investment for their transition plans.
- Providing an unbiased source of information, allowing for a more standardised comparison between different assets and businesses that does not rely on voluntary disclosures and therefore increases the transparency of the climate risk assessment and reporting process.
- Underpinning, in combination with other geo-located data, nature-based solutions and ecosystem markets by allowing transparent verification of environmental impacts that reduces the risks of greenwashing.
- In combination with other geo-located data, provide information on weather-related losses (landslides, flooding, drought, fires, cyclones, etc) and risks.

SHOWCASE: METHANE WATCH

Methane is the second largest driver of global warming after carbon dioxide, but efforts to cap and eventually reduce methane levels in the atmosphere have been undermined by a lack of data on the sources of emissions. Methane Watch is a demonstration project by a French company Kayrros that is developing an integrated data platform focused on detecting methane hotspots, quantifying the emissions flow rate, attributing them to an area and/or asset and providing a series of historical emissions for customers. Kayrros will provide data to the International Methane Emissions Observatory, improving transparency on methane emissions, while the improved reporting capabilities will help end users, and financial asset managers, with the required level of detail to make investment decisions.

SUSTAINABLE TOURISM

Tourism is a large contributor to many national economies; prior to the pandemic, the tourism industry directly contributed 4.4% of GDP and 21.5% of service exports on average in OECD countries[10]. However, tourism can have a negative environmental impact.

KEY CHALLENGES

1. **Tourism puts enormous stress on local land use, and can lead to soil erosion, increased pollution, natural habitat loss, and more pressure on endangered species. Ironically, these effects can gradually destroy the environmental resources on which tourism itself depends.**

2. **The inherent characteristic of the tourism sector exacerbates the challenges, due to its highly fragmented and diverse nature, covering a wide range of industries from very large to small and micro-businesses.**

3. **There is a need to define a new tourism, which with the help of technology and digitalisation, that can tackle all these issues and support a more sustainable tourism that respects and protects the environment.**

10. OECD (2020), OECD Tourism Trends and Policies 2020, OECD Publishing, Paris

HOW CAN SPACE SUPPORT SUSTAINABLE TOURISM?

Space-based assets, combined with other technologies, can help the tourism sector to transform.

- Satcom is essential to ensure communications whenever the terrestrial communications are absent or not reliable and to support digital solutions eg, in the field of mobile immersive applications.
- SatEO can be used for land cover monitoring, monitoring of river,s and for monitoring the natural habitat of wildlife. SatEO can also be used to monitor the expansion of cities and villages, which usually leads to growing touristic capacities but also introduces challenges like the need for sustainable development of public transport networks and touristic infrastructure and logistics.
- Satnav is essential to track and trace tourists. Satnav can enable visitor flow-monitoring and enable geo-fencing and time-fencing features, for a more sustainable exploitation of different areas. In addition, satnav receivers and sensors installed in tourist sites can be used as complementary ground surface deformation measurement points for a more accurate environmental impact assessment.

SHOWCASE: FATMAP LIVE

FATMAP Live is a web platform that provides insights about foreseeable conditions and the terrain to adventurers. The platform shows historic weather data to judge conditions of a trail, possible trends for the maintenance of the trails, current local weather and webcam footage to quickly check current environmental conditions at the destination, and avalanche risk modelling. It was developed by British company Terrascope.

IRIS

Europe has one of the world's most congested airspaces and it is estimated that by 2040 European air traffic will grow to 16.2 million flights, up 53% since 2017. Iris is making airplane flights greener and more efficient using a new satellite-based communication system, developed in partnership with satellite communications provider Inmarsat.

Currently, most aircraft are tracked by radar when over land and in coastal areas, and pilots communicate with air traffic control by voice. This technology is becoming outdated and the existing terrestrial infrastructure will face a capacity shortage by 2024-27[11]. There is an upcoming need for a technology evolution.

Introducing digitalisation by fitting aircraft with Iris satellite data communication technology enables air traffic controllers to manage the skies more efficiently using a high bandwidth satellite datalink between the aircraft and the ground.

Flight plans can be continually updated during the flight to maintain an optimal trajectory towards the destination. This allows air traffic controllers to schedule landings well in advance, maximising airspace and airport capacity, while minimising the fuel burned and its environmental impact. Iris is predicted to save between 1.5 million and 3 million tonnes of carbon dioxide per year in Europe between 2024 and 2040.

In June 2022 easyJet joined Iris as the programme's first airline partner, agreeing to evaluate the system on eleven Airbus A320neo planes. Iris has been fully validated within Europe and is due to become operational on commercial flights across Europe at the start of 2023. The next phase of the Iris programme – Iris Global – will focus on the technologies and certification required to share the fuel, carbon dioxide and congestion-saving benefits of Iris with regions far beyond Europe.

11. https://www.eurocontrol.int/sites/default/files/2019-07/challenges-of-growth-2018-annex1_0.pdf

TECHNOLOGIES AND PRODUCTS ENABLING GREEN SERVICES

There are therefore multiple examples of satcom technologies and products enabling green services across several sectors.

REMOTELY CONNECTED PLATFORMS FOR EFFICIENT RESOURCE USE

Today, satcom enables a variety of services thanks to its global coverage and fast data transfer. One example is the remote control of connected devices, which can be a useful means of monitoring and maintaining offshore or desert power generators, remote smart factories and other remote infrastructures.

Technologies such as cloud virtualisation can help data collection, monitoring and processing. Edge computing and artificial intelligence can enable solutions that would help enterprises to better monitor and manage their energy consumption. Sensors and satellite IoT devices connected to an edge platform in factories, plants and offshore platforms can be used to monitor energy use and analyse demand in real time. Edge-enabled systems could support the real-time assessment of supply and demand for limited renewable energy resources, such as solar and wind power. Edge computing would be used to provide a real-time view of the energy supply and demand levels in remote areas, by interacting with satellite IoT applications.

In the domain of clean and renewable energy, voice and data connectivity can be for instance brought to technicians performing inspection of offshore wind farms, to improve their safety and support their work by providing connected Augmented Reality services guiding them in their tasks.

Satcom can also be used to relay in real-time data from in-situ sensors monitoring water levels in dams water level and snow cover in remote mountainous regions, allowing to predict daily available hydropower production levels..

MONITORING AND SURVEILLANCE TECHNOLOGIES FOR URBAN AND REMOTE AREAS

Reduced size of airborne terminals combined with high data rate and reduced communication latency will enable communications from/to autonomous platforms such as drones, remotely piloted aircraft systems and high-altitude platform systems, which can be used to monitor natural ecosystems, cities, transport, etc. These systems will provide additional connectivity in needed areas to complement Earth observation satellites' data. Satcom links are therefore enablers for the deployment of remotely piloted aircraft systems beyond radio line of sight, enabling the detection of oil spills, illegal fishing and other natural-capital-threatening activity at sea. In addition, in the maritime domain, satcom contributes to dedicated systems for monitoring and communication. Automatic identification system data collected from space allows authorities to determine vessels' identity and position. This is key to enforce and monitor fishing regulations, identify illegal fishing and support natural heritage protection.

In the domain of biodiversity and wildlife protection, satellite communications are widely used to track animals, using eg, the ARGOS satellite system.

Satellite communications may also be key to relay any data from in-situ sensors networks deployed in remote areas for monitoring environmental indexes such as water quality or level, or detect animal or poacher presence. Compact sensors, energy harvesting IoT solutions, solid state batteries and AI monitoring will be amongst the many technologies in support of these services.

AUTONOMOUS VEHICLES

Autonomous driven cars require a constant quasi real-time data connection to monitor the traffic and predict different situations, allowing the vehicle to react autonomously. Satcom becomes pivotal for the success of the autonomous drive, especially in remote locations. Indeed, very low latency communications and AI are essential building blocks, but other technologies such as flat panel antennae, solid state batteries and energy harvesting are also key for the success of the infrastructure.

Autonomously driven cars will increase considerably the efficiency of private transports, enabling large-scale vehicle sharing that will decrease the number of vehicles on the road and reduce congestion, accidents and pollution[12].

LONG-RANGE SMART-MOBILITY

The long-range mobility, such as trains, airplanes and ferries, are positively impacted by satcom services. Thanks to technologies such as flat panel antenna and AI, data coverage in the cockpit and IP-based flight decks enable pilots to get essential real-time information to optimise fuel consumption. The improved predictive maintenance and airport operations mean faster turnaround and less fuel spent during the taxiing operations. For railways, the benefits can be measured in terms of extensions of the future railway mobile communications system, improved safety and predictive maintenance.

ARTIFICIAL INTELLIGENCE (AI) AND DIGITAL TWINS

AI, including machine learning, digital twins, deep learning, and reinforcement learning, has shown successful results in satellite communications and can play an important role in the green transition. In particular, the application of AI to a wide variety of satellite communication aspects have demonstrated excellent potential in areas such as smart cities, space-air-ground integration for 5G/6G, and interference management. The effective adoption and use of satellite-enabled AI solutions represent transformative potential for municipalities. Satellite communications, combined with AI, allow for a more accurate view of the city and a more efficient way to manage services (eg, recycling and rubbish collection, infrastructure maintenance and traffic management). AI is also closely linked to 5G/6G, where it plays a big role in the network planning, optimisation, and management. Lastly, AI supports the efficient optimisation of spectrum, a limited resource that must be used responsibly.

12. https://greenerideal.com/news/vehicles/driverless-cars-environmental-benefits/#:~:text=One%20driverless%20car%20can%20literally,trips%20that%20contribute%20to%20emissions

AUGMENTED REALITY ENABLING SMART WORK AND SMART TOURISM

Augmented reality that uses immersive technologies will benefit enormously from very low latency data exchange rates, opening the way to a multitude of new services.

Augmented reality could reduce the need for unnecessary business travel and increase the opportunities for smart tourism, thanks to technologies such as cloud virtualisation and edge computing.

5G/B5G TESTBEDS

To facilitate the validation of use-cases relevant to the green transitions and to de-risk associated technologies, several 5G and B5G/6G testbeds are being developed, with focus on the following areas:

Vehicle-to-everything services demonstration over satellite

The demonstration of vehicle-to-everything 5G services via satellite supports the green transition of the automotive market (eg, self/assisted driving, telemetry support and updates for vehicles), for which specific technologies are currently developed in 5G standardisation groups. Using existing satellite assets and on-ground commercial, off-the-shelf components, the testbeds support the definition of future vehicle-to-everything applications and associated technical enhancements.

Future railway mobile communication system (FRMCS)

The digitalisation of railways has become a priority to increase the sector's competitiveness and its strong contribution to a greener transport system. The FRMCS will be an essential enabler of a sustainable mobility by 2030. The European Telecommunications Standards Institute has already started to prepare the FRMCS standard with satcom as a component of the future system. The terrestrial component will use 5G new radio as the air interface and therefore it is expected that using the same waveform over satellite will ease their integration. To support the FRMCS standardisation, it is necessary to implement end-to-end physical layer studies and associated testbeds, using 5G new radio for both the terrestrial and satcom links, with their results being an input to the European Telecommunications Standards Institute's standardisation documents.

Testbeds for beyond 5G end-to-end solutions and services

The objective is to develop ground/space infrastructure to allow the experimentation of 5G/6G satellite features and capabilities, enable technology verification and demonstration, and foster rapid validation of end-to-end solutions and services. The testbeds can validate a variety of B5G technologies and concepts such as the use of AI, machine learning, cloud, virtualisation and edge computing for sustainable mobility, energy and utilities.

TECHNOLOGIES AND PRODUCTS FOR A GREENER SATCOM INDUSTRY

Telecommunication satellites have traditionally been associated with large spacecraft flying in geostationary orbit. Geostationary satellites allow full coverage of services to Earth with a relatively low number of highly reliable satellites. The telecommunication satellite industry has thus focused on delivering high performances at competitive cost rather than environmental impact.

The recent dawn of large satcom constellations in low Earth orbit has brought urgency to reduce the carbon footprint of space industry. The large-scale production of mega-constellations means that great care needs to be given to manufacturing processes. In fact, while the key driver will be high production volume at low cost, the use of the available resources needs to be optimised for maximum efficiency. This will have a direct impact of limiting the satcom carbon footprint. Amongst the different technologies under development with the support of ESA, some key examples are reported below.

FLAT-PANEL ANTENNAS

Flat-panel antenna design plays a pivotal role in both satellite and terrestrial communications, including converged 5G/6G networks. Not only can they reduce the antenna form factor and improve spectral efficiency, but they can also enable new use cases for smart and sustainable mobility, such as narrowband-IoT, autonomous vehicles, future railway mobile communication systems and remote piloted aircraft connectivity. In this context there would be a variety of terminals, ranging from very lowpower IoT devices and handheld smartphones, to reconfigurable intelligent surfaces, up to very small aperture terminals with beamforming capabilities. The technology evolution needs to aim at multibeam, flexible and scalable flat-panel antennas, with high integration density and low power consumption.

Phased-array techniques at millimetre wavelengths can result in low power consumption compared to wifi-frequency links due to the higher array antenna gain combined with advanced semiconductor technologies. Phased arrays have been used for many years for defence, radar and space applications purposes. In more recent years their increased utilisation covered ground and 5G applications calls for form-factor reduction and energy savings.

Reconfigurable intelligent surface is a technology based on many low-cost passive reflecting elements where each passive element can induce amplitude and phase shifts thus beamforming and nulling the signal in an area of interest. Reconfigurable intelligent surfaces can coat planar or conformal objects that constitute a radio channel such as walls, building facades and other urban features. Therefore, the technology can address both the core problems of energy efficiency and spectral efficiency, and cochannel interference, playing a key role in 6G wireless communication.

Organic substrates – such as paper and textiles – have been recently used in the development of antenna components. When combined with the progresses of 3D printing, this technology can make it possible to print low-cost, eco-friendly radio-frequency antenna components using a computer and an inkjet printer. Applications include wearable devices for narrowband-IoT and QR code antennas for anti-counterfeiting and security applications.

ADVANCED SEMICONDUCTOR TECHNOLOGY

Integrated circuits and power semiconductors significantly contribute to consumption and energy losses wherever electric power is used, both in space and on ground. They include components and chips that are the fundamental building blocks of digital processors, analogue front-end, high-power amplifiers and flat-panel antennas. New materials support the energy efficiency efforts of the semiconductor industry. Highly efficient processors are needed for computing and beamforming applications, which can only be achieved with ultra deep submicron technology. Power devices based on so-called wide-bandgap materials such as silicon carbide and gallium nitride enable higher power density
and reduced switching losses.

With the deployment of 5G, and already having beyond-5G wireless communication systems in mind, there is a clear demand for high-performance computing combined with high-quality analogue functions and the move towards milimetre wavelength and THz frequencies to be handled by radio-frequency circuits. Therefore, a wide variety of semiconductor technologies is required and there is a strong push for technology diversification to achieve benefits at the system level. Gallium nitride in a Doherty power amplifier configuration can increase power efficiency by over 50%, significantly reducing the consumption of power-hungry terrestrial 5G multiple-input and multiple-output systems, as well as very-small-aperture terminal ground terminals. The new generation of silicon ultra deep submicron technology chips can yield typical energy savings of 30% to 70% while boosting radio-frequency antenna performance.

CLOUD, VIRTUALISATION AND EDGE COMPUTING

Cloud computing – moving an organisation's data away from on-premises servers to the virtual environment – is becoming commonplace also in the satellite sector. Major cloud firms such as Google, Microsoft, and Amazon Web Services are forging significant alliances with leading European satellite companies including SES and OneWeb. The virtualisation of data in cloud platforms, instead of their physical deployment in different areas, has the potential to improve the utilisation of computing resources and decrease the energy and power consumption, whilst decreasing both capital and operational expenditure of mobile network providers.

Despite these advancements in the mobile network side, new applications (eg, video-on-demand, gaming and many 5G use-cases) increase network bandwidth consumption considerably. High bandwidth consumption is linked to high energy usage, as the network is used more heavily and requires power to deliver the increasing amount of data. In this context, edge computing could reduce network loads, optimising energy used for compute and storage, as processing power is moved from the cloud to a point closer to the end user or device. Traffic backhauled over the mobile network could be further mitigated by hosting content nearer to the customer. By running applications at the edge, data can be processed and stored nearer to the devices, rather than relying on data centres that are hundreds of miles away. This could lead to a significant reduction in energy consumption related to network transport, while also benefiting from the low latency that edge provides. Also, modern satellites can accommodate processing payloads, whose capabilities can be exploited beyond those of a simple relay system. Data generated on the Earth could be offloaded to the satellite network which accepts computing tasks from ground, eg, for offloading tasks generated in lowpower IoT terrestrial devices.

ENERGY HARVESTING

One of the strategic lines of 5G and beyond is the massification of IoT devices, allowing continuous monitoring of a vast number of devices. The high number of batteries used to operate such devices can create a significant impact in carbon dioxide creation for 5G communication and beyond. An electromagnetic energy harvester can reuse existing electromagnetic signals already present in the air, such as 5G/6G, WiFi, WiGig and others, or can be harvested from a specifically tailored satellite beam of energy that is directed to the receiving device itself. Wireless power transmission could supply an important part of energy in 5G and beyond for IoT sensor sustainability. Other approaches to increasing the energy efficiency in IoT devices include wake-up radio, where the sub-systems are placed in sleep-mode until triggered into operation by a wake-up radio signal, and simultaneous wireless information and power transfer, where a data-signal can be added directly to the power transmission signal.

INTER-SATELLITE LINKS

The inter-satellite links of satellite constellation are being developed using both radio-frequency and optical communication systems. In networks using inter-satellite link technology, satellites not only have the relay forwarding function, but can also communicate with other adjacent satellites. Users can be connected directly via inter-satellite links without relying on ground equipment. These links can therefore considerably reduce the environmental footprint of ground gateways, in terms of both energy consumption and real-estate occupancy. The benefits are also formally recognised in the 5G new radio non-terrestrial network 3rd generation partnership project standard[13].

LEAD-FREE ASSEMBLIES

Lead-free assemblies will provide environmentally friendlier replacements for various lead-containing solder materials and to implement greener electronics assembly processes to meet the environmental demands of future missions and to respond to the challenges imposed by environmental legislation. Lead-free assemblies are required in both geostationary and constellation systems, where low-cost and commercial off-the-shelf parts are or are becoming the main technology drivers, but reliability is still critical in view of the large number of satellites involved and operating simultaneously.

GREEN PROPULSION

Propulsion systems are pivotal for allowing satellites to perform all the orbital and attitude manoeuvres required by the mission and operation plan. The classic propellants, however, are not eco-friendly.

Even electric propulsion can impact the environment due to the complex extraction and handling processes of the materials used.

Several projects supported by the European Space Agency aim to develop green propellants such as water and others for replacing the classic hydrazine systems, and to use krypton, indium, iodine, water and others to replace xenon for electric propulsion.

13. 3GPP TR38.821 v16.0.0: " Solutions for NR to support non-terrestrial networks (NTN) (Release 16)"

DEMISABLE PLATFORMS

In line with the space debris mitigation regulations, all the satellites flying in low Earth orbit need to ensure a safe de-orbiting at the end of their lifetimes. The re-entry can be either through a controlled manoeuvre, which is expensive but allows for a safe landing in the oceans, or by an uncontrolled reentry in which the satellite must completely vaporise when it hits the atmosphere in order to avoid hitting populations.

For uncontrolled re-entry, some parts of the satellite are more problematic than other. These include carbon fibre items such as primary structures, high-pressure propellant tanks, joints and bracketry, or bulky metallic components such as reaction wheels, magneto-torquers and so on. Several development activities are ongoing, both at component and system levels, to ensure the full demisability of the platforms, which is crucial for the large number of satellites expected to fly in low Earth Orbit in the future.

ADDITIVE AND ADVANCED MANUFACTURING

In recent years many innovations have been made in the field of manufacturing techniques and processes. Advanced manufacturing, and in particular additive layer manufacturing are today popular techniques, qualified for space applications, that bring several advantages especially to complex shaped parts. In fact, not only does it enables complex geometries, often removing the need for welding or connections, thus removing unnecessary mass, it also has the potential to increase series production by automating the manufacturing, potentially assisted by artificial intelligence tools.

Even though the advanced manufacturing technologies are still in very early stages of their development,the green benefits are clear. Indeed, it allows for the reduction of production wastes and, combined with AI, it envisages further optimisation of the processes. It is also enabling unprecedented features such as in-orbit manufacturing and on-ground and in-orbit repair procedures.

The techniques are many, often customized to the mission need. At the current stage it is still necessary to further develop and optimise the different technologies and decrease the carbon footprint of critical aspects such as power generation.

SATCOM IN VERY LOW EARTH ORBIT

With the development of the smallsat technologies, some operators are opting to flying even lower than the classic low Earth orbit altitudes (~800 km). Below a certain altitude (say, 250-350 km) satellites are in very low Earth orbit.

Flying in very low Earth orgnit implies many challenges requiring huge investments in research and development. However it also brings considerable advantages and, in come cases, it becomes an enabler of new markets and services. For instance, thanks to a very low latency of the signal, improved link budget and global coverage, services such as telemedicine, direct-to-handheld communications, augmented reality and autonomous driving all become possible.

One of the main benefits of constellations in very low Earth orbit is the uncontrolled, fast re-entry at the end of service. As soon as propulsion is stopped, the drag generated by the residual atmosphere leads to an inexorable decay of orbit. This means that no space debris will be generated from these orbits, which makes satcom in very low Earth orbit naturally clean for the purpose of debris mitigation.

CONCLUSION

Space applications are essential to the development of green services. When integrated with other products and technologies, satellite data can address environmental and climate-related challenges across every industrial sector. The satcom industry also has a responsibility to develop in a sustainable way and various technologies, like flat panel antennas, are helping satcom to become greener.

In the coming months, ESA will launch several green initiatives offering European companies the opportunity for funding and support to develop new green services, technologies, and products.

To find out more about these initiatives and to apply, please visit https://business.esa.int/ and scroll down to 'Featured Opportunities', or see https://artes.esa.int/how-apply