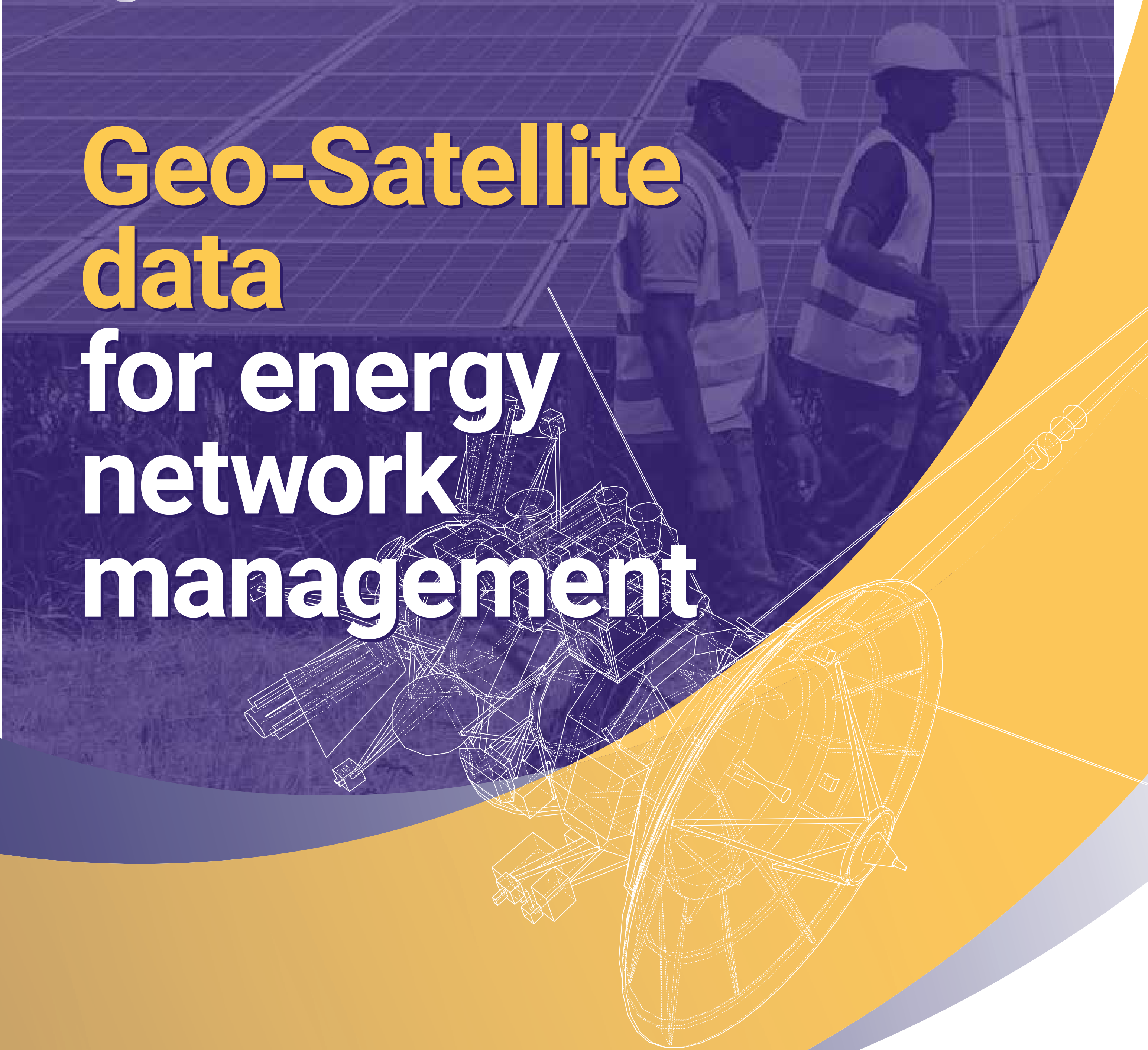
Digital Energy

Geo-Satellite data for energy network management



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Acknowledgements

We would like to extend our gratitude to the contributors who participated in the interviews, as well as the members of the review committee, without whom the realization of this study would not have been possible. Their expertise and advice were essential, and their contributions are reflected in this collective work.

Our thanks go to the entire panel :

- For ESA and the World Bank: Alex Chunet, Félicien Roquet.
- For CNES: Olivier Queyrut and Jean-Marc Delvit.
- For CPCS: Romain Frandji.
- For Enedis: Yves Barlier and Martial Joseph.
- For Hexacode: Jean-Pierre Girard.
- For GE Vernova Digital Grid: Benoit Pradairole and Sylvain Mandreau.
- For Immergis: Samuel Masson.
- For Météorage and RTE: Michel Bena, Solal Bordenave.
- For Schneider Electric: Baptiste Jouffroy.
- For Vidaplace: Nabin Raj Gaihree.
- For Zesco: Bwalya Chisulo.

This study was conducted by Philippe Tordjman. The reviewers were Fabrice Creste and Nathan Grenier-Bellegarde from Yélé Consulting.

01

Background to the study

Digital Energy is a programme implemented by Agence Française de Développement with the support of the European Union, working to develop innovative digital solutions for a fair energy transition. In this context, several thematic studies will be carried out in the field of innovative digital solutions for the energy sector.

Digital Energy aims to :

- Accelerate access to energy
- Reduce our dependence on fossil fuels
- Improve the operational efficiency of players in the electricity sector

Digital Energy offers a range of complementary instruments to support energy players in their digitalization process and, ultimately, enable the creation of partnerships between Operators and Start-ups.

▸ *More information is available on the* **digital-energy.eu** *platform*

This report concerns the first thematic study launched in 2023 on the general theme of «Efficient Network Management», on «Innovative technologies based on geosatellite data to improve the management of electricity networks». Onepoint and AETS were commissioned to carry out this study by Agence Française de Développement.

01. Principles and scope of the study

The study began with a scoping phase involving consultation with a range of stakeholders with different profiles, including users and suppliers of satellite data in the energy and electricity networks sector. The aim was to build up a complementary panel between suppliers of technological solutions and services (companies, start-ups, financiers) and end users such as electricity companies. An initial series of interviews was conducted to obtain their views on the various solutions, issues, use cases and examples of projects.

This scoping phase made it possible to identify and select the three main subjects of interest in the field of efficient network management, on which this study focuses, namely :

- Network planning and deployment, with a focus on energy access programmes
- Managing the environment around infrastructures and natural and climatic risks
- Infrastructure management and predictive maintenance

The study focuses on the use of geosatellite imagery data, including visible and multispectral optical images as well as SAR (Synthetic Aperture Radar) and InSAR (Interferometric Synthetic Aperture Radar) data, which will be described in more detail later. It also looks at the use of terrestrial and aerial data, such as aerial photographs and on-board laser scanners such as LiDAR (Laser Imaging Detection And Ranging), which are alternatives or complements to the implementation of complete solutions to produce results that can be used with sufficient accuracy. A look will also be taken at the use of terrestrial sensors and data exchange using the telecommunications capabilities of satellites.

In summary, the study looks at the combined use of geosatellite imagery, aerial photography, LiDAR scanners and terrestrial sensors, while taking advantage of the telecommunications capabilities of satellites to implement a wide range of integrated and effective solutions in the energy and power grids sector.

The table below summarises the applications developed or used, showing the technologies and types of satellite data put forward by the companies interviewed during the scoping interviews.

	Main applications	Technologies	Use of geosatellite data
ZESCO	Asset inventory, Planning and geolocation, Incident management support	ArcGIS, Arc FM	Use of geomaps on GIS Interest in APM
SCHNEIDER Electric	Vegetation management using aerial imagery, Asset Performance Management (APM), Optimising operations and investment	Asset Performance Management / ArcFM	Use of geosatellite data geosatellite data for visualisation
IMMERGIS	Ground surveys, Geo-referencing, Characterisation of infrastructure and surroundings (soil, obstacles, vegetation, etc.) in 2D and 3D	On-board 2D/3D SCAN, LiDAR	Geosatellite data for visualisation with correlation on 2D/3D mapping

	Main applications	Technologies	Use of geosatellite data
HEXACODE	Digital twin of the APM health condition with predictive, statistical and prescriptive analyses (Maintenance and Capex Optimisation)	Real-time APM platform	Visualisation of operational condition and alarms on Geohash (Google, Leaflet Maps)
CPCS	Multi-source analysis (photo, radar, geosatellites) by experts and AI tools to identify infrastructure and conditions, reconcile network and customer data and assess the impact of works.	Analysis tools, AI	Geosatellite data input for analysis
METEORAGE	Lightning analysis, precise location to assess the impact on the state of the network	Electromagnetic antenna and lightning locator application	Correlation with satellite weather data for lightning forecasting
RTE	Grid planning, Generation forecast based on weather data (PV and Wind), Vegetation Management (Aerial), APM for CAPEX optimisation	GIS, RTE tools and projects with partners, LiDAR, Aerial photos	Use of weather data, Geosatellite images in Visualisation
VIDA	Development of applications and analysis of multi-source data (geosatellite, airborne, cartography, GIS) to assess the impact of environmental and climatic risks on deployments.	Analysis tools, AI	Geosatellite images as input for analysis and visualisation
ENEDIS	Network planning study, Construction of a digital twin for the network, predictive maintenance (fault detection with Linky, Big Data & AI to estimate the probability of failure), Wear characterisation (inspection and AI), Vegetation management by helicopter and drone survey	GIS Smallworld, IBM Maximo + Enedis projects	Geosatellite images on display
CNES	Support for project development, e.g. vegetation monitoring, fire risk and impact, Correlation between light intensity and consumption, Building census, Monitoring sensitive production areas	Geosatellite, multispectral and radar data	Geosatellite images as input for analysis and visualisation
GE Vernova Digital Grid	Network planning and modelling, Vegetation management, Renewable generation forecast, Asset performance and response management	SmallWorld GIS for planning	Geosatellite images as input for analysis and visualisation
IGN-FI	Fusion of geosatellite, cartographic and aerial data, Identification of building sites and informal structures, Precise elevation measurements	Analysis tools, e.g. RAFALE application	Geosatellite images as input for analysis and visualisation with mapping

02. Aims of the study

The aim of this study is to present the main use cases, solutions and players using geosatellite data to improve the management of electricity networks.

A collaborative and dynamic approach was adopted throughout the study. In addition to discussions on use cases, technologies, opportunities and challenges related to the subject, the many and varied players involved also contributed to the framing and review phases of the study.

This can be explained by AFD's desire to create a space for dialogue, with the aim of forming a community of stakeholders (companies, institutions, start-ups, research programmes, etc.) that will last beyond the study and interact around the Digital Energy project. This is the purpose of the **digital-energy.eu** platform, which provides a forum for exchanging views and developing practical applications for these technologies.

02

Satellite Data Serving Electrical Grids

The use of satellite data, imagery, and technologies plays an increasingly significant role in the energy and electrical grid sectors. It addresses stakeholder needs in a world that is becoming more and more connected, with a focus on planning, optimising operations, and managing or preventing technical and environmental risks.

This study covers the use of imagery in the broadest sense of the term, including visual and non-visual imagery, ground or aerial imagery technologies to complement satellite data, and applications linked to satellite telecommunications capabilities.

Observation satellites with their on-board remote sensing equipment can cover vast geographical areas in record time and on a regular basis. They provide unprecedented and invaluable information to analysts and network and regional managers. Satellite data thus helps to optimise the management of electricity networks, both for power generation and for power transmission and distribution.

The benefits of satellite data extend from the design and deployment phases through to the operational phases in areas such as :

- **Network planning and deployment,** as observation satellites help to plan the construction of infrastructure, locating the best sites for the installation of lines, substations and renewable energy plants such as wind and solar farms, as well as mini-grids. Prior to this planning, they help to identify areas to be electrified as part of energy access programmes, and to supervise the deployment and progress of projects.

- **Asset and infrastructure monitoring,** because observation satellites help to monitor, on a regular basis, the state, operational condition and integrity of assets such as power lines and poles. They also help to assess vegetation encroachment, sunshine levels from photovoltaic power stations and hydroelectric dam levels for production forecasts, at local, national and international levels.

- **Natural risk management,** because observation satellites help to model and detect various climatic phenomena and events linked to natural hazards, such as storms, floods, fires and land subsidence. They also improve the anticipation and assessment of risks and operational impacts on the functioning of networks.

- **Optimisation of maintenance operations,** because observation satellites help to improve the efficiency of maintenance operations by geo-referencing infrastructures and characterising their surrounding areas on increasingly detailed images, and by prioritising and targeting the locations where maintenance and repair teams work after incidents.

- **The use of satellite telecommunication** to exchange data in real time with various field sensors on elements of the electricity network, from the implementation of dedicated systems for remote fault detection, various measurements or climatic alarms (fire, wind, etc.), to the complete supervision of electricity infrastructures, particularly in areas where terrestrial telecommunication coverage (radio, 3G, 4G, etc.) is poor or non-existent.

In summary, the use of satellite data, imagery, and technologies offers considerable opportunities in the energy sector. It can make significant contributions to advancements in the efficiency, safety, and sustainability of electrical grids. Satellite technologies complement the range of terrestrial or aerial solutions in terms of scope, speed, precision, and cost. They are integrated into an approach that allows for selecting 'the right measure at the right level,' as illustrated in the figure below.

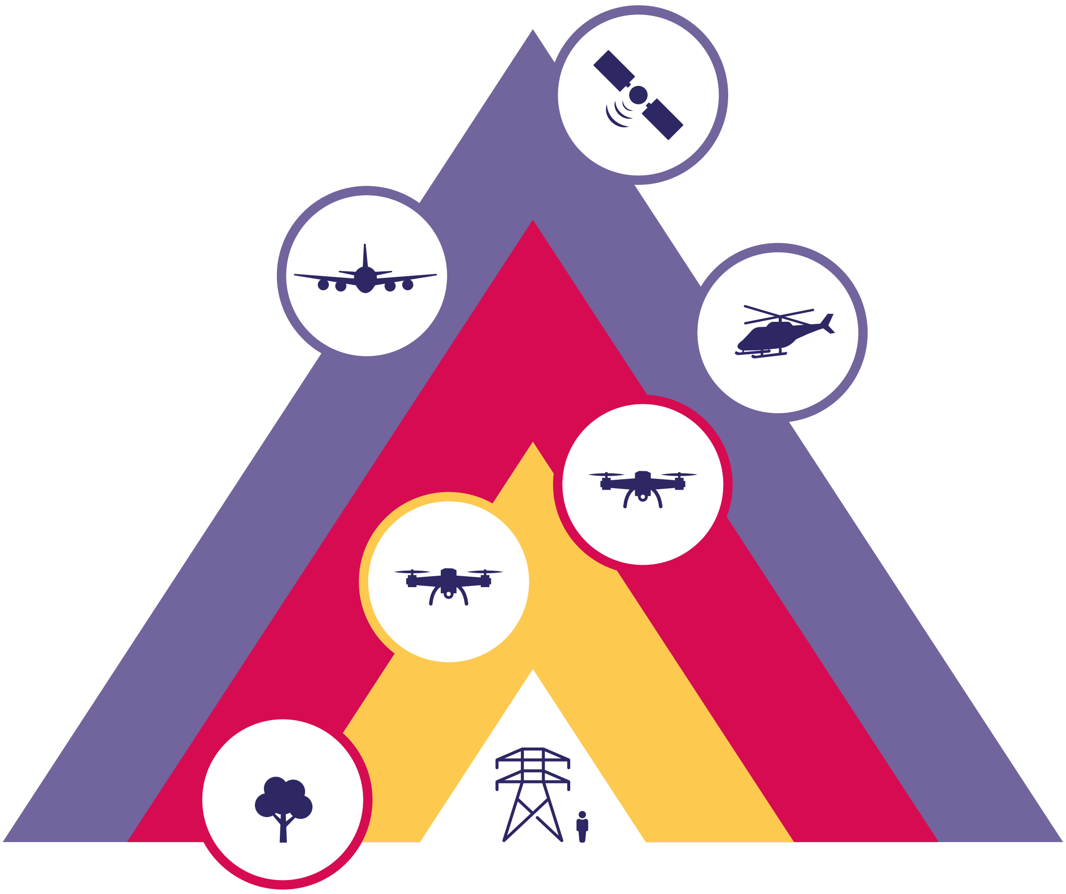


Fig. 01 The right measure at the right level

03

Overview of satellite technologies

Satellite technologies are diverse, as are their technical and budgetary implications. This chapter begins with a general overview of the functioning and roles of Geographic Positioning Systems (GPS). The dynamics of satellite programmes and launches are then explored, with a review of recent advances in the sector. This section then presents:

- The different fields of application for satellites,
- Satellite orbits,
- Earth observation satellites,
- The main constellations,
- Resolutions and data types,
- Advanced techniques such as SAR (Synthetic Aperture Radar) and InSAR (SAR Interferometry) data.

Finally, the aspects linked to data availability and the associated costs are reviewed.

01. A word about Geographical Positioning Systems (GPS)

This study cannot begin without first mentioning the role of satellite positioning systems, referred to under the generic term GNSS (Global Navigation Satellite Systems), the best known of which are :

- **The GPS system** (United States), the oldest, is used worldwide with a constellation of 31 satellites,
- **The GLONASS system** (Russia) with a constellation of 24 satellites,
- **GALILEO** (Europe) with a constellation of 24 satellites.

In addition to these main systems, we can mention the following :

- **Beidou** (China) and **QZSS** (Japan) for regional coverage,
- **IRNSS** (India)

The term GPS (Global Positioning System), which has become a very common name, will be used in the rest of the study to designate GNSS in general. GPS systems are at the heart of current terrestrial positioning performance. The positioning principle is based on triangulation calculations, or more precisely trilateration (distance measurement), which can be summed up simply as follows : it is based on the measurement of distances between a GPS receiver and several satellites orbiting the Earth, which

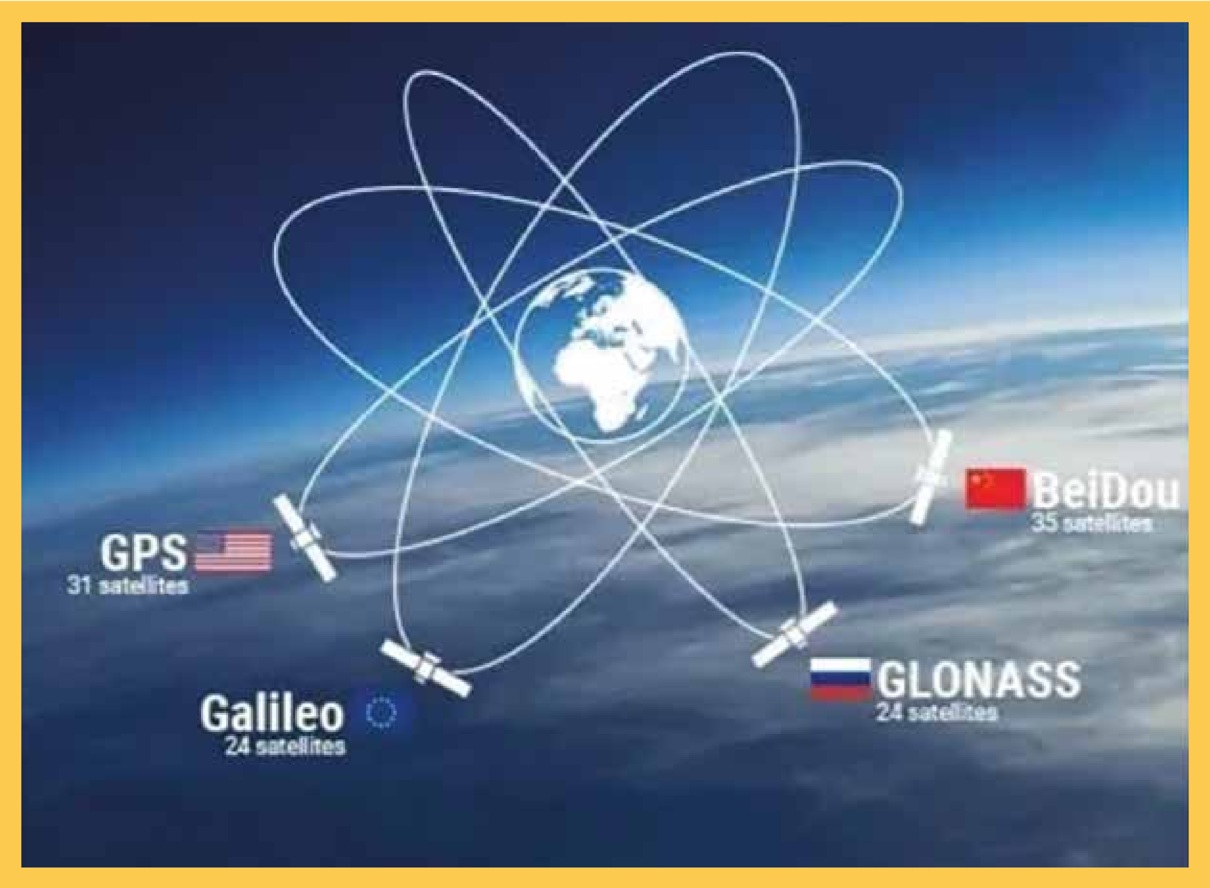


Fig. 01 GNSS constellation Positioning satellites *(multi-internet sources)*

transmit radio signals containing information about their positions and the exact time of transmission. Each terrestrial GPS receiver, itself synchronised to within 10ns (order of magnitude), receives these signals and calculates the time needed to receive them. By knowing the speed of propagation of the signals (speed of light), the receiver can determine the distance between itself and each satellite. To determine a precise position in three dimensions (latitude, longitude and altitude), the GPS receiver must receive signals from at least four satellites. With the distances measured, the receiver uses geometry to triangulate its exact position by crossing the distances of each satellite and calculating the point of intersection.

These systems make it possible to determine the geographical position of an object or person equipped with a GPS receiver with an accuracy of an order of magnitude of a metre, to calculate travel speeds and to ensure time synchronisation of the receivers.
There are countless applications using this positioning information, some of which are well known to the public, such as Google Map, Waze, on-board GPS systems in cars, sports applications on connected watches, and so on. In the field of electrical networks, GPS plays a vital role today :

- GPS makes it possible to set the time and synchronise all the electronic equipment installed on the networks and centralised (thermal, nuclear and hydroelectric power stations) and decentralised (wind farms, photovoltaic power stations, etc.) generation facilities in one or more countries with an accuracy of better than a microsecond. In this way, computer and automation systems and control centres can ensure the inter-machine, inter-network synchronisms that are essential to the stability and smooth running of electricity networks.
  Equipment using synchronous time signals includes GPS time receivers and NTP (Network Time Protocol) servers for broadcasting synchronous time references to telecommunications networks, and PMS (Phase Measurement Systems) systems for monitoring phase shifts between different areas of the power grid and anticipating the risk of blackouts (used, for example, in Wide Area Monitoring applications to minimise the risk of blackouts).

- GPS can be used to geoposition and georeference most infrastructure equipment (assets) by recording GPS coordinates and representing them very precisely on satellite and cartographic media in tools and databases such as GIS, online cartographic databases (OpenStreetMap, OpenInfraMap, etc.), Google Map, etc.

- GPS systems can be used to optimise the determination of locations and on-site intervention routes for operations and maintenance teams in maintenance support applications such as WFM (Work Force Management), CMMS (Computer Aided Maintenance Management) or APM (Asset Performance Management).

02. Dynamics of satellite programmes and launches

At the end of 2023, more than 7,300 operational satellites were in orbit, including :

- Around **1,200 dedicated to earth observation**,
- Around **5,400 telecommunications satellites** (including more than 3,600 belonging to SPACE X's Starlink constellation),
- The remainder for space observation, scientific and military applications.

In terms of launches, 2023 was a record year, with 211 successful launches worldwide, more than 50% of which were carried out by the United States, mainly by SpaceX as part of the creation of the Starlink constellation, which should contain nearly 12,000

satellites by the end of 2025.
A total of 2,900 satellites will be in orbit by 2023, including 2,253 for telecommunications and more than 250 for Earth observation.

03. Satellite applications

Satellites can be classified into different categories and fields of application, such as :

- **Scientific** satellites designed for research into the Earth's physics (ionosphere, gravity, electromagnetic spectrum, atmosphere, geodesy, etc.) and space observation (astronomy, cosmology, etc.)
- **Earth observation** satellites
- **Weather** satellites
- **Communication** satellites (internet and communication)
- **Positioning** satellites (GNSS)
- Satellites for **military use**

The applications and use cases presented in this report are mainly based on data and images from Earth observation satellites. Meteorological data and the telecommunications capabilities of satellites are also used in the energy sector.

04. Satellite orbits

The different satellite orbits are categorised as follows :

Low Earth Orbit (LEO)
- Altitude: 200 to 2,000 km above the Earth.
- Features: short revolution time (90 to 120 minutes), suitable for high-resolution Earth observation and certain communications such as Starlink.

Medium Earth Orbit (MEO)
- Altitude: 2,000 to 35,786 km.
- Features: mainly used for navigation satellites such as GPS.

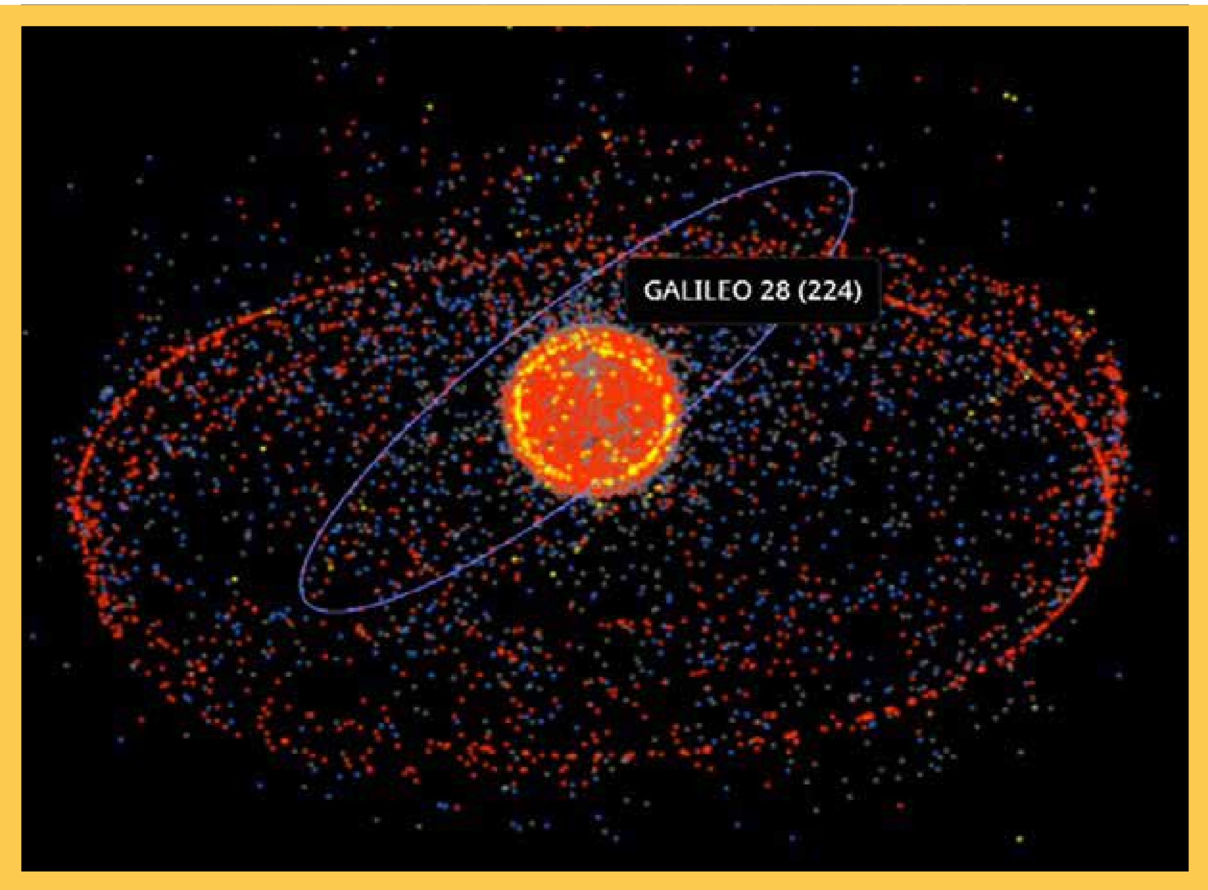


Fig. 02 https://sky.rogue.space/ Dynamic visualisation of thousands of satellites

Geostationary Orbit (GEO)

- Altitude: approximately 35,786 km.
- Features: GEO satellites are stationary in relation to a point on the Earth, which makes them suitable for meteorological and terrestrial communications and monitoring.

Sun Synchronous Orbit (SSO)

- Altitude: variable, often in the LEO range.
- Features: these orbits allow the satellite to pass over a region of the Earth at the same solar time each day. This type of orbit is chosen for satellites making photographic observations because the solar illumination of the places observed is practically constant from one shot to the next, making it easier to detect changes that have occurred between two overflights.

05. Earth observation satellites

Earth observation satellites are designed to monitor and study the land and sea surface, as well as certain meteorological data such as cloud cover. Also known as remote sensing satellites, most are placed in Low Earth Orbit (LEO) to provide high-resolution data. However, some are positioned in geostationary orbit for continuous coverage of an area of the Earth. Other satellites are positioned in a sun-synchronous orbit to benefit from a constant angle of sunlight and provide a coherent overview of the Earth. Depending on their specific missions, satellites can be equipped with a variety of sensors, such as optical cameras, radars, photometers or atmospheric instruments.

These are the types of satellites that are used mostly for observation and processing relating to the infrastructure and surroundings of electricity grids.

In the field of observation satellites, the many technological advances of the last ten years have made it possible to obtain very high-resolution satellite data (down to 0.3 metres), high revisit rates with several passes over the same area per day, and a wide variety of image types, in infrared, multispectral and hyper-spectral bands, as well as SAR radar imagery for representations after processing in 2D and 3D.

06. The main observation satellite constellations

SENTINEL is a set of satellites in the European Copernicus programme :

- **Sentinel 1 :** Radar-equipped satellites (SAR) delivering all-weather radar images.
- **Sentinel 2 :** High-resolution (10 metres) multispectral optical imaging satellite
- **Sentinel 3 :** Medium-resolution multispectral optical image and SAR radar satellite

MAXAR provides a set of very high-definition WorldView satellites :

- **WorldView-3**, one of Maxar's most advanced operational satellites, can provide images with a resolution of up to **30 centimetres** for panchromatic (black and white) imagery and around **1.2 metres for multispectral** (colour) imagery including 8 distinct bands, including visible and near infrared (VNIR) for assessing vegetation cover and type. WorldView-3 also features **super-spectral** analysis with 8 additional bands in the short infrared (SWIR) for applications such as material classification and fire detection.

Fig. 03 **The main observation satellites**

- **GeoEye**, provides very high-resolution images of 40 centimetres in panchromatic and 1.65 metres in multispectral.

AIRBUS DS, a division of Airbus and a major player in the aerospace industry, offers a range of satellite constellations for various applications, the main ones being summarised as follows :

- **Pléiades** : a constellation of very high-resolution observation satellites, provides detailed images for mapping, urban planning and natural disaster management, with a resolution of around 0.5 metres.
- The **SPOT** (Satellite for Earth Observation) series of satellites provides images with a resolution ranging from 2.5 to 10 metres, useful for agriculture, forest management and environmental monitoring, enabling extensive and regular coverage of the Earth.
- **TerraSAR-X and TanDEM-X**, the SAR radar technology satellites, provide data independent of weather and lighting conditions for precise topography images, 3D mapping and analysis of fine variations in terrain height.

07. Resolutions and types of data satellite

There are three main characteristics that define satellite data: temporal, spatial and spectral resolution.

Temporal resolution refers to the time required for a satellite to orbit and revisit the same specific area, which determines the frequency (also known as revisit time) of the data captured. This frequency can, for example, be daily, weekly or monthly.

Spatial resolution refers to the level of detail captured. It is measured in metres; a resolution of 0.30 metres corresponds to a square or pixel with a side of 0.30 metres. A comparison of some optical image resolutions is shown below.

Fig. 04 **Example of resolution: Source: Radiant Earth Foundation**

The native resolutions of images from sensors can be increased using processing techniques based on several images and types of frequency band, such as pan-sharpening. This technique increases the resolution of colour images by superimposing them on panchromatic images.

Spectral resolution refers to the wavelengths or range of the electromagnetic spectrum captured by the sensors on board the satellites.
These different sensors allow :

- Visible (photographic) optical measurement,
- Optical multispectral analysis with groups of nearby bands (UV, IR) or hyper-spectral analysis with several hundred continuous bands,
- The use of the microwave spectrum for SAR (Synthetic Aperture Radar) radars.

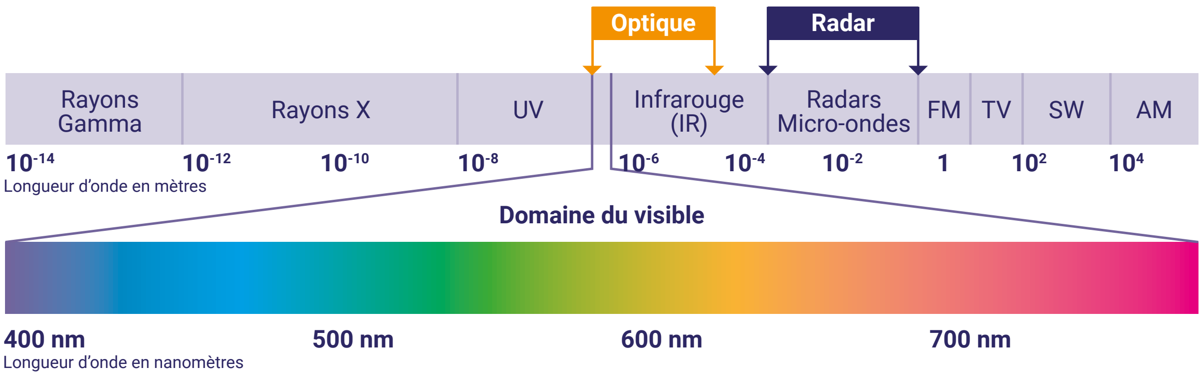


Fig. 05 **Wavelength bands**

The main types of application as a function of wavelength bands are summarised in the table below.

Clouds and optical observation

A major limitation of optical observation is the lack of visibility in the presence of clouds, which is highly dependent on latitude and time of year. Some regions, such as equatorial zones, can be very often under cloud cover, making observations unpredictable and difficult. Studies such as that carried out by NASA have shown that 67% of the Earth's total surface is generally covered by clouds, and that on average 30% of areas over land are cloud-free at any given time.

Frequency band	Wavelength	Type of application	Examples of use
Ultraviolet (UV)	10 nm - 400 nm	Monitoring the ozone layer and the atmosphere	• Monitoring ozone depletion and detecting atmospheric pollutants • Atmospheric gas analysis and aerosol studies
Visible (VIS)	400 nm - 700 nm	Terrestrial imaging	• Detailed mapping, land use monitoring and infrastructure monitoring • Managing urbanisation and monitoring urban growth
Near infrared (NIR)	700 nm - 1 µm	Precision agriculture Vegetation management	• Crop health monitoring, irrigation management, disease detection. • Biomass assessment, forest ecosystem monitoring
Medium infrared (MIR)	1 µm - 15 µm	Thermal analysis	• Locating and monitoring fires • Analysis of urban heat, detection of heat leaks
Far infrared (FIR)	15 µm - 1 mm	Climate analysis	• Studying surface temperature, monitoring climate change • Rainfall observation
Microwave (SAR Radar)	1 mm - 1 m	Topography and relief detection	• Terrain mapping, landslide studies • Flood monitoring, earthquake surveillance, • Infrastructure detection
Microwave (Radio)	> 1 m	Telecommunications	• Data transmission

The images we are most familiar with that are clear of clouds are for the most part produced using a multiple-photography technique known as «temporal compositing». This method involves collecting several images of the same place on Earth at different times, then selecting the parts of each image that are free of clouds to create a single clear composite image. On the downside, this slows down the frequency of updates to the image available once processed and limits incident detection capabilities.

08. SAR data and the InSAR technique

Synthetic Aperture Radar (SAR) and Interferometric Synthetic Aperture Radar (InSAR) are based on advanced remote sensing technologies that use the properties of radar waves to obtain detailed information about the Earth's surface. Although these technologies share similar SAR data, they are used for slightly different applications due to their unique characteristics. The advantage of radar technology is that the images are not very sensitive to cloud cover, which is not the case with optical and multispectral imagery.

Synthetic Aperture Radar (SAR)

- **Transmitting radar waves :** SAR works by transmitting radar waves from a satellite or aircraft to the Earth's surface. These waves penetrate clouds and can be transmitted day or night, offering great flexibility in data collection. SAR satellites are often referred to as all-weather satellites.
- **Reception of echoes :** the SAR system then receives the echoes of these radar waves after they have been reflected off the Earth's surface. The time between emission of the wave and reception of the echo is used to determine the distance between the satellite and the Earth's surface.
- **Image creation :** using the time differences (phase) of the signals received, SAR can create a detailed image of the surface relief. "Aperture synthesis» refers to the ability to simulate a very large radar antenna (or aperture) in motion, enabling high-resolution images to be generated.

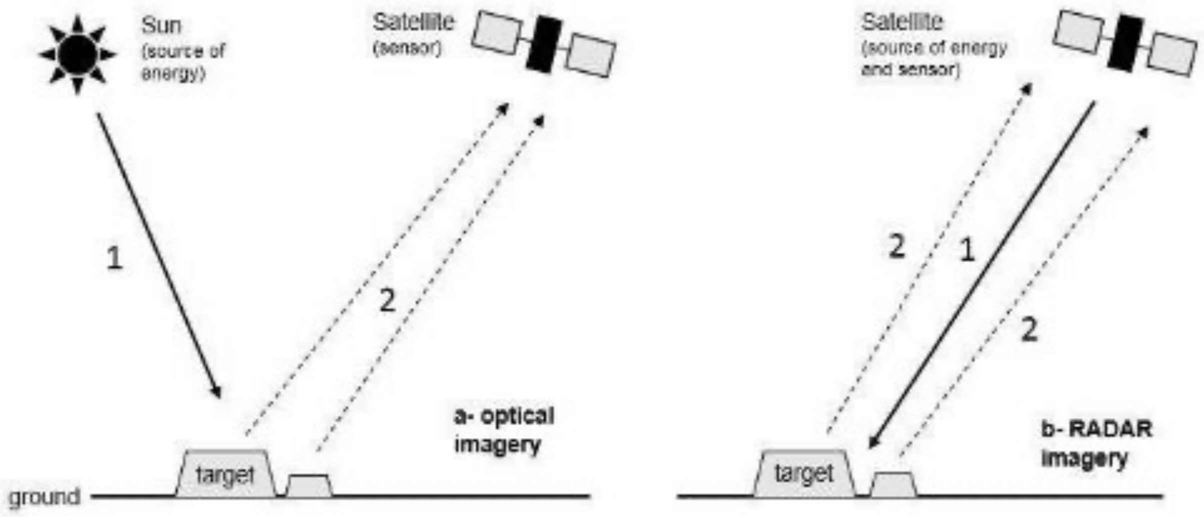
Synthetic Aperture Radar Interferometry (InSAR)

- **Multiple image acquisition :** The InSAR technique uses SAR data by comparing two or more SAR images captured by the satellite over the same area but at different dates.
- **Analysis of the phase of radar waves :** by analysing the phase difference between these images, the InSAR technique can detect displacements of the Earth's surface with an accuracy of centimetres or even millimetres.

- **Creation of deformation maps :** phase data is then used to create interference maps that illustrate the deformations of land surfaces that have occurred between shots, showing displacements due to earthquakes, landslides, volcanic eruptions or changes in man-made structures.

SAR technology is used for a wide range of applications, including topography mapping, environmental change monitoring, agriculture, and ice and ocean monitoring.

Fig. 06 **Optical/multispectral/hyper-spectral image and Radar (SAR) image**



The InSAR technique is particularly useful for monitoring ground deformation, managing natural hazards, monitoring infrastructure and studying geological processes.
In the energy sector, it can be used to monitor soil around electricity infrastructures, making it possible to :

- Detecting subsidence and landslides that could affect infrastructure foundations ;
- Measuring the height of the different vegetation canopy layers.

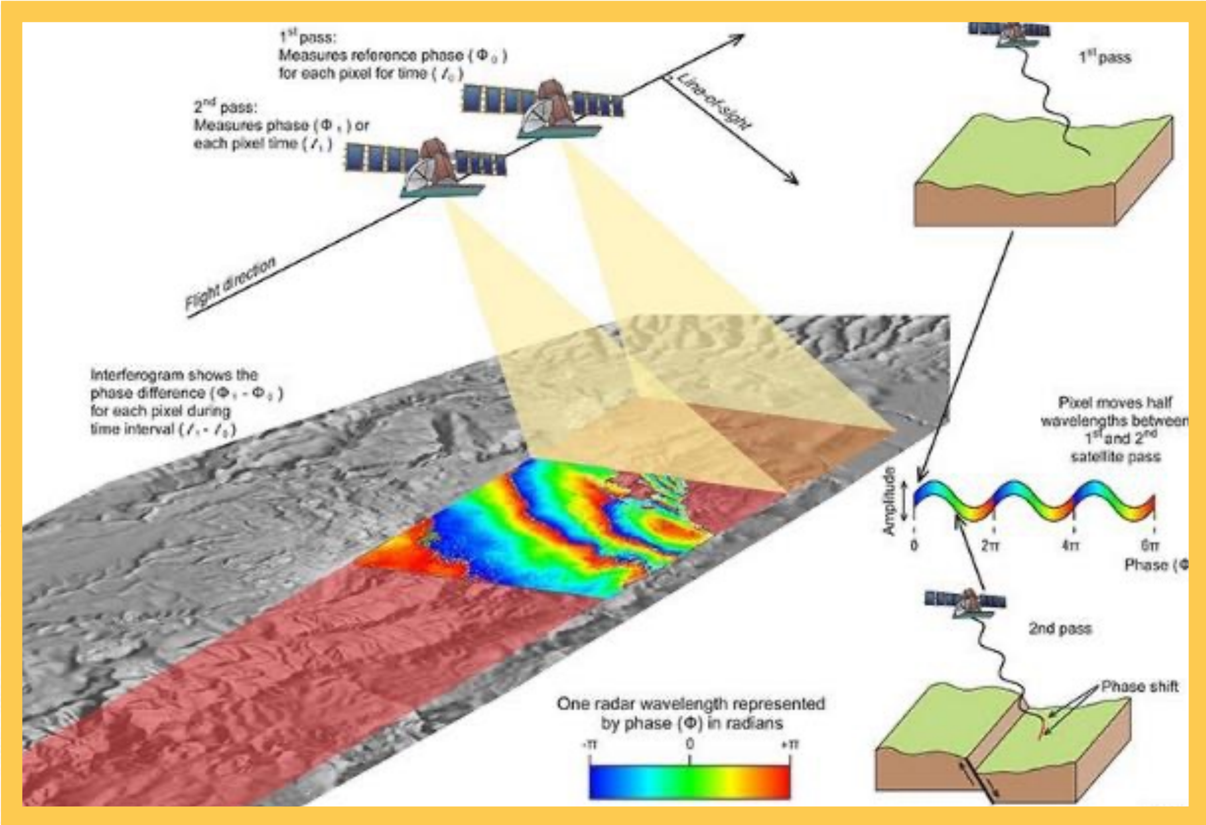


Fig. 07 **InSAR technique**

09. Data availability

Many satellites have been launched as part of government programmes, serving wider communities and making their data available to the public, researchers and commercial companies on an open-source basis. These include satellites operated by NASA (Landsat) and the European Space Agency (ESA) as part of the COPERNICUS programmes. This data can be accessed via platforms such as PEPS (CNES), Theia and DIAS.

Other satellites belong to commercial companies that sell access to this data. These include companies such as Maxar (formerly DigitalGlobe), Airbus DS, Planet, ICEYE, etc.

Furthermore, it is possible to leverage data archives from numerous public Earth observation satellites launched several decades ago. This enables the analysis of changes in land cover as well as in human infrastructure over time.

This multitude of satellite technologies and programs reduces the average cost of imagery while also making data available on various platforms (either as open data or commercially). Furthermore, the number of stakeholders, particularly companies and start-ups, aiming to offer specific and advanced image analysis services is growing.

The table below summarises the data types, resolutions and energy applications for a selection of satellites. This list is not exhaustive, but it illustrates the diversity of satellites, sensors and possible applications in the energy sector.

Satellite category	Programme Satellite	Image type	Resolution	Revisit	Energy applications' examples
Earth observation	Landsat 8	Multispectral/ Thermal Optics	15m - 100m	16 days	Mapping solar and wind resources, monitoring major infrastructures
Earth observation	WorldView-3	Optics High Resolution Multispectral	Up to 0.3m	1-2 days	Detailed monitoring of infrastructure, urbanisation, monitoring of vegetation near power lines .
Earth observation	Sentinel-1	Synthetic Aperture Radar (SAR)	5m - 25m	6 days	All-weather imaging. Monitoring land changes and movements, assessing the risk of impact around infrastructures and flooding
Earth observation	Sentinel-2	Optics High Multispectral resolution	10m	5 days	Detailed monitoring of infrastructures, urbanisation, monitoring of vegetation near power lines
Meteorology	GOES-16	Multispectral optics	500m	Continuous	Weather forecasts, Analysis of climatic impacts on energy production
Navigation and Position	GPS (USA), Galileo (EU)	N/A	N/A	Continuous	Optimising maintenance routes, monitoring energy assets
Environment and Climate	Sentinel-3	Multispectral/ Thermal	300m	1-2 days	Environmental monitoring, environmental impact assessment of energy projects
Earth observation	Pleiades 1A & 1B	High-resolution optics	0,5m	Each day (with the two satellites)	Precision mapping for infrastructure planning, construction monitoring and natural risk management
Earth observation	Pleiades Neo	High resolution optics/ Multispectral	0,3 m	2 times a day	Detailed and temporal monitoring of infrastructures, urbanisation, vegetation near power lines, incident monitoring and impacts

10. Cost of satellite images

The costs associated with acquiring geospatial satellite data can vary significantly depending on the following factors :

- **Resolution :** Higher-resolution imagery is generally more expensive due to the added value it provides in terms of detail and precision.
- **Frequency :** Obtaining images of the same area at regular intervals or on-demand may increase costs.
- **Customisation :** Services for ordering images specific to a certain area and at a specific time (on-demand acquisitions) can result in additional costs.
- **Data processing and analysis :** Costs may also include image processing to make them usable, such as geometric correction, radiometric correction, and data analysis.

Here is a general overview of the orders of magnitude for satellite data costs (2022-2023 period) :

- **High-resolution images :** high-resolution satellite images (less than 1 metre per pixel) are among the most expensive, with prices ranging from **a few euros to more than 25 euros** per square kilometre for recent, high-quality images. Suppliers such as Airbus DS with its Pleiades satellites and Maxar with its Worldview and GeoEye satellites offer such images.
- **Medium-resolution images :** medium-resolution images (between 1 and 10 metres per pixel) are generally less expensive, with costs ranging from **a few cents to a few dollars** per square kilometre. Programmes such as Sentinel1-2, run by the European Space Agency (ESA) as part of the Copernicus programme, and NASA's Landsat programme offer free access to medium-resolution images.
- **Subscriptions and licences :** for companies and institutions requiring continuous access to satellite data, suppliers often offer annual subscriptions or licences. These arrangements can cost from **a few thousand to several million dollars** a year, depending on the extent and frequency of the data required.
- **Free and open-source data :** there are several sources of free satellite data, such as NASA's Landsat and ESA's Sentinel programmes (accessed via the Copernicus website), which provide medium- and high-resolution images covering the entire globe. Although free, the use of these data may require additional resources for processing and analysis.

04

Various use cases for electrical grid management

01. Preamble

The study of the themes selected during the scoping phase has made it possible to identify numerous relevant use cases. These use cases will be presented and detailed in the following chapters. They provide concrete examples of how satellite data can be utilised to improve grid management. They cover the following three themes :

- Access to energy, network planning and deployment,
- Management of network infrastructure environments and climatic events,
- Infrastructure management and predictive maintenance.

These themes also revealed numerous functional intersections, suggesting an integrated approach to the study. A notable example of this cross-disciplinary approach is « vegetation management », an important subject highlighted by electricity companies. Vegetation management plays a role in network planning, maintenance and natural risk management.

02. Network planning and deployment - access to energy

This section examines the use of satellite technologies in energy access programmes and electricity network planning. It focuses in particular on use cases related to the identification of areas to be electrified. The aim is to develop optimal scenarios, particularly by balancing the expansion of the existing grid with the implementation of off-grid solutions, such as mini-grids and photovoltaic systems. This optimisation takes into account the expected benefits of electrification in terms of the social and economic development of the target areas. Satellite data provides invaluable information on topography, different levels of land cover, soil type, vegetation cover, built-up areas, urban density, existing infrastructure and natural and meteorological hazards.

Combined with demographic and economic data, they facilitate the exploration of various deployment scenarios. This guides the selection of optimal solutions based on objectives such as energy access, activity, cost control for construction and operation, efficiency, reliability, and network resilience.

Governments, private and public project developers, network operators and power plant operators all need this data and analysis to support their decision-making processes.

2.1 Access to energy: identifying the areas to be electrified

Identifying the areas to be electrified is the first step in planning electricity networks. Medium- and high-resolution satellite images can be used to accurately map inhabited areas not served by the electricity grid, and to analyse areas suitable for the deployment of renewable energy production units.

Many projects rely on satellite images in the pre-study phases for preliminary assessments of areas already served by the grid and those requiring electrification, either by connection to the grid or deployment of isolated mini grids. For example, the **«Global Electrification Platform»** project uses these technologies to estimate the costs and methods of electrification throughout the world, by integrating data on populations, existing infrastructures and available energy resources (see overview of programmes p.35).

These preliminary assessments of areas are also possible using open-source medium-resolution satellite imagery. Comparing images of the same area at different dates enables the characterisation of urban or rural expansion rates through historical data. Moreover, human presence, and by extension electrified activity zones, can be detected and assessed using nighttime light intensity imagery (NTLI).

Moreover, the use of satellite data is particularly relevant for regions that are difficult to access, such as sparsely populated villages and remote areas. In these locations, field data is often limited or outdated, necessitating potentially lengthy and costly site visit campaigns.

This data then enables the development of various energy access strategies, which can be summarised as follows :

- Direct connection of new customers to the existing electricity network. This approach is often the most economical where the grid is already close and underused. It includes infrastructure reinforcement and the integration of renewable energy sources.

- The electricity network is extended to unserved areas by building new transmission and distribution lines, or by hybridisation with local renewable energy production systems, thereby reducing dependence on remote power stations and high-voltage lines.

- The implementation of mini-grids or autonomous electricity production units such as solar panels, small wind turbines and biogas plants.

The right combination of these different approaches makes it possible to achieve the goal of universal access to clean, affordable energy.

2.2 Planning and electricity networks' deployment

Once electrification strategies have been defined, satellite data continues to provide valuable information at various stages of planning. This is the case, for example, with multispectral optical imagery, SAR radar, or meteorological and solar irradiation data. Such information provides a detailed overview of the area through numerous characteristics: topography, land use and type, levels of land utilisation, vegetation cover, buildings, existing infrastructure, as well as natural and weather-related risks.

Georeferencing and mapping assistance

Satellite images make it easier to geo-reference existing infrastructures. They are often supplemented by terrestrial or aerial data (photographs and LiDAR with automatic recognition of infrastructures and elements - known as robot mapping) and can be used to :

- Enhance existing databases, usually available in a GIS (ESRI /ArcGIS, SmallWorld, OpenGIS, for the most common) to produce geospatial maps showing the location of existing lines, pylons, substations, equipment and buildings.

- To create databases or update obsolete and poor-quality ones.

These cases are frequently encountered as it is often challenging to maintain asset databases, which include their characteristics and information about their condition.

Depending on the type of infrastructure, the satellite data will be supplemented and cross-checked with ground or aerial data when the levels of accuracy cannot be achieved with satellite images alone. This is particularly true for small-scale infrastructure (ranging from less than 1 to 10 metres depending on the resolution), such as power lines, pylons, medium- and low-voltage equipment, and small solar or wind power plants, which remain challenging to detect accurately from space.

The identification of power lines and pylons

Medium-voltage lines (typically between 11kV and 60kV) may be insufficiently documented in certain regions. The added value of satellite data analysis lies in improving network knowledge thanks to their wide geographical coverage. This is particularly useful in areas where infrastructures are sparse. It also allows for the consideration of large volumes of assets, such as pylons or line sections.

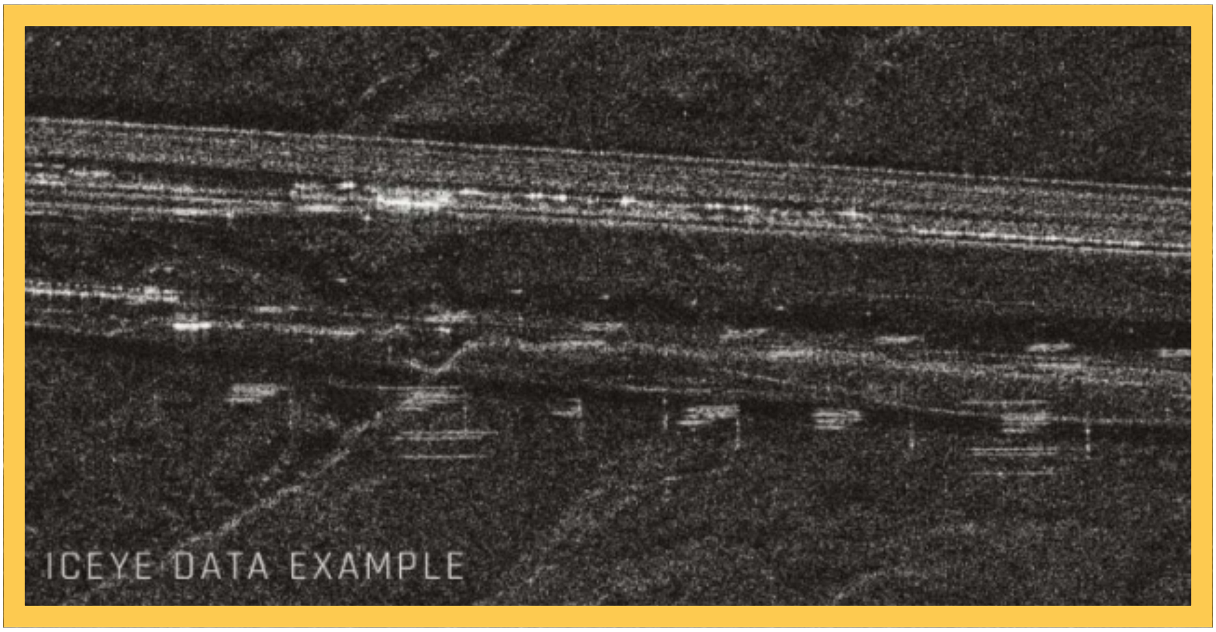


Fig. 08 **Example of line and pylon detection with SAR system.**

However, these medium-voltage lines and equipment remain barely visible, or even invisible, to satellite observation. Even more so than for high-voltage (HV) and extra-high-voltage (EHV) infrastructure, ground inspections (using vehicle-mounted cameras or LiDAR) and aerial imagery from drones, helicopters, or planes remain, for now, the only alternatives that provide the necessary levels of precision, despite their significant costs and implementation times.

For high-voltage lines, the electrical cables connecting poles or pylons may be too thin to be reliably detected by satellite optical sensors, even at high resolution. However, the pylons themselves may be more or less visible depending on their size. For instance, high-voltage pylons (225kV) will be more observable than 90kV pylons, which are currently at the limit of detectability in raw optical imagery. Additionally, supplementary methods can be implemented, such as the detection of «vegetation corridors» to locate the lines they contain, or the use of SAR radar data, as illustrated above (Fig 08 : Ceye Data Example).

Network modelling

Satellite data contributes to network modelling by providing essential information on topography (mountains, slopes, obstacles, etc.) and the environment. It makes it easier to choose routes for power lines and locate network infrastructure such as substations, pylons and centralised or decentralised energy production sites.

For example, they allow the analysis of the shortest and least costly routes for transmission and distribution lines, or those least exposed to natural hazards.
Moreover, meteorological data is useful for powering network calculation and modelling applications to optimally size infrastructure and line capacities, as well as to simulate network behaviour under various conditions.

Assessing and integrating renewable energy deployment zones
By analysing solar radiation, wind profiles and other environmental factors, developers can identify the most promising sites, particularly for the installation of photovoltaic or wind power plants that are deployed centrally or widely dispersed, with conditions varying from one area to another.

The integration of renewable energies presents new challenges for the management of electrical grids, particularly in terms of electricity production variability, grid stability, and supply-demand balance. It is integrated into the energy management systems (EMS) of grid control centres. Satellites provide additional tools for operators by providing real-time data on weather conditions affecting solar and wind power generation, as well as information on dam height levels (measuring the lake footprint or lake height of a dam with SAR data).

2.3 Overview of energy access projects and programs in Africa

Around **600 million people in Africa** still do not have access to electricity. Despite recent progress, electrification efforts face major challenges in terms of affordability. Advances in « off-grid » solutions, particularly solar and battery technologies, and new business models are complementing the provision of access through extensions and grid connections. The IEA (International Energy Agency) reports that off-grid systems **accounted for more than half of new connections in 2022** in sub-Saharan Africa.

Several programmes and projects financed at both the African and global level are being implemented to facilitate and accelerate access to energy. These projects include the provision of tools and databases, particularly satellite based. Some projects and tools are presented in this section.
The "Data-Driven Electrification in Africa" programme of the International Energy Agency (IEA) and Power Africa aims to accelerate access to energy on the continent. This initiative has given rise to two digital tools, listed below, which enhance the ability of energy planners to make data-driven decisions.

- **« GIS Catalogue for Energy Planning in Africa »**

This is a centralised repository of GIS data and tools for energy planners.
The IEA has collected geospatial models and datasets for the energy sector. This platform compiles geo-referenced datasets detailing population distribution, renewable energy resources, energy system infrastructure, main demand centres, as well as non-geospatial datasets on population growth rates, regulatory indicators, utility performance and electricity market characteristics across the continent.

▸ *Finds IEA's tools and contents on their dedicated space* **here**

- **« Building-level Electricity Needs Estimation Model »**

Based on models integrated **Open Energy Maps**, an open-source GIS tool developed in collaboration with the MIT Energy Initiative, this model is designed to estimate and forecast electricity demand at building level in developing countries. The tool uses a machine learning model trained on geo-referenced electricity consumption data from meters in three pilot countries: Ghana, Senegal and Uganda. It predicts electricity demand for buildings that have no meter data or are not yet electrified, with high resolution and accuracy.
The **Open Energy Maps** platform aims to promote the transparency and accessibility of renewable energy data. Key features include interactive mapping tools that allow users to visualise data on solar, wind, hydroelectric and other forms of renewable energy.

These tools are designed to be used by all types of stakeholders, including academic researchers, energy project developers, policy makers and the general public.

▸ *Below are some examples accessible on the* **OEMaps Platform**

IRENA programmes (International Renewable Energy Agency)

IRENA is making the Electrification Platform (IEP) for West Africa available online and free of charge. It provides an overview of electrification investment scenarios in West Africa.

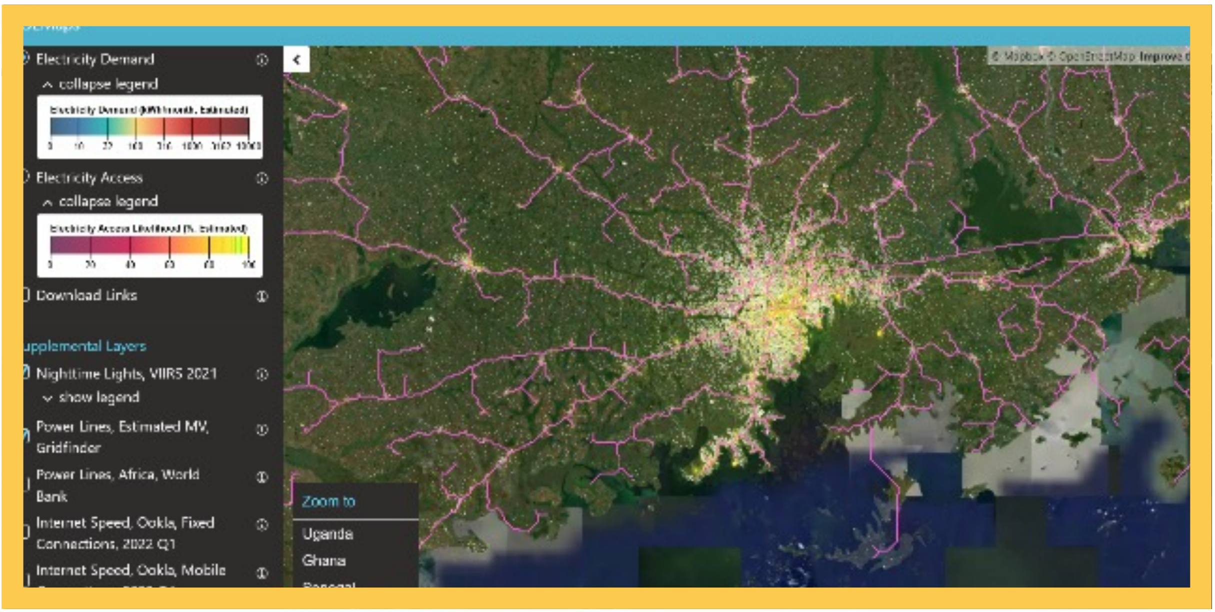


Fig. 09 **Uganda: night lighting with added mapping of the medium-voltage network**

The platform shows which combination of technologies (centralised grid connection, different types of mini-grids or stand-alone photovoltaic system) can provide electricity at the lowest cost in the different scenarios.

In addition to the choice of technology, investment costs and capacity requirements, the platform highlights the value of storage for the electrification of mini grids compared with other alternatives.

▸ *Data and projects accessible on the* **IRENA platform**

The ESMAP (Energy Sector Management Assistance Program)

This is supported by a consortium led by the World Bank and including the Agence Française de Développement, the European Union, Canada, the United Kingdom, Switzerland, Luxembourg, Norway and others. The aim is to help spread the use of low-cost geospatial planning for electrification, particularly in countries with poor access to electricity.

The Global Electrification Platform (GEP) has been developed as an open source and open data tool to accelerate the achievement of the sustainable development goal of universal access to modern energy services by 2030.

Fig. 10 **Senegal Example of energy access scenario analysis**

This platform enables the assessment of grid, mini-grid, and off-grid solutions and serves as a tool in high energy access deficit countries for comparing and evaluating different options for energy access.

GEP provides a global scenario-based model of least-cost electrification planning for access and a web mapping application, GEP Explorer, which presents the results of the model, allowing users to adjust certain parameters that affect electrification planning.

Access to the GEP platform

Microsoft Philanthropies' humanitarian program

in partnership with the Humanitarian OpenStreetMap Team (HOT) community, is supporting initiatives to use AI to create open data maps. Bing Maps has published data on 17 million buildings in Uganda (7 million) and Tanzania (11 million). Microsoft Maps and Geospatial has also made available open data on building footprints, covering 36 million buildings in Nigeria and 15 million in Kenya. These building footprints, generated by machine learning algorithms applied to satellite imagery, were obtained from images collected between 2020 and 2021 by Maxar Technologies. The data is available free of charge for downloading and use under licence.

Fig. 11 **Ghana: example of grid-connected and non-grid-connected energy access mix scenarios**

The **AFRICA Knowledge Platform programme**, supported by the European Union, provides a platform of data and tools developed by the European Commission's Joint Research Centre (JRC).

The **Clean Energy Access Prioritiser** (CEAP) is an open-source decision support platform designed to identify priority areas for clean energy deployment and investment. It incorporates spatial planning functions and allows users to evaluate clean energy projects based on various criteria such as energy demand, environmental aspects, and socio-economic factors.

The **Clean Energy Acces Tool** (CEAT) is a clean energy access tool (scheduled to be operational in 2025). It enables a more detailed geospatial analysis of the clean energy context, for the electrification of essential social infrastructures such as health centres, hospitals, schools and refugee camps. CEAT visualises the energy requirements of health facilities and the associated technological costs.

Fig. 12 **Extracting building data for energy access analysis: Uganda and Tanzania**

03. Management of infrastructure - environmental and climatic risks

The study and monitoring ofthe environment around energy infrastructure is essential for its deployment and integrity, as well as for assessing the risks it faces.

Satellites are playing an increasing role in these studies and in assessing the risks associated with extreme weather phenomena such as storms, floods and forest fires. By providing real-time and historical data, they enable a better understanding of the risks and a more rapid assessment of the scale of the consequences. Thanks to this data, the implementation of risk adaptation strategies to protect vital infrastructures is facilitated, improving the effectiveness of preventive measures, the predictive analyses needed to make people and infrastructures safe, and the optimisation of interventions before and after natural incidents.

The main risk assessment and impact analysis studies using geosatellite data can be categorised as follows :

- Identifying and assessing the constraints linked to the deployment of infrastructure and equipment, considering the nature of the soil, natural obstacles, existing buildings and vegetation,
- Analysis of the impact on planning and deployment,
- Event detection and risk assessment for meteorological conditions such as storms, lightning strikes, floods, landslides and forest fires,
- Damage assessment after incidents.

It should also be noted that for network and power plant deployment projects, due to regulatory requirements, risk and environmental impact assessment studies are increasingly being requested in tender specifications, starting from the design and financing phases. Analyses based on satellite imagery therefore seem to be becoming essential in the preparation of these documents.

3.1 Management of risks related to landslides

The Earth's surface is in constant motion. This is due to various natural phenomena: tectonic activity, volcanism, human activities such as groundwater extraction or mining, landslides, soil contractions linked to water run-off or drought. This dynamism of the earth's surface can have major repercussions on infrastructure, networks and natural ecosystems.

In recent years, growing awareness of the risks associated with landslides has led to a demand for comprehensive, reliable information on these movements.
The European Ground Motion Service (EGMS) was created in response to user needs expressed at the Copernicus User Forum. This service is at the cutting edge of technology in terms of spatial remote sensing. It uses InSAR (Interferometry Synthetic Aperture Radar) data from Sentinel-1 to detect and measure ground movements in Europe with **millimetre-level accuracy**. In the private sector, the Finnish company ICEYE has recently launched its constellation of SAR/InSAR satellites, which offer similar precision and revisit rates of one day.

These technologies can be used for a variety of applications. For instance, local authorities can use them to monitor the structural integrity of dams, bridges, railways, and buildings. They also enable urban planners to make data-driven decisions regarding the location of new infrastructure by assessing the likelihood of natural hazards such as landslides. Researchers can also leverage EGMS data to study the effects of climate change, such as permafrost thawing and coastal subsidence.

In the field of electricity networks, ground movements can have repercussions on high infrastructures such as pylons and lines, resulting in steep inclines with the risk of reducing corridors, and increased risks of branches snagging or tipping over, particularly in mountainous areas (see fig. 13 below).

More critical infrastructures, such as dams, can also be monitored. The figure below shows the detection of a drift **of 7.6 mm per year in the vicinity** of a dam in Spain.
The detection of ground movements in areas close to infrastructure allows for the an-

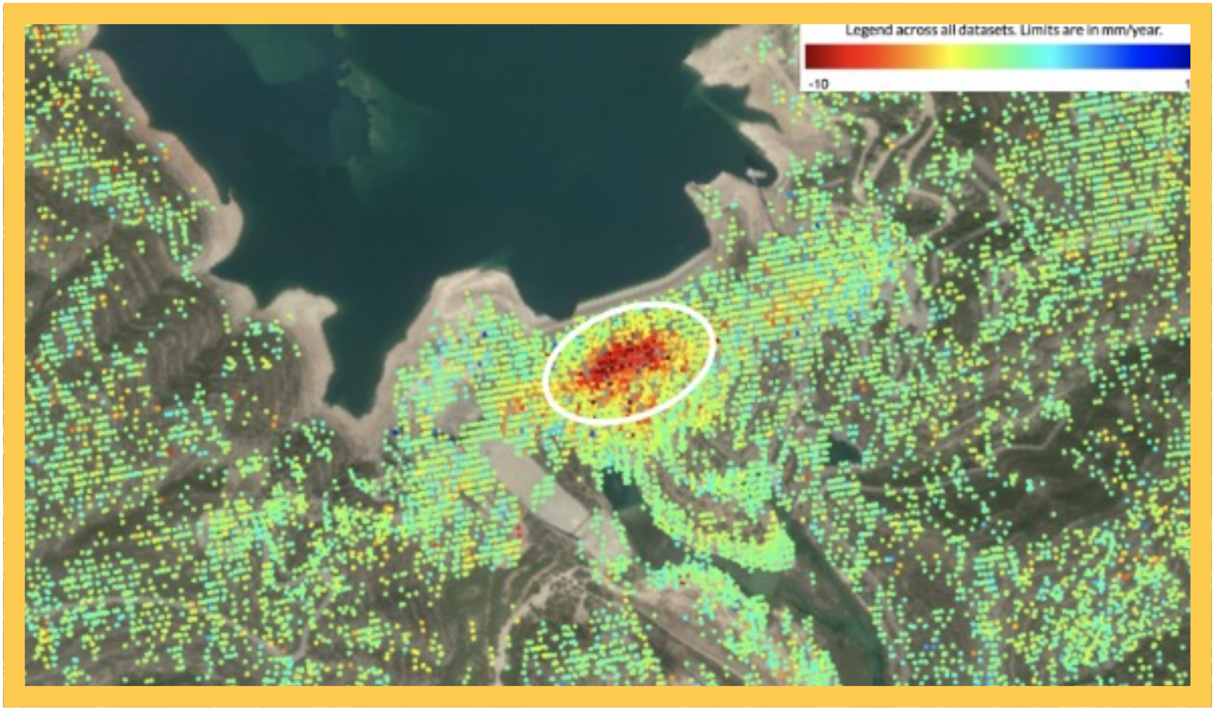


Fig. 13 **EGMS service image Land subsidence around a dam in Spain (7.6 mm/year)**

ticipation of major accident risks.

3.2 Managing infrastructure in response to weather conditions

Energy infrastructures are particularly sensitive to weather conditions and vulnerable to extreme climatic events. Proactive management and adequate preparation can mitigate the impact of these events on the integrity of electricity networks. The use of meteorological and satellite remote sensing data plays a major role in this preventive approach. The following sections explore how these data are used, both during extreme events and in the management of normal weather variations.

- **Extreme events**

Extreme weather events, such as storms and floods, can have catastrophic consequences for the integrity of electricity infrastructures. These impacts can include the breakage of lines, the cascading collapse of pylons or the submergence of critical equipment. Satellite meteorological data is used upstream of the event to provide accurate forecasts. These forecasts can then be used to prepare the network for a fallback situation, on sections likely to be less affected, using contingency and topological reconfiguration analyses to limit the risk of widespread outages.

In addition, the accuracy of risk forecasts is further improved by combining satellite data with data from storm forecasting and lightning strike location systems using antenna networks deployed on the ground. In this way, the areas likely to be affected by storms and lightning strikes are better identified, enabling electricity companies to pre-position their response teams and equipment in the best possible way, reducing response times and minimising service interruptions in the affected areas once the event is over.

Most electricity companies have weather forecasting data services that they integrate into their control centres. This integration enables them to optimise operations and strengthen the ability of electricity networks to withstand extreme weather events and quickly restore service after an interruption.

After a storm or natural incident, satellite images can be used to quickly assess the extent of the damage. In the hours or days following the event (with short revisit period satellites such as Pleiade Neo and Sentinel 2), these images provide a detailed view of the areas affected, particularly when massive tree falls have led to widespread destruction of power lines.

Thanks to the high resolution of satellite images, it is possible to identify precisely where infrastructure has been damaged or destroyed. This rapid detection capability is essential for several reasons. Firstly, it enables electricity network managers to prioritise their response according to the severity and extent of the damage. Response teams can be deployed more efficiently because they have an overview of the damage and potential obstacles on the ground. This not only improves worker safety but also the efficiency of infrastructure restoration operations. The worst affected areas can be prioritised for urgent repairs, helping to restore service more quickly and minimising disruption to end users.

Finally, the data obtained from satellite images can be used for post-incident analysis, so that preventive measures can be put in place to reduce the vulnerability of infrastructure to future extreme events. By incorporating this information into resilience plans,

Fig. 14 **Observation of the damage and destruction of the hydroelectric dam after the storm in Derna, Libya in 2023 (Pleiades Neo images (30 cm resolution)**

electricity companies can strengthen their ability to anticipate and manage the impact of natural disasters on their networks.

- **Climate variations**

Normal climatic variations, such as wind, sunshine, cloud cover, rainfall and ambient temperature, do not generally cause damage or power cuts, but they do have a major impact on electricity production and the efficiency of electricity networks.

Conventional meteorological data from satellites plays a fundamental role in forecasting electricity production. This data is often supplemented by local temperature sensors, solar irradiation sensors and anemometers, which can be integrated via the satellite-based Internet of Things (IoT) to provide precise, localised information for real-time grid adjustment and balancing.

04. Maintenance operations and predictive maintenance

The areas of application for satellite imagery in maintenance are as follows :

- Geo-referencing of infrastructure assets and equipment, with different modes of analysis and representation,
- Detection, census and inventory of assets using «robot mapping» technologies based on LiDAR, 2D and 3D scanning and automated image analysis,
- Asset and maintenance management (on fault and in predictive mode), condition

management (asset condition) and failure risk management with digital solutions such as APM, right through to the creation of Digital Twins,
- Managing on-site interventions and inspections,
- Vegetation management.

In connection with these areas of application, the operational and economic objectives for an electricity company are as follows :

- **Improving the quality of asset data.** The collection and verification of accurate data can be used to derive useful information about assets, enabling the development of effective «digital twin» models for the detailed representation of infrastructures, their operational conditions and various modelling and risk analysis simulations.
- **Monitoring network condition and forecasting.** Asset condition monitoring is important because it provides information about the health of assets. The aim is to use condition information to detect early signs of failure, enabling maintenance and replacement programmes to be optimised as part of a predictive maintenance approach.
- **Optimise maintenance operations.** Improve the profitability of inspection and maintenance programmes by reducing expenditure and/or increasing the added value of the results of the various programmes.
- **Identify encroachments effectively.** The critical assets of the network include pylons, crossarms, and conductor lines. Encroachments can be caused by vegetation and, in many countries, the proximity of buildings.

The methods and actions to achieve these objectives are of several kinds :

- **Stocktaking and asset management**
  These activities involve creating or updating detailed inventory databases, often by retrieving and aggregating data from multiple sources (GIS, manual files, Excel, ERP, etc.), which may be incomplete or out of date, and must include the geolocation and sufficiently detailed characteristics of each asset (pylons, cables, insulators, substations, buildings, transformers, etc.). Precise knowledge of asset location and updating is often difficult to achieve in dynamic mode.
- **Ground inspections**
  These activities relate to inspections carried out by agents climbing on poles, aerial inspections close to the ground on a lifting platform, or using poles, or simply by visual inspections from the ground.
- **Aerial inspections**
  These activities are carried out either at low altitude using drones or helicopters, or at medium altitude using fixed-wing aircraft or autonomous drones, or at very high-altitude using satellites.
- **Inspection data processing**

Inspection data processing involves, on the one hand, the collection of results from inspections and tests, which can be manual by entering the results on test sheets or, in recent trends, automated using photographic or LiDAR sensors, and on the other hand, analyses to obtain an inventory and identify assets and their surroundings requiring short-term or immediate maintenance operations. In addition to mechanical and electrical inspections of assets for oil leaks, corrosion, etc., this approach also includes analyses of line ground clearance, structural clearances and clearances from vegetation.

- **Predictive analysis**
  These activities relate to the analyses and calculations that will be carried out based on statistical, scientific or business models, or with the help of AI, applied to the results of inspection data and initial processing. For example, data on vegetation density and location, as well as vegetation growth forecasts, can be used to assess line encroachment in predictive mode.
- **Real-time monitoring**
  This activity relates to the installation of sensors (IoT) in satellite or terrestrial communication to detect lightning strikes, floods, forest fires, land deformations, or to collect information from telemetry or SCADA systems, for example.

4.1 Satellite data and maintenance information systems

Utilities manage numerous information systems such as ERP, customer management systems (CMMS), maintenance management systems (CMMS) and works management systems (WFM), as well as control tools such as supervisory control systems (SCADA), energy management systems (EMS) and distribution management systems (DMS). Most utilities also use a GIS (generally from one of the leaders, ESRI or Smallworld). For distribution networks, the latter is often incomplete and difficult to keep up to date due to the lower cost of assets, their very large number, and their constant evolution.

The increasing availability of satellite data raises questions about its effective use and integration into the environment of the driver information and maintenance management systems described above. The sheer volume of data, the high accuracy of the maps and the new fields of application mean that operational modes and the performance levels required of the systems need to be reassessed. This includes interfaces with existing systems, the ability to process massive volumes of data, the right level of complementarity with GIS, speed and ease of access to information, and interfaces with CMMS and other systems.

CMMS systems with work management (WFM) are essential tools for managing teams and resources on the ground for routine work and emergencies. For example, a city like Rio de Janeiro can require up to 15,000 interventions per day in the event of events.

The WFM organises interventions and enables the details of each intervention to be collected on site.

With ageing fleets and growing networks, and faced with regulatory and environmental constraints, companies need to optimise their infrastructure to improve network durability, minimise the risk of failure and reduce maintenance costs. Companies are therefore looking to equip themselves with asset management systems (APM) that integrate asset inventories, monitoring of maintenance inspections and incidents, assessment of asset health and prescriptive and predictive analyses. As with CMMS, these APM tools need to be able to manage the massive volume of information rapidly when it concerns hundreds of thousands, or even millions of assets for the largest transmission and distribution networks. Satellites then contribute to the performance of APMs, which integrate geosatellite mapping to provide a holistic view of the state of health of assets and their surroundings. This represents a step towards real time digital twins of the health condition on geosatellite representations.

05. Vegetation management

Sizing up the problem for electricity companies

A study by fortuneUSinsights for 2018-19 estimates that OPEX spending on vegetation management amounts to $8 billion annually in the United States, which could translate into around $30 billion worldwide.

Similarly, a study by the CNUC (College of Nature Resources, USA) of more than 60 electricity companies showed that almost a quarter of incidents and outages were linked to vegetation.

For an electricity distribution company, vegetation management alone can account for 30% of OPEX, and 10 to 15% for a transmission company.

Poor vegetation management can therefore have a significant impact on key service quality indicators such as SAIFI (average interruption frequency index) and SAIDI (average interruption duration index per customer). Over and above the regulatory obligations and penalties, this can have dramatic consequences.

One of the most emblematic examples is the series of wildfires that affected California in 2017 and 2018. The investigation determined that the ignition of the fires was attributed to trees that should have been cut down and came into contact with power lines operated by the company PG&E. As a result, PG&E faced liabilities amounting to billions of dollars due to inadequate maintenance and underestimation of risks. These incidents have brought the issue of exposure to fire-related risks to the top of the priority list.

The management of assets such as power lines and pylons involves huge volumes, usually in the hundreds of thousands. For example, EQL in Australia manages 1,500,000 pylons, RTE in France has 262,000, and PG&E in California has 700,000, covering distances of tens or even hundreds of thousands of kilometres of lines. This sheer volume, combined with the diversity of territories and widely differing population densities, contributes to the complexity of managing these infrastructures. By way of illustration, the estimated value of the transmission and distribution (T&D) networks installed in the United States is USD 2,000 billion.

It is also a regulatory and risk management issue for companies. Legal obligations to manage vegetation, mandatory inspections of pylons and lines, as well as monitoring areas of high population growth and unplanned construction are constant challenges. Electricity networks can cause significant damage, particularly by starting fires, especially in forested areas during periods of drought. In addition, they must consider the risk of pylons «sliding» in areas of unstable terrain, such as mountainous, tropical and drought-affected areas.

In summary, the reduction in OPEX, which accounts for up to 30% of the total expenditure of utilities in the US, combined with increased regulatory and security constraints and the objectives of more resilient networks, is driving utilities to seek high-performance solutions with a holistic approach to optimise these expenses.

The problem of lines with vegetation

An overhead power line has what is known as a sag, which depends on the conductor, the ambient temperature, the tangential wind and the current flowing through the line, as well as a sway, which is the sway or oscillation of the line as a function of the wind. A power line is therefore not a «static» piece of equipment but evolves vertically and horizontally. Linking the model to operating data during modelling is therefore also necessary for assessing encroachment zones.

Aerial and satellite inspections

The companies use different technologies and methods to address vegetation management issues such as :

- Helicopter overflight with LiDAR and photography (visible and near-infrared spectrum),

- The use of near-infrared satellite imagery,
- The use of drones to inspect pylon heads (RTE, for example, has trained more than 500 operators on Flying Eye drones),
- Trials in the USA and Australia of autonomous drone flight and Beyond Ligne of Sight (BVLOS) in agreement with the civil aviation authorities,
- The use of LiDAR on the ground to model distribution infrastructures,
- The use of ground-based near-infrared cameras for vegetation.

Despite the dynamism of the satellite imagery sector, most of the imagery still used today for inspections and vegetation is of aerial origin (helicopter, aeroplane and drones). Satellites are used more for mapping and fire management support, with projects such :

- Collaboration in 2023 between CNES and Kayrros,
- The GardeFeu mission in Canada, scheduled for 2029. The GardeFeu mission will be a constellation of satellites whose infrared sensors will measure the energy produced by forest fires, known as fire radiative power (FRP),
- Collaboration between Cerema and CNES in France to characterise fires in terms of intensity and propagation speed using PRT (Total Radiative Power) data.

In the field of fire monitoring, the current high-resolution definition of visible imagery (30 cm) is starting to make satellite imagery usable for covering large areas. However,

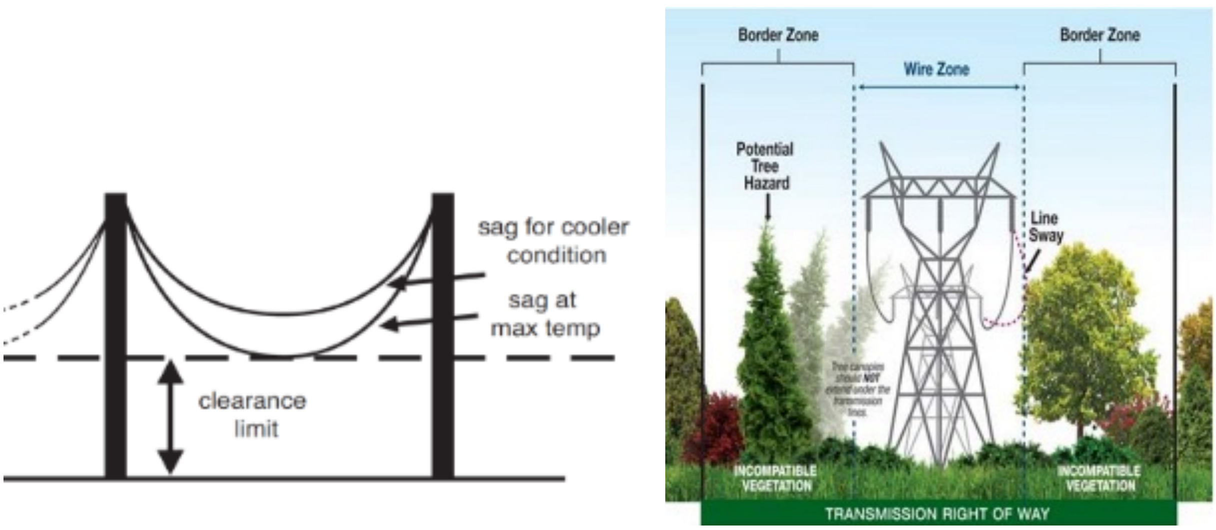


Fig. 15 **Representation of safety zones linked to line sag (SAG) and oscillations (SWAY)**

the results remain too imprecise for detecting vegetation encroachments on power lines, even in the multispectral domain.

Satellite data for vegetation management

The arrival of satellite constellations has considerably reduced the cost of satellite images. However, these images are not yet commonly available in the multispectral bands needed for NDVI analyses. Synthetic Aperture Radar Interferometry (InSAR) is still problematic for determining encroachment.

However, SAR and InSAR images enable very precise elevation measurements to be made on volumes of vegetation (less so on the tops of the trees themselves). By merging and interpreting optical data with radar data, it is possible to improve the assessment of corridor zones and the risks of encroachment.

Use of aerial photos and LiDAR in combination with satellite images

Several projects or existing companies (such as LiveEO) are working on improving assessments by combining satellite imagery with aerial photographic and LiDAR data.

The implementation of Artificial Intelligence for data processing enhances the ability to merge and correlate results from different operations: traditional drone flyovers, ground inspections, and LiDAR captures of infrastructure. AI applications could extend to recommending actions at various time scales, including predictive approaches. The impacts of climate change (flooding, landslides in mountainous areas) and megafires make these new treatment capacities imperative.

An electricity company, EQL (Queensland, Australia), has taken a comprehensive approach this challenge by implementing a complete and coherent database system. This approach aims to manage the volume and diversity of collected information to optimise inspection and vegetation management policies. This step serves as a prerequisite for applying a Machine Learning process to heterogeneous data.

5.1 Dynamics of Aerial Imaging

As a preamble and as an indication, the orders of magnitude of the costs per flight hour can be outlined as follows: a drone, in autonomous flight, will fly approximately three times slower than a helicopter and thus a drone mission will last 3 times longer. Ameren quotes an all-inclusive helicopter flight hour in the USA at $9,000/hour, compared with

Fig. 16 Processed LiDAR Drone image

$750/hour for a drone.

The use of LiDAR

LiDAR stands for Light Detection and Ranging. As a reminder, a LiDAR is a piece of electronic equipment that is part of the time-of-flight (ToF) sensor family. A LiDAR uses a lase optical beam for detection, analysis and tracking. It uses a calculation method to determine the distance between the sensor and the target obstacle.

The aerial imagery market is highly fragmented, both geographically (around 50% in North America) and in terms of use. The main leaders account for no more than 25% of the global market.

However, it remains worthwhile to examine their portfolio, as they are best positioned, either through the acquisition of innovative startups or through internal development, to leverage the cross-functionality of applications. This enables them to accelerate the integration of images from different sources and benefit from large-scale automated processing for specific domains. North American players include Blom ASA, Digital Aerial Solutions, Cooper Aerial Surveys, Fugro, Landiscor Aerial Information, EagleView Technology, Nearmap, Kucera International, Quantum Spatial and Terra Flight Aerial Imaging Inc.

Dynamics of aerial imagery - the case of drones at the foot of a structure

The development of autonomous UAVs that can be operated on site (or via the Cloud), initiated in 2019 in Singapore and China, are now included in the catalogue of UAV manufacturers such as DJI as an industrial solution.

This equipment enables a pre-programmed inspection to be carried out following an incident, a weather event, for example, enabling a power substation or a section of corridor to be reported (if national legislation allows autonomous flights). DJI currently markets the DJI Dock as a standard solution for this purpose.

The data mix and consolidating the offering

At this stage, very few players have positioned themselves on global solutions combining a range of technologies (satellite, drones, aerial, IoT, etc.). While there are many regional or global players covering part of the offer, very few players have organised themselves to cover the whole field. This factor is not linked to the natural fragmentation of companies when it comes to services, but to the complexity linked to the fragmentation of technologies.

Some key players are beginning to organise themselves to offer a wider range of value and over a wider geographical area. The recent arrival (in terms of solutions) and breakthrough of Artificial Intelligence in many areas will undoubtedly accelerate the capacity to analyse the huge volumes of data generated by satellite or aerial (drone, plane, helicopter) imagery, as well as enhancing instant analysis of inspection photographs

.

Multi-technology, multi-product solutions, supported by an automatic image analysis platform and applications, will undoubtedly rapidly transform, if not revolutionise, this market.

05

IoT sensors Satellites

In the field of IoT (Internet of Things) sensors, particularly those connected to the Internet via satellite communications, the measurement of the operational state of transmission lines and towers is evolving rapidly. DLR (Dynamic Line Rating) is the technology currently in vogue on every continent. The question is open as to whether these or other sensors could be extended to measure other information such as noise (corona effect), the presence of activity under the line, and the movement and inclination of the pylons.

In the field of distribution, there are also developments in North America on measurement equipment (temperature, current, voltage, fault detection) with research on making these IoTs more complete (SAG measurement, oscillation, fire detection, imaging) with a simplified approach to installation and autonomy (self-powering) of IoT sensors on the line.

Regulatory frameworks are evolving, and it is difficult to build new lines in many parts of the world. For example, ACER in Europe (the European Regulators Agency) now requires electricity companies to measure and provide the market with real-time capacity for corridor lines (and constrained lines) outside the corridor, which will require many transmission lines to be measured in real time, either using IoT or weather stations and modelling. All projects to build new assets will be refused if existing ones are not used to their full capacity in real time, which should increase the need to equip lines with satellite-based IoT sensors, in the event of a lack of terrestrial radio coverage.

There is a lot of work being done to install these IoTs cost-effectively (Schneider Electric patent for installing IoTs using drones on MV networks, for example). The Internet of Things (IoT) is a key element in the creation of true digital twins of asset operational conditions. By providing real-time data, the IoT can improve modelling of asset conditions for more efficient management.

In terms of IoT, most of the current instrumentation is located in electrical substations, whether for transmission or distribution. However, the need to monitor infrastructure far from these substations, as well as the requirements of natural risk management (forest fires, land movements, collapses), are prompting more and more consideration to be given to the use of sensors on lines and pylons (see also the monitoring of line corridor capacities above). The development of satellite-communicating sensors solves the problem of «white» areas, which is particularly relevant to large, mountainous regions.

Here are a few examples of projects and companies in the satellite IoT field :

- Kinéis in France, with a satellite constellation planned for 2024, for fire detection projects using DRYAD fire sensors,
- Swarm in the USA,
- LeoBlue in France with a Bluetooth/satellite messaging system for natural disaster alerts.

06

Examples of projects

CPCS (Canada)

cpcs.ca

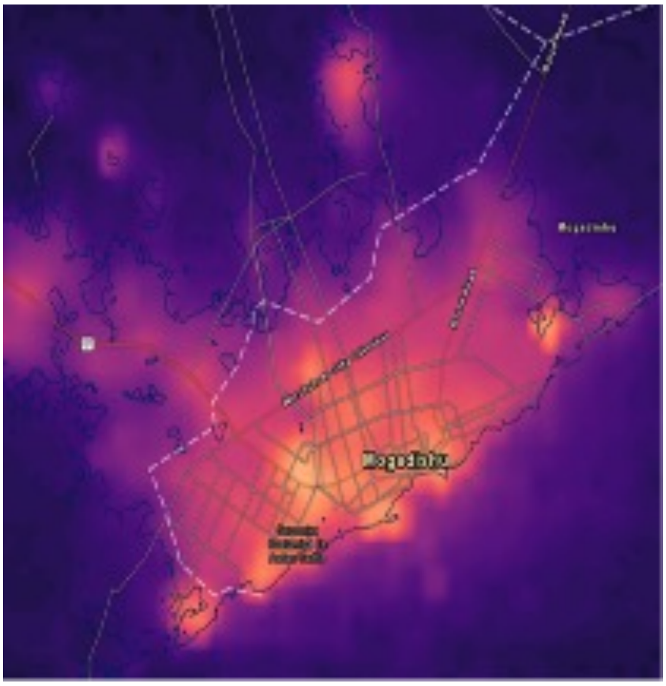
CPCS is an international consultancy firm specialising in the infrastructure sector (transport, energy) and public-private partnerships (PPPs). CPCS develops tools for processing voluminous data from maps/videos/photos/images for the identification, characterisation and geo-referencing of infrastructures.

Main technologies

- HD photography and GPS,
- AI-based image recognition,
- Characterisation and geo-referencing of MV and LV equipment (poles, transformers, insulators, crossarms, street lighting lanterns, etc.),
- Use of Night Time Light (NTL) satellite images correlated with economic activity, urbanisation and population density to analyse electricity coverage in order to optimise the planning and deployment of electricity services,
- NTL analysis uses VIIRS (Visible Infrared Imaging Radiometer Suite) images, correcting for atmospheric and radiometric disturbances to improve analysis of low-luminosity areas.

Project

- Using artificial intelligence to map electricity distribution networks, in collaboration with ASER and Senelec (SENEGAL),
- Modelling the extension of the distribution network in Mogadishu (Somalia).



ALTEIA (France)

https://alteia.com

Alteia offers a complete set of tools for rapidly aggregating, contextualising and analysing visual data from aerial and satellite imagery and other data sources.

Type of services

- Georeferencing of actual network infrastructure using imagery (satellite, mobile mapping, aerial),
- Census and analysis of solar farms using imagery (satellite, mobile mapping, aerial),
- Monitoring the construction of solar farms,
- Maintenance management by planning the collection, ingestion and analysis of visual data (photos, LiDARs, videos) by AI for fault detection and inventories,
- Vegetation management,
- Identifying the impact of climatic events by comparing before and after a storm.

Main technologies

- Optical Satellite Data,
- Aerial orthophotography, LiDAR scans (from planes, helicopters, cars),
- Google Streetview, Aether platform (ALTEIA) for visual data management with deployment of AI for processing.

Project

- Site selection,
- Monitoring site progress,
- Anomaly analysis for maintenance management.

MASAE (France)

www.masae-analytics.com

Masae Analytics provides services, mainly in Africa, Eastern Europe and the Middle East, on mapping needs following war damage or natural disasters, supporting planning and measuring impact. In the energy sector, Masae assesses the coverage and electrification potential of off-grid areas and uses geo-referenced infrastructure and socio-demographic data to help target areas with high potential for business development.

Type of services

- Segmentation of rural areas according to electricity demand (for mini-grid developers),
- Estimation of access to energy and population density in refugee camps,
- Mapping of existing electrical infrastructure in specific districts,
- Geo-referencing of infrastructure and equipment,
- Management of vegetation and vulnerable lines,
- Identification of areas affected by natural disasters and impact on energy/ telecommunications infrastructures.

Main technologies

- RGB satellite data,
- Satellite imagery sources for night-time lighting (NTL),
- Open-source Road layout data and pathfinder algorithms to redraw the network.

Project

Selection of priority areas for mini-grid deployment in Liberia.

The aim was to target non-electrified or unreliable areas with the highest population density, the greatest need for electricity and economic viability.

IGN with IGO (France)

www.igo.fr

IGO develops services and tools for structuring and analysing aerial, satellite or terrestrial (LiDAR) data with partners such as (IGN, Geofit, Aerodata, etc.) or supplied by customers, to exploit them in 3D.

Type of energy services

- 3D representation of infrastructure (lines, substations) to improve decision-making, consultation and communication with citizens,
- Helps maintain vegetation.

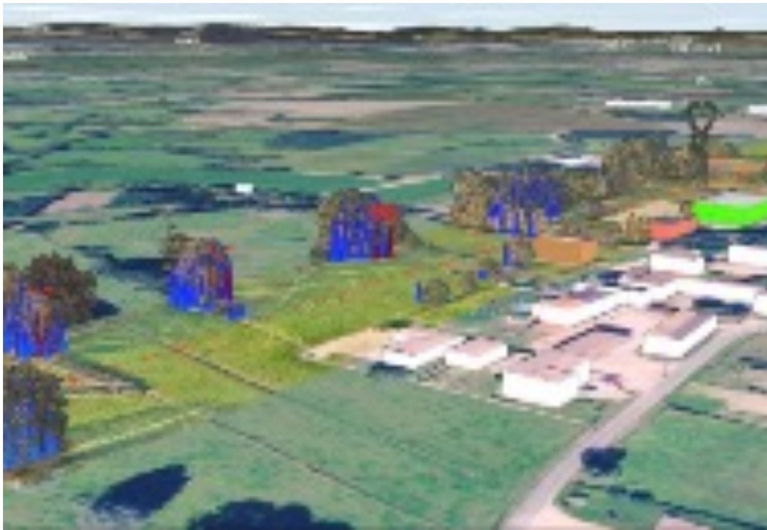
Main technologies

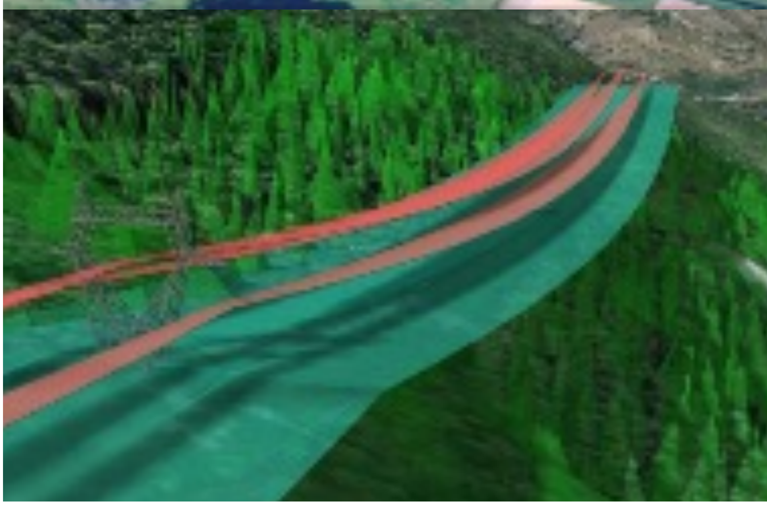
- RGB satellite data,
- Cartography,
- Aerial photo, LiDAR,
- 3D processing software (Skyline),
- RGB satellite, aerial photography, LiDAR on helicopter,
- Vegetation detection: 3D considered to calculate rights of way,
- Integration of LIDAR data and calculation results,
- Viewing pruning points.

Project

Asset Management

- Improving safety and maintenance - RTE,
- Optimise line transit in real time depending on the weather and vegetation.





METEORAGE (France)

www.meteorage.com

METEORAGE is a company specialising in lightning detection for the prevention of lightning-related risks. It operates a ground-based sensor detection network in France that has been extended to most of Europe, with services available worldwide.

Type of services

- Lightning risk assessment for the protection of energy infrastructures,
- Anticipation of imminent lightning risks to help decision-making for operations and safety,
- Real-time monitoring of thunderstorms and storms,
- Verification of lightning strikes after a storm, assessment of potential damage to electrical networks.

Main technologies

- Electromagnetic antennas,
- Reconciliation of information with satellite and meteorological data,
- A network of ground-based electromagnetic antenna sensors to pinpoint the exact location of the lightning strike,
- Cross-referencing with satellite meteorological data and maps,
- Representation on a base map (ESRI, Google, etc.) for visualisation and georeferencing.

Project

- Management of lightning strikes for electricity companies RTE, Elia,
- Predicting and identifying lightning strikes,
- Risk assessment,
- Correlation with lines affected and impacts detected nearby,
- Adapting the network (production and routing).

KAYRROS (France)

www.kayrros.com

Kayrros specialises in advanced data analysis for the energy sector, exploiting the potential of satellite images and data, combined with artificial intelligence.

Type of services

- Monitoring methane emissions and leaks,
- Monitoring the deployment of renewable energy projects and production capacity,
- Monitoring oil stocks by tank height measurement,
- Monitoring forest fires,
- Infrastructure mapping using satellite image analysis.
- Use of satellite data - Sentinel 1P, 2P, 5P,
- Detecting leaks and sources of methane emissions using satellite data,
- Automatic detection of pylons and lines using HD satellite image interpretation. (Pleiades, Planet, Maxar).

Main technologies

- Satellite imagery and meteorological data (Sentinel, Hyperspectral, Infrared),
- Real-time data processing with AI to optimise solar and wind generation and forecast production.

Project/technologies

- Methane Emissions Monitoring (Worldwide),
- Oil & Gas sector,
- Feasibility of mapping HV electricity networks in Ivory Coast,

Schneider Electric (France)

www.se.com

Schneider Electric is a French multinational company specialising in energy management and automation. In the field of Asset Management, Schneider Electric integrates advanced solutions that include the use of satellite images for monitoring and predictive maintenance of energy infrastructures with their Asset Strategy Advisor solution.

Type of services

- Asset management tools for maintenance,
- Vegetation management.
- Re-aligning assets (satellite photos make it easier and quicker to locate assets, as GPS pointing is tedious on a large scale,
- Risk analysis on the Asset Strategy Advisor platform.

Main technologies

- Asset Strategy Advisor,
- ArcFM GIS.

Project/technologies

- Identification of vegetation risk in the LOME conurbation (CEET Togo),
- Identification of the probability and consequences of failure of Medium Voltage conductors due to vegetation to optimise preventive pruning,
- 3D satellite images, 0.5m resolution (stereo) and 2D images at 3m resolution supplied and pre-analysed by LiveEO and Overstory,

HEXACODE (Canada)

www.hexacode.ca

Hexacode is a Canadian start-up that has developed an APM platform to create a real-time digital twin of the operational condition of critical electrical, mechanical and civil infrastructures.

Type of services

- Digital twin of APM asset health status,
- Integration of calculation models and asset inventories.
- Follow-up to inspections and tests,
- Damage modelling,
- Diagnostics and Alarms,
- History of events and changes,
- Statistics by asset model and for the entire network,
- Status and alarms displayed on a map with statistics.

Main technologies

- Hexacode APM software platform with georeferenced inventory and history,
- Condition assessment using modelling, real-time data, inspections and integration of AI models,
- Predictive and prescriptive analysis,
- Vsualisation of assets and results on GoogleMaps, ESRI world imagery, OpenStreetMap

Project/technologies

- Representation of network assets (poles, circuit breakers, pylons, transformers, etc.),
- Health assessment to reduce the risk of failure and optimise maintenance operations,
- APM with inventory tracking,

RTE (France)

www.rte-france.com

RTE operates France's electricity transmission network, which comprises 100,000 km of HV lines, 7,000 km of HV underground lines, 2,900 substations and 37 interconnections with neighbouring countries.

Project/technologies

- Vegetation management,
- Wind and PV production forecasts infraday and day +1,
- Defence plan (blackout),
- Detection of ground movements and structures,
- Asset management (Mona project),
- Copernicus Challenge projects (Vegetation detection, Infrastructure security),
- 15 helicopters, 500 UAV remote pilots. LIDAR to measure the height of vegetation near power lines, geosatellite images in support,
- PMU Systems (GPS Synchro).

VIDA Place (Germany)

www.vida.place

VIDA provides reliable risk data for any physical asset and portfolio on a global scale. This includes location-specific data on climate risks, biodiversity, environmental indicators, social and governance conditions, renewable energy potential, and more.

Type of services

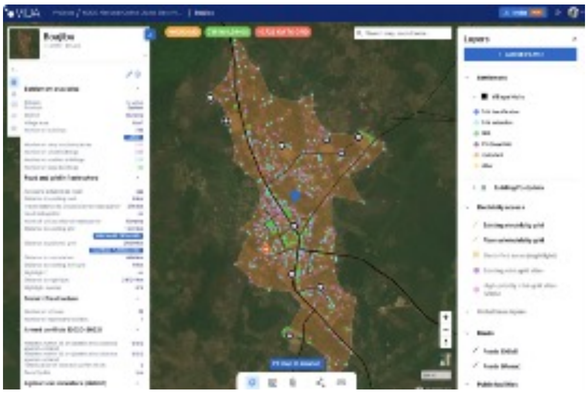
- Mapping software,
- Analysis services.

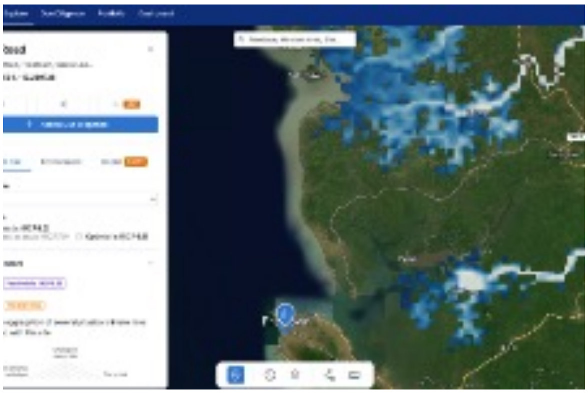
Main technologies

- Mapping software to assess deployment opportunities and the risks associated with the location of urban, civil and renewable energy infrastructure

Project/technologies

- Selection of the best location opportunities,
- Natural risk assessment,
- Spatial analysis of population zones, activities and flood risk,
- Analysis tools with multi-source technical and economic Artificial Intelligence.





Enedis (France)

www.enedis.fr

Enedis is the main operator of the electricity distribution network in France.

Project/technologies

- Network mapping on satellite map,
- Detection of anomalies on MV lines and poles (by drone with Alteia),
- Construction Digital twins with geo, satellite data for study and planning,
- Flood detection with satellite image and ground sensor correlation,
- HD camera on drones,
- AI for automatic detection of organs and anomalies,
- UAV remote pilots. LIDAR to measure the height of vegetation near power lines, Geo images in support.

GE Vernova (France)

www.hexacode.ca

GE Vernova is a multinational company specialising in the management and automation of energy networks.
In the field of Asset Management, GE is developing advanced digital solutions that include the use of satellite images known as Visual Intelligence for the monitoring and predictive maintenance of energy infrastructures.

Type of services

- Assets Management Performance for maintenance,
- Vegetation management,
- Turnkey projects and services.

Main technologies

- Visual Intelligence,
- GIS SmallWorld.

Project/technologies

- Vegetation management,
- Network planning and modelling,
- Asset performance management system for predictive maintenance and preparation of interventions in the field,
- Management of meteorological data, aerial photos and LiDAR for forecasting, production and analysis of incidents.

07

Players

Several companies and organisations active in the field of the study are listed in the table below. The list includes players who either participated directly in the interviews conducted during the study (names underlined in the table), or who were mentioned during the discussions or identified during the literature search. As the sector is dynamic, this list is not exhaustive and represents only a sample of players.

● Organization ● Company ● Start-up

Company	Offer
● ABSOLUTE SENSING	Satellite sensors IR optics
● AEROSPACE VALLEY	Competitiveness cluster
● AIRBUS	Pleiades satellites, SPOT, Vision, SAR Radar Constellation, Imagery
● ALTEIA	Imaging intelligence (all types of sources)
● ASTROCAST	IoT Satellite
● CLS /ALTAMIRA	Imaging intelligence (InSAR for landslide monitoring)
● CNES	Support Technology programmes and data exploitation
● CPCS	Intelligence Imaging
● DATA TERRA	Group of players (CNES, etc.) Intelligence Imaging
● DGE	Support for space innovation / France 2030
● ENEDIS	Utility
● ESA	Satellites (Sentinel, Galileo, MeteoSat, etc.)
● ESRI	GIS and Imagery Intelligence
● EXPERTISE FRANCE	AFD's technical expertise and project group
● GENERAL ELECTRIC	GIS, APM and imagery intelligence
● GEO4I	Intelligence Imaging
● GEODIGITAL	Intelligence Imaging
● GLOBEO	Intelligence Imaging
● GOOGLE	Satellite, Aerial and Terrestrial Image Supplier
● HEXACODE	APM, Imaging intelligence
● IGN	Intelligence mapping, imagery
● IMMERGIS	Intelligence Imaging
● JAKARTO	Intelligence LiDAR data
● JRC	European Community Research Centre
● KAYRROS	Intelligence Imaging
● KINEIS	Satellite IoT sensor
● MASAE ANALYTICS	Intelligence Imaging
● METEORAGE	Lightning sensor and location
● NOVELTIS	Contribution to the Satellite and Imagery Intelligence Programme
● PIXSTAR	Intelligence Imaging

PRELIGENS	Intelligence Imaging
QUANT-CUBE	Intelligence Imaging
REUNIWATT	Intelligence Imaging / Forecasting Solar Irradiation
RTE	Utility
SCHNEIDER ELECTRIC	GIS, APM, Imaging Intelligence
SIXENSE	Imaging intelligence (Slide)
SATELLITE VU	Imaging intelligence (Temperature)
TOMORROW.IO	Imagery intelligence (weather forecasting)
THALES -TELESPAZIO	Pleiades satellites, SPOT, Vision, SAR Radar Constellation, Imagery
UP42	Intelligence Imaging
VIDA PLACE	Intelligence Imaging
VITO REMOTE SENSING	Intelligence Imaging
ZESCO	Utility

08

Future prospects

01. Market size

The market for geosatellite data and technologies is growing rapidly, driven by the proliferation of Earth observation satellites, lower data access costs, the development of processing and analysis capabilities and growing demand from user sectors, including the energy sector. According to a study by Euroconsult, the global satellite data market is expected to reach **$8.1 billion** in 2029, compared with $4 billion in 2019, representing average annual growth **of 7,2 %**. The energy sector accounts for around 10% of the current market, or **$400 million**, and is expected to grow at a rate like that of the overall market.

The most common current applications for image analysis focus mainly on **the planning and expansion of power grids, the assessment of natural hazards and the large-scale monitoring** of transmission line corridors to identify areas requiring vegetation maintenance.

02. Current limitations and obstacles

However, in the energy and electricity sector, which has a long history of «terrestrial» technologies and operational uses, there are still obstacles to be overcome, the main ones being listed in the table below :

Nature	Limitations and impact on the electricity and energy networks sector
Resolution	High optical resolutions (2m-20m) in open data are still insufficient to identify and list MV distribution network assets, lines and some HV networks. It is not yet possible to detect faults on the infrastructure itself. The assessment of the distance of vegetation in contact with power lines is not sufficiently accurate to assess the risks of encroachment..
Revisit time	A long revisit time (several days) limits the ability to monitor incidents and damage following technical or natural events (tower failures, fires, etc.).
Detection capacity	Optical imagery is limited by meteorological conditions (clouds) and sunshine, leading to potential delays in updating images. These images can be supplemented and hybridised with SAR and InSAR data but require complex processing to interpret the data. The detection of pylons and lines by hybridisation of InSAR and optical images is still in its infancy.
Costs	The costs associated with the acquisition of very high resolution or specific data and their advanced processing can be prohibitive for some projects (price per km2 for large areas, cost and time for a request to target a specific area).
Training and Expertise	Correctly interpreting satellite images, especially for technical applications such as monitoring power grids, requires new specialist skills and a change in operational approach that takes time within companies.

Removing obstacles and optimising the use of geospatial data

Certain obstacles can be overcome by raising awareness and training players in the sector about the opportunities offered by geospatial data. This data must be reliable and secure, while offering superior detection performance at competitive costs compared with other terrestrial or aerial technologies.
In the area of paid-for data, a standardisation effort is also needed. This would reduce the cost of processing and interpreting data from multiple sources, making it more efficient and economical to use.

03. Future prospects

Access to satellite data has evolved considerably in recent years, thanks to a transition to an era in which open data, the Cloud and Big Data play a central role. These technologies have revolutionised the way satellite data is stored, processed and made available. Data access platforms and services such as Google Earth Engine, Copernicus Open Access Hub, Maxar and Planet Labs offer simplified access to vast quantities of satellite data, paving the way for complex, large-scale analyses.

This transformation encourages partnerships and collaboration, reducing the silos between disciplines. Open-data initiatives encourage the sharing of knowledge and data, strengthening research and development efforts within the scientific community and among industry professionals. This openness facilitates cross-disciplinary collaboration, enabling satellite data to be cross-referenced with other types of data, such as optical and radar data from the air and on the ground, physical sensors on networks and land, and real-time information and supervision systems.

In this context, the new generations of satellites, such as Worldview3-4 and Pleiades-Neo, offer significantly improved spatial resolution, **between 0.3 and 0.5 metres,** with revisit frequencies reduced to less than 24 hours. The new Worldview-Legion constellation promises revisit rates **of up to 15 visits per day**. The ICEYE constellations offer millimetre-level accuracy in InSAR technologies, and the first imagery with representations of lines, pylons or vegetation details is appearing.

The most significant advances include the ability to process raw data from native satellite resolutions and to hybridise data from various other sensors and sources. This hybridisation increases the possibilities for analysing the sites observed, by combining, for example, very high-resolution optical images with InSAR technologies for all-weather observability.

The increasing integration of artificial intelligence (AI) and machine learning into satellite data processing is radically transforming the ability to extract relevant information and detect anomalies. AI algorithms such as Deep Learning can identify complex 'patterns' in data, facilitating the automatic classification of objects in images. This ability to rapidly process and analyse large quantities of satellite data opens new prospects for monitoring critical infrastructure, their deployment and maintenance, as well as monitoring natural hazards. This new performance will push back the limits of detection and analysis and accelerate the exploration of new uses.

The outlook is therefore favourable for the energy sector, and particularly for electricity networks, where the number of items of equipment and infrastructure can run into millions over vast areas on the scale of a single country or even a single company, especially as network infrastructure is ageing in many countries, having to support the extension of the network on the one hand, and the integration of renewable energy plants (photovoltaic and wind power) on the other.

09

Conclusion

Satellite data and images represent a powerful and evolving tool for the power network sector. Their ability to provide detailed, large-scale information on electricity infrastructures offers considerable advantages for their planning, monitoring and maintenance.

Although there are still some limitations, such as the difficulty of optically identifying and discerning infrastructure that is too small or anomalies within the networks (MV pylons, lines, part of the HV, proximity of vegetation, etc.), electricity networks, with assets numbering in the hundreds of thousands (km of lines, equipment, substations, power stations, etc.), are good candidates for precise, regular satellite surveillance over vast areas.

Today's challenges are often linked to the right economic trade-off between a sufficient level of precision with average resolution and frequency of visit at low cost, and very high-resolution data with advanced processing for better results in terms of detection and geographical coverage. However, the dynamics of the sector are moving towards better results at the same cost.

The sector is therefore very active, with many major industrial and IT companies and start-ups positioning themselves to address a broad spectrum of applications in response to the needs of companies in the electricity and energy sector.

There are also several commercial and research partnerships between electricity companies, start-ups, manufacturers and players in the space sector to test applications and use cases. The Digital Energy Facility (DEF) programme, funded by the European Union and run by the Agence Française de Développement, which identifies and supports innovative digital solutions for the energy sector, bears witness to the abundance of applications in this sector, with several use cases illustrated in this study (detection of line infrastructure, vegetation management, assessment of electrification levels, etc.).

Other examples include the «Copernicus Challenges» managed by CNES and Aerospace Valley, with collaborative projects with RWE (optimal siting of offshore wind farms) and RTE (vegetation management), and the partnership between Planet Labs and PG&E (vegetation management and fire risks).

Rapid advances in satellite technologies, with the launch of new constellations, improvements in on-board sensors and processing, and the availability of native very high resolution images, are opening up new prospects for monitoring critical equipment, major transmission and distribution networks, and renewable energy plants. The integration of artificial intelligence and the combination of other data sources in image processing further enhance these capabilities.

Although precise real-time monitoring (a few hours) of operational conditions and incidents on infrastructures is not yet fully feasible, the market is getting closer. New constellations such as Airbus' Pléiades Neo, WorldView-Legion, CNES's COD3 programme, as well as SAR constellations from ICEYE and Capella Space, will offer resolutions of a few tens of centimetres, several visits per day, 3D images and all-weather surveillance capabilities thanks to SAR technologies. These advances will also enable the detection of millimetre-scale movements, considerably improving the management and maintenance of critical infrastructures.

The availability of all this data, which is more accurate and faster, will accelerate the development of digital image processing for image intelligence service providers, and will drive the evolution of current digital platforms for infrastructure management and maintenance within the companies themselves. These platforms will have to adapt with greater capacity in terms of the quantity of data, assets, components and modelling to be processed in real time to effectively manage this new mass of information. Companies are looking to implement different types of Digital Twin for networks, such as digital twins for the state of the environment, production forecasts and the state of health of networks to optimise operations and maintenance.

Artificial intelligence and automation technologies, such as automatic detection and characterisation of assets and their condition, will provide invaluable assistance. However, to be fully effective, tools and platforms will need to improve their scalability and, above all, their ease of use. This will enable design and planning teams, operations and maintenance teams, and infrastructure managers to take full advantage of these advanced technologies.

10

Bibliography and useful links

Bibliographic research is based mainly on internet searches for articles on the subjects selected, presentations of solutions on the websites and brochures of technology players (companies, start-ups), presentations of projects from institutional programmes, and documents collected from the players interviewed.

Bibliography

- «EGMS: A general introduction» - Dr Renalt Capes - 2nd March 2023
- « Auscultation par satellite pour la surveillance des ouvrages : application de la méthode d'interférométrie radar satellitaire pour la modélisation, la surveillance et la détection d'anomalies » - Guillaume Hochard, Fabien Ranvier - soldata
- « UCS-Satellite-Database 5-1-2023 » - Union of Concerned Scientist
- « Vers une gestion favorable à la biodiversité sous les lignes haute tension » - Sciences Eaux & Territoires n°25 – 2018 – Jean-François GODEAU - Ecofirst s.c.r.l. Jean-François LESIGNE - Attaché environnement à RTE
- « Amélioration des résolutions spatiale et spectrale d'images satellitaires par réseaux antagonistes » - Anaïs GASTINEAU - Thèse 2021 - Université de Bordeaux
- «EUSPA EO and GNSS Market Report» - European Union Agency for the Space Programme (EUSPA), 2024 issue 2
- https://atmosphere.copernicus.eu/sites/default/files/202207/CAMS_Wilfire%20Wrap%20Up_05.07.2022_Final_France.pdf

Useful links

- www.copernicus.eu/fr
- dinamis.data-terra.org
- www.connectbycnes.fr/challenges-copernicus-2023
- https://egms.land.copernicus.eu/
- www.spaceclimateobservatory.org
- https://sentinel.esa.int
- www.geosophy.io/

- https://pleiades.cnes.fr
- www.aerospace-valley.com/
- www.planet.com/pulse/planet-introduces-new-high-resolution-pelican-satellites-and-fusion-with-sar/ (Garde Feu Canada)
- Union of Concerned Scientists (record of the operational satellites)
- http://geo-entreprises.afigeo.asso.fr/ (l'annuaire des géo-entreprises de l'Afigeo.)
- https://maxar.com/
- www.igo.fr/igoglobe-cloud3d/
- https://earth.esa.int/eogateway/catalog
- www.esrifrance.fr/contenus-services-en-ligne.aspx
- www.pixalytics.com/category/earth-observation/
- www.ge.com/digital/applications/smallworld-gis-geospatial-asset-management
- www.kineis.com/en/kineis-iot-everywhere/
- https://swarm.space/
- https://energies-and-infrastructures-monitoring.groupcls.com
- www.eoportal.org
- www.applisat.fr

11

Satellite and service programmes

SCO: Space for Climate Observatory

www.spaceclimateobservatory.org

The *Space for Climate Observatory* is an international initiative launched in 2019, bringing together a group of public and private entities involved in the Earth Observation (EO) sector.

Example : The **Thermocity** project involves studying urban heat islands and heat loss by developing an urban thermography analysis tool based on satellite images.

Copernicus programme

www.copernicus.eu/fr

The Copernicus programme, led by the European Union in partnership with the European Space Agency (ESA), is the most ambitious Earth observation initiative to date. Designed to provide accurate, up-to-date data on the Earth's environment, it serves a variety of applications ranging from climate monitoring to natural disaster management. Thanks to a constellation of Sentinel satellites, Copernicus offers an unprecedented view of our planet, contributing to environmental protection, resource management and the security of European citizens. Its wealth of data is freely accessible, encouraging innovation and supporting European environmental policy. This programme marks a turning point in the way we observe and understand our planet, underlining Europe's commitment to sustainability and environmental preservation.

European Ground Motion Service

Copernicus EGMS - (European Ground Motion Monitoring Service) is an operational service for monitoring slow ground movements based on InSAR Sentinel-1, which has been in place since 2022. It offers unprecedented millimetre-level accuracy, which will enhance analyses of these movements. The Bureau de Recherche Géologique et Minière (BRGM - in France) participated in the validation of EGMS in 2022 and is carrying out projects in support of public risk management policies: volcanoes, earthquakes, vulnerability of coastlines to climate impacts, land movements and landslides.
These phenomena can be studied using satellite data to produce hazard maps or provide input for modelling. For example, BRGM uses optical satellite imagery (Sentinel- 2 Copernicus, SPOT, Pléiades) to estimate coastal bathymetry (underwater relief). BRGM also uses interferometric analysis of radar images (Sentinel 1) to monitor land movements associated with many types of risk (mining subsidence, shrinkage and swelling of clays, etc.).

It is likely that the results of these programmes will be very useful in the fields of energy networks for monitoring the surroundings and soil of infrastructures.

CO3D programme

The four CO3D (Constellation Optique en 3D) satellites are small satellites that will map the globe in 3D from low orbit, starting in 2025. They will meet the needs of both the public and private sectors.

To take over from the stereoscopic services (3D relief images) provided by the Pleiades satellites, CNES has set up the CO3D programme, the aim of which is to provide global geographical data in 3 dimensions. By flying over the same area at different inclinations, it is possible to generate 3D cartography from the images acquired over this area. This explains the need for four satellites to be able to acquire images quickly and monitor potential developments. Each CO3D satellite will be equipped with a single optical instrument, with a spatial resolution of 50cm in the visible red, green, blue and near infrared bands. After specific processing of the results on the ground, they will provide 3D maps of all the world's land surfaces, known as DSMs (Digital Surface Models) with an altimetric resolution of around one metre. The DSMs produced will cover around 25 million km² each year, a rate that is unique in the world for such a high level of accuracy. They will be used by defence and civil society but should also generate new opportunities for start-ups and established companies that will exploit them commercially. The entire globe should be covered in 5 years and depending on the needs of certain specific users (glaciologists, snow experts, geologists, etc.) some areas will be reshaped several times a year.

IGN HD LiDAR programme

The **IGN's HD LiDAR** programme, to be carried out between 2021 and 2025, will produce and disseminate 3D mapping of the whole of France's soil and subsoil using LIDAR data with an average resolution of 10 points/m2. The data will be acquired by a helicopter-borne LiDAR system after 7,000 flight hours. The data will be accessible via Opendata. The HD LiDAR data will be integrated into GIS systems (such as ArcGIS) and will complement the satellite data.

This programme meets the need for spatial observation and analysis in many areas of public action (risk prevention, observation of forestry resources, regional planning, etc.) and is a lever for the development of future value-added services. The energy sector stands to benefit from this data. Start-ups such as Tucoenergie and Cythelia Energy, in partnership with IGN, are developing applications for analysing solar potential based on 3D roof and topography data.

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Satellite data providers

01. Planet Labs

Planet Labs, often referred to as Planet, is an American aerospace and data processing company that operates a fleet of satellites to provide data and images of the Earth in near real time. With its constellation of more than 150 satellites, mainly CubeSats called Doves, Planet is able to offer global daily coverage of the Earth's surface, marking a revolution in access to Earth observation data. This information is crucial for a range of applications, from precision agriculture and environmental monitoring to disaster management and urban planning. Planet's information website provides users with an intuitive interface for accessing high-resolution satellite images, making it easier to take decisions based on accurate, up-to-date data.
Planet's new PELICAN constellation for Earth observation, designed to rapidly capture changes and events as they unfold, will comprise 32 satellites and provide 30cm optical resolution images that will be merged with SAR images.

02. Google

Google uses images from Maxar Technologies to provide some of the visual data for Google Earth and Google Maps.

Access to Maxar imagery for businesses and organisations is generally on a commercial basis, which means that the use of these images for specific projects or business applications may require the purchase of licences. Maxar offers a range of imaging products and services, and costs can vary depending on several factors, including the resolution of the images, the geographical area covered, and the type of use (commercial, government, educational, etc.).

For individual users, access to images via public platforms such as Google Earth or Google Maps is free. These services allow the general public to view high-quality satellite images free of charge, but use of these images for commercial purposes or redistribution generally requires an appropriate licence.

Companies and organisations interested in using Maxar satellite imagery for their projects should contact Maxar directly or through their sales channels for information on licences and associated costs.
Google combines data from a variety of sources to create the detailed images and maps we see on Google Maps and Google Earth. This process involves integrating satellite images, aerial photographs, 3D models and other geospatial data to provide a complete and up-to-date view of the Earth's surface. Here's a general overview of how Google processes and combines this data :

Data acquisition

- **Satellite images :** Google acquires high-resolution satellite images from suppliers such as Maxar Technologies (formerly DigitalGlobe), which capture images of the Earth from space.
- **Aerial photographs :** Google also uses photographs taken from aeroplanes, which offer a higher resolution than satellite images for certain regions.
- **Street View and 360-degree images :** For street-level views, Google uses cars, tricycles and even rucksacks fitted with cameras to capture 360-degree panoramic images.

Image processing

- **Overlaying and stitching :** Satellite and aerial images are overlaid and stitched together to create a continuous map. This involves adjusting colours, contrasts and correcting distortions so that images from different sources align correctly.
- **Geometric correction :** To ensure that images correspond precisely to their geographical location on earth, Google makes geometric corrections using known landmarks and GPS data.
- **Update and Maintenance :** Images are regularly updated to reflect changes in the built and natural environment. Google uses algorithms to detect areas requiring priority updates.

Creating 3D Models

- **Photogrammetry :** For 3D buildings and structures, Google uses photogrammetry, a technique that reconstructs three-dimensional objects from photographs taken from different angles.
- **LiDAR Data Integration :** In some cases, LiDAR (Light Detection and Ranging) data is also used to create accurate 3D models of terrain and geographical features.

03. ICEYE

ICEYE is a Finnish company that has deployed more than a dozen SAR satellites in orbit with the ambition of continuing to expand its constellation to improve global coverage and revisit frequency. However, the exact number of satellites in operation can change rapidly due to new launches and constellation updates. ICEYE aims to create an unprecedented Earth surveillance capability, providing frequent, high-resolution radar images for a variety of applications around the world.

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Appendices

01. Glossary

- **AI (Artificial Intelligence) :** A set of theories and techniques used to create machines capable of simulating human intelligence.

- **Digital Twin :** A digital twin is a virtual replica of an object, process or system that can be used for simulation, analysis and control based on real-time field information and model calculations. In the context of power networks, a digital twin can represent a physical infrastructure such as a power plant, a transmission line, or an entire distribution network.

- **EO (Earth Observation) :** Monitoring the planet to gather information about its physical, chemical and biological systems via satellites.

- **GIS (Geographic Information System) :** A system designed to capture, store, manipulate, analyse, manage and present spatially all kinds of geographic data.

- **GNSS (Global Navigation Satellite System) :** A system that provides geolocation and timing services to a GNSS receiver anywhere on Earth.

- **GPS (Global Positioning System) :** US satellite navigation system that provides geolocation and time information to a GNSS receiver anywhere on Earth.

- **HV (High Voltage) :** Electrical voltage levels generally higher than 36 kilovolts (kV). High-voltage lines are used to transmit electricity over long distances, from generating stations to distribution substations.

- **InSAR (Interferometric SAR) :** SAR interferometry. Technique using two or more SAR images to create maps of displacement or topography.

- **LIDAR (Light Detection and Ranging) :** Detection and telemetry using light. Remote sensing technology that measures the distance to an object by illuminating the target with a laser and analysing the reflected light.

- **LEO (Low Earth Orbit) :** Low Earth Orbit. Orbit around the Earth at an altitude of 160 to 2,000 kilometres, used by most Earth observation satellites for better image resolution.

- **MEO (Medium Earth Orbit) :** Medium Earth Orbit. The region of space around the Earth above low Earth orbit (LEO) and below geosynchronous orbit. Satellites in MEO, typically located between 2,000 and 35,786 kilometres above the Earth's surface, are often used for navigation and global communications, such as those in the GPS system.

- **Mini-Grids and Micro-Grids :** Also called “Mini-Réseaux“ in French, is a small-scale electricity network, generally powered by a combination of diesel generator and or storage batteries and renewable sources (mainly photovoltaic). These networks generally operate autonomously but can be connected to the main electricity grid. They serve whole communities or specific sectors such as hospitals, universities or industrial facilities.

- **M/L (Machine Learning) :** Automatic learning. Branch of artificial intelligence that enables a system to learn and improve from data without being explicitly programmed for certain tasks.

- **MV (Medium Voltage) :** Electrical voltage level used in electricity distribution, generally between 6kV and 36 kV.

- **NDVI (Normalized Difference Vegetation Index) :** An index calculated from satellite images to estimate the density and health of vegetation.

- **NTLI (Night Time Light Intensity) :** Analysis of light intensity at night.

- **EO :** Earth observation.

- **Panchromatic :** Refers to a type of satellite or photographic image that captures visible light in a broad band of wavelengths in a single layer, producing high-resolution black-and-white images. Panchromatic sensors are used to obtain fine details of the earth’s surface and can be combined with multispectral images to increase the spatial resolution of colour images.

- **SAIFI (System Average Interruption Frequency Index) :** Average frequency of power interruptions per customer.

- **SAIDI (System Average Interruption Duration Index) :** Average duration of power supply interruption, indicated in minutes per customer.

- **SWIR (Short-Wave Infrared) :** Are part of the electromagnetic spectrum, located between the near infrared (NIR) and mid infrared (MIR) bands.

- **VIIRS (Visible Infrared Imaging Radiometer Suite) :** Suite Used on a large scale to map light intensity and pollution.

02. Appendix (summary of the advantages, limitations and prospects identified in scoping interviews)

As a preamble, the main advantages, limitations and prospects mentioned during the initial discussions with the companies contacted are summarised below :

Main uses and benefits of geosatellite data

- Improving the quality of visualisations and automating the detection and geo-referencing of infrastructure (lines, pylons, etc.) in GIS-type platforms (Geographic Information System, Asset Performance Management) or other dedicated systems,
- Helping with the design, modelling, planning, deployment and operation of infrastructures and networks,
- Facilitate maintenance and interventions by operational teams in the field,
- Improve and accelerate the characterisation of their environment (land, vegetation, buildings,
- Assess climate risks and their impact (storms, floods, fires, etc.),
- Improve forecasts of renewable energy production.

Limits identified

- Resolutions of just a few metres limit the detection of small electrical infrastructures, particularly in distribution,
- Satellite revisit frequencies (1 to several days), which reduce the scope for short-term analysis applications to detect incidents in infrastructure and its surroundings,
- Costs can become high or irrelevant for large, sparsely populated areas requiring sub-metre resolution,
- The need for aerial photos, radar, ground inspection and sensors, which are still essential and costly to obtain the necessary precision.

The future prospects

In terms of Applications

- Improved observability of infrastructure condition (accuracy and frequency of monitoring),

- Consider detecting operational anomalies on the network (e.g. hot spots, line collapse, etc.),
- Improving the accuracy of monitoring vegetation cover around infrastructures,
- Improved observation of light levels and correlation with connections and areas of access to electrical power,
- Improve the production of real-time digital twins of the state of infrastructures (Develop Digital Twin presentation)

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Thanks to new technologies and services such as :

- Improvements in infra-meter, infra-red and radar resolution, in line with shorter revisit cycles,
- Increased capacity for multi-sector analysis (social, production, climate, environments), multi-source data (photos, satellites, IoT, external systems), with the massive contribution of AI (Artificial Intelligence), automated detection and characterisation of assets.

About the AFD Group

The AFD Group contributes to implementing France's policy on sustainable development and international solidarity. Composed of the French Development Agency (AFD), responsible for financing the public sector and NGOs, research, and training; its subsidiary Proparco, dedicated to financing and supporting the private sector; and Expertise France, a technical cooperation agency, the Group finances, supports, and accelerates the transitions necessary for a fairer and more resilient world.
It is with and for the populations that we build, in collaboration with our partners, shared solutions in over 150 countries, as well as in 11 French overseas departments and territories. Our goal? To reconcile economic development with the preservation of common goods: climate, biodiversity, peace, gender equality, education, and health.
Our teams are engaged in 4,200 projects on the ground, thus contributing to France and the French people's commitment to the Sustainable Development Goals (SDGs). For a shared world.

For more information, visit :

www.afd.fr