2023

# Report on Energy and Raw Materials

## User Needs and Requirements

#EUSpace

EUSPA
European Union Agency for the Space Programme

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# 1 INTRODUCTION AND CONTEXT OF THE REPORT

The Energy and Raw Materials sectors play a key role in the challenges of today, from the green energy transition to the supply of critical raw materials. Services enabled by Earth Observation (EO) and Global Navigation Satellite Systems (GNSS) data aim to tackle part of the complexity and challenges faced by the two sectors. Consequently, EO and GNSS user requirements, strongly interlinked with the growing and evolving market trends, are driven by:

- Heavy current and planned investments in renewables driven by climate change and recent geopolitical developments, as outlined in the REPower EU plan [RD1]. The deployment of these renewable energy sites brings about challenges where EO data and services can help (for example in the context of land use: where to place new very large renewable energy sites for maximum power generation yet with minimal impact on stakeholders like nature/biodiversity?)
- Depletion of the number of 'easy' mining deposits which haven't already been developed: mining exploration projects are forced to explore the most remote parts of the globe, making manual surveys expensive and time consuming, where EO data and services can provide cost-effective alternatives
- Increased environmental impact assessment and monitoring requirements for industrial permitting as companies face pressure to accept greater responsibility for environmental sustainability
- More performant upstream solutions tailored for specific market needs, such as high-resolution and frequent data, enable various applications such as the monitoring of key energy (delivery) infrastructure as well as mining sites.

In this framework, EO and GNSS solutions have a legacy of providing significant added value to the energy and raw materials industry will continue to do so.

The User Consultation Platform (UCP) is a periodic forum organised by the European Union Agency for the Space Programme (EUSPA), where users from different market segments meet to discuss their needs and application-level requirements relevant for Position, Navigation and Timing (PNT), Earth Observation (EO) and secure telecommunications. The event is involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers and application developers. It also gathers organisations and institutions dealing, directly and indirectly, with the two European satellite navigation systems, Galileo and EGNOS and newly since 2020, also with the EU Earth Observation system, Copernicus, and with GOVSATCOM, the upcoming system for secure governmental satellite communications. The UCP event is a part of the process developed at EUSPA to collect user needs and requirements and take them as inputs for the provision of user driven space data-based services by the European Space Programme.

In this context, the objective of this document is to provide a reference for the European Space Programme and for the Energy and Raw Materials communities, reporting periodically the most up-to-date user needs and requirements in the Energy and Raw Materials market segments. This report is a living and evolving document that will periodically be updated by EUSPA. It serves as a key input to the UCP, where it will be reviewed and subsequently updated and expanded to reflect the evolutions in the user needs, market and technology captured during the event.

The report aims to provide EUSPA with a clear and up-to-date view of the current and potential future user needs and requirements to serve as an input to the continuous improvement of the development of

the space downstream applications and services provided by the European Space Programme components. In line with the extended mandate of EUSPA, the Report on User needs and Requirements (RURs) previously focused on GNSS, have been revamped to also encompass the needs of Earth Observation (EO) commercial users and is now organised according to the market segmentation of the EUSPA EO and GNSS Market Report.

Finally, as the report is publicly available, it also serves as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of PNT and of EO technologies.

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by space downstream applications which combine several signals and sensors. Therefore, the report does not represent any commitment of the European Space Programme to address or satisfy the listed needs and requirements in the current or future versions of the services and/or data delivered by its different components.

## 1.1 Methodology

The following figure details the methodology adopted for the analysis of the energy and raw materials user requirements at application level.

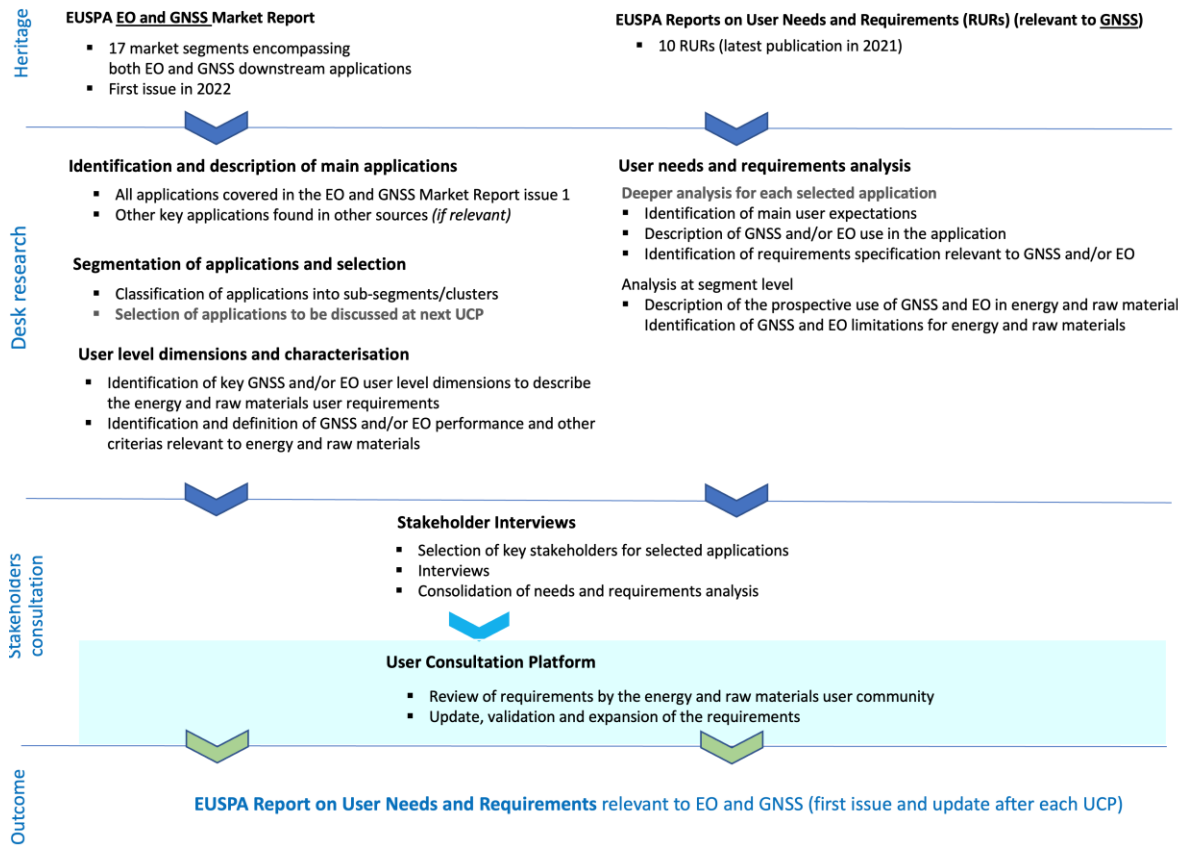


**Figure 1 Energy & Raw Materials user requirements analysis methodology**

As presented in the figure 1, the work leverages on the latest EUSPA EO and GNSS Market Report, adopting as starting point the market segmentation for EO and GNSS downstream applications and takes on board the baseline of user needs and requirements relevant to GNSS compiled in the previous RURs published by the agency.

The analysis is split into two main steps, including a "desk research", aiming at refining and extending the heritage inputs and at gathering main insights, and a "stakeholders' consultation" to validate main outcomes.

More in details, the "desk research" was carried out to consolidate when required the list of applications and their classification, to identify the key parameters driving their performances or other relevant requirements together with the main requirements specification, etc. A deeper analysis was conducted for a set of applications prioritised for discussion at the last UCP event. The outcomes of this preliminary analysis were shared and consolidated prior to the UCP with a small group of key stakeholders, operating in the field of the selected applications.
These requirements analysis results were then presented and debated at the UCP with the Energy & Raw Materials user community. The outcomes of the Energy & Raw Materials forum discussions were finally examined to validate and fine-tune the study findings.

The steps described above have resulted in the outcomes that are presented in detail hereafter.

## 1.2 Scope

This document is part of the User Requirements documents issued by the European Union Agency for the Space Programme for the Market Segments where Position Navigation and Time (PNT) and Earth Observation (EO) data play a key role. Its scope is to cover requirements on PNT and Earth Observation-based solutions from the strict user perspective and considering the market conditions, regulations, and standards that drive them.

The document is **split in two** parts: **Energy** and **Raw Materials**. For each section, it starts with a market overview, focusing on the market evolution and key trends applicable to the whole segment or more specific ones relevant to a group of applications or to the use of GNSS or EO. This section also presents the main market players and user communities. The report then provides a panorama of the applicable policies, regulations, and standards (section 4). It then moves to the detailed analysis of user requirements (section 5). This section first presents an overview of the market segment downstream applications, and indicates for each application, the depth of information available in the current version of the report: i.e., broad specification of needs and requirements relevant to GNSS and EO, partial specification limited at this stage to needs and requirements relevant to GNSS or limited to an introduction to the application and its main use cases at operational level. The content of this section will be expanded and completed in the next releases of the RUR.

Following its introduction, sections 2.5 and 3.5 are organised as follows:

- Sections 2.5.1 and 3.5.1 present current GNSS and/or EO use and requirement per application, starting with a description of the application, presenting main user expectations, and describing the current use of GNSS and/or EO space services and data for the application and providing a detailed overview of the related user requirements. The section addresses first "type A" applications, then "type B" applications and finally "type C" applications.
- Sections 2.5.2 and 3.5.2 describe the main limitations of GNSS and EO to fulfil user needs in the market segment.
- Prospective use of GNSS and EO in Energy & Raw Materials is addressed in sections 2.5.3 and 3.5.3
- Sections 2.5.4 and 3.5.4 include a synthesis of the main drivers for the user requirements in Energy & Raw Materials.

Finally, sections 2.5.6 and 3.5.6 summarise the main User Requirements for Energy & Raw Materials in the applications domains analysed in this report.

The current version of the report will be expanded and completed through its future releases. The RUR is intended to serve as an input to more technical discussions on systems engineering and to shape the evolution of the European Union's satellite navigation systems, Galileo and EGNOS and the EO system, Copernicus.

# 2 ENERGY

## 2.1 Executive Summary

This part of the report aims to enhance the understanding of market evolution, strongpoints, limitations, key technological trends, and main drivers related to the uptake of GNSS and EO data and services across the different energy domains, both renewable energy and fossil energy. In this first version of the report a focus is placed on renewable energies due to major accelerations in the planned deployment of wind, solar and other renewable energy plants over the coming decades. These elements are essential to frame the appropriate technology and service offering development against the requirements of the respective users.

### Key Trends and Market Evolution

An overview of the EO energy market trends is presented in section 2.2. Key trends include:

- **Climate change, geopolitical developments, and ever-increasing energy demand push governments to further accelerate the green energy transition**
- **Environment, Social and Governance (ESG) considerations drive need for identification of go-to-areas (land use) for massive new wind and solar energy sites as well as the reduction of unnecessary emissions of methane, supported by upcoming legislation forcing energy companies to reduce their emissions below a certain threshold.**
- **Grid balancing is becoming a major issue as intermittent renewable technologies (wind, solar) increases variability and limited predictability of the grid**

The steep drop in unit costs of common renewable energy sources such as on- and offshore wind, solar photovoltaics (PV), concentrated solar power (CSP), and Li-ion battery packs, forms an additional catalyst to the previously mentioned environmental and geopolitical drivers. In this pursuit, Europe has overshot its renewable energy target in 2020, which was furthermore the greenest year ever for the electricity mix. Much work however remains to achieve the outlined targets, where the dedicated EU Solar Energy strategy for example aims to double the solar PV capacity by 2025 and install 600GW by 2030, with some countries (Austria, Belgium, Lithuania, Luxembourg, and Spain) even pushing for 1000GW [RD46], equivalent to roughly the world's current capacity.

Key to the massive deployments of large wind and solar farms is land-use: these sites require significant space on- and off-shore and may negatively impact biodiversity [RD13] or even alter weather patterns [RD12]. Furthermore, the energy generation market is moving towards small scale production. As the electricity system relies on an exact balance of demand and supply to ensure reliable delivery, this balance must be exactly maintained. Traditionally this was done using large electricity plants and a well-developed electricity grid (mainly operating on fossil fuels), yet now with the large-scale deployment of intermittent renewable technologies (solar, wind), grid operators have a challenging task at hand to keep the balance.

### Current and Prospective Use of GNSS and EO in Energy

EO and GNSS powered services have a multitude of applications within the Energy segment. For renewable energy project developers, EO can aid in the selection of the site location by assessing the annual energy production (AEP) potential by measuring and modelling wind, solar and offshore renewable energy parameters. EO-based monitoring can also support grid resilience and reduction of the environmental impact of existing (delivery) infrastructure. EO also allows the efficient monitoring of assets, as well as and factual consistent progress of sustainability goals.

For prospective use of EO data the key challenge of land-use for new renewable energy sites must be considered: where should the massive new renewable energy sites be placed without an unacceptable impact on nature and biodiversity? In this light, new obligations have been imposed on Member States to identify "go-to areas" for the installation of renewable energy sites as part of the REPowerEU plan. For this application, EO data and services will play a critical role in the identification of such sites, considering key parameters such as the energy generation potential using satellite-measured solar irradiance or wind data as well as measuring potential impact on nature and biodiversity.

**Drivers for users' requirements**

In addition to the key market trends mentioned above, user requirements are furthermore driven by policy, regulation and standards as covered in section 2.3, mainly:

- **Policy: REPowerEU Plan**
- **Regulation: EU Taxonomy for Sustainable Activities**

## 2.2 Market Overview & Trends

### 2.2.1 Market Evolution

The complex Energy sector includes a long list of stakeholders such as governmental authorities, energy and utility companies, energy traders and supply chain managers. For them, satellite technologies can provide invaluable data under the form of various EO and GNSS applications.

**Introduction to the Energy Market Segment**

EO data has a multitude of applications within the Energy segment. For instance, EO data helps renewable energy project developers and investors identify the most suitable areas for the exploitation of renewable energy sources (solar parks, wind parks, hydropower plants, etc.), plan their development and monitor their integrity/status. It furthermore helps support identification, management, and overall reduction of risks (e.g., infrastructure damages caused by wind or dust storms). EO data helps threat monitoring and forecasting for specific risks not covered by standard weather forecasts and can complement general weather forecasts with specific local assessments for energy providers, while providing an assessment of the future evolution of risks.

As illustrated in EUSPA's Market Report 7, the revenues from the sale of both EO data and services to the energy and raw materials sectors in 2020 amounted to €305m. *Site selection, planning and monitoring for Renewable Energy* is the second largest segment in the market, holding 24% of the market share, where *Environmental impact assessment of energy and mineral resources plants* is in third place with a share of 17%.

Role of Copernicus Data & Services

In the Energy market segment, Copernicus data and services are specifically suitable for long-term projections and optimisation of energy systems, for example to verify the future energy mix and its reliability. It furthermore helps to understand the reliance of the new systems (solar, wind, ocean) on the climate system underpinning them.

To illustrate: wind engineers use Copernicus data and services not only to understand climate change but also to understand the variability in climate, seen for example in 2021 when the wind was well below average across a large swath of Northwest Europe. For more specific wind farm analysis service providers use the climate re-analysis data set from the ERA5 satellite (often a 20-year hindcast is considered optimal) that provides hourly data on many atmospheric, land-surface and sea-state parameters to dynamically downscale the data and provide information at much higher resolution, at windfarm scale, used in the investor due diligence process.

For solar PV, the Copernicus Atmosphere Monitoring's solar radiation service provides key insights, with historical time series information on the amount of solar energy that reaches the Earth's surface at user specified location for both clear sky and cloudy sky conditions.

### 2.2.2 Key Market Trends

The below key market trends drive user needs and requirements in the energy sector.

- **Climate change, geopolitical developments, and ever-increasing energy demand push governments to further accelerate the green energy transition**
    - Energy markets face extreme volatility driven by geopolitical tensions, while governments and businesses are increasingly committed to steep decarbonization targets. The demand for electricity is furthermore projected to triple by 2050, and by that time renewable generation is projected to reach 80–90% of the global energy mix [RD10].
    - **The key to reaching the energy transition goals is to increase the share of electricity in the power mix and increase the share of renewables in the generation of electricity** – this requires significant acceleration of the deployment of renewable energy sites, driving a significant part of the users' needs and requirements (e.g., for effective and cost-efficient site selection, planning, and monitoring)

- **Environment, Social and Governance (ESG) considerations drive need for identification of go-to-areas (land use) for massive new wind and solar energy sites**
    - As wind and solar sites already come at a lower cost than existing fossil fuels in most countries and are projected to become increasingly cost competitive globally, these sources of renewable energy will play a major role in the green transition [RD11] and will see a major acceleration in their deployments.
    - **A key challenge here is not cost, it is that of land use for solar and onshore wind.** Where will these massive wind and solar sites be built without impacting stakeholders like nature and biodiversity? Massive wind farms have the potential to disrupt weather patterns [RD12], and solar farms can create problems with imperilled species management, disruption of dispersal corridors, and loss of beneficial vegetation [RD13]. **The European Commission recognises this critical challenge and has obliged Member States to identify go-to areas for renewable energy site installations for the 2030 targets [RD1].** EO will play an important role in the identification of these go-to areas, aiding in specific aspects of the process, such as to assess power generation potential and potential biodiversity impact.

- **Grid balancing is becoming a major issue as intermittent renewable technologies (wind, solar) increases variability and limited predictability of the grid**
    - The electricity systems of the world depend on an exact balance of demand and supply to ensure reliable delivery. With the large-scale deployment of decentralized renewable energy production, the dynamics of the electricity system will be heavily affected. Traditionally, balance is maintained top down through large electricity plants and a well-developed electricity grid (mainly operating on fossil energy sources).
    - The deployment of intermittent renewable technologies (solar, wind) in the electricity system increases the need for regulatory and reserve capacity to handle the variability and limited predictability [RD13]. As renewable energy operators need to know how much power can be generated by renewables, it is critical to forecast renewable energy

generation in the next days, hours, or even minutes. Furthermore, utility operators have the need of an inventory of installed PV power versus the remaining PV rooftop potential on a neighbourhood scale, to be able to make proper forecasts on the scale of a few years (being the length of the investment cycle for new infrastructure).
    - To aid in the predictability, the key need is for better weather forecasts where EO data plays a major role and will drive the need for higher resolution data at regional scale (e.g., provided by Copernicus services such as CAMS), which will in part be filled through METEOSAT 3rd generation, due for launch in December 2022.
    - There is a trend towards achieving high grid security and resilience. The energy transition requires a large amount of new (underground) infrastructure and the construction of this creates risk to existing infrastructure. Furthermore, when critical infrastructure is damaged (e.g., Nord Stream explosion in 2022), this has major effects on the global markets and further pushes the need for secure and resilient infrastructure.

Technology trends include:

- Sensor diversification
- Full vertical integration along entire EO value chain versus focusing on small part of EO ecosystem
- AI for retrieving information from big data sets such as satellite imagery time series, aerial photographs and lidar point clouds
- Combining data sources and data services
- Public crowdsourced data as a source of information
- Sentinel 3 and Sentinel 6 increase the volume and coverage of data which can be fed into the Copernicus products used by experts in the offshore renewable energy sector

Research gaps include:

- Satellite data normalization across sensors from different constellations
    - There is more satellite data than can be analysed by humans. So, more automation and AI needs to be applied. Currently this is often focused on a specific satellite source. As a result, an automation or model working great on 50cm data from one satellite source will typically not work when it is fed 50cm data from another constellation. There should be more focus going into making this data interoperable.
- Constellation fusing
    - This is already happening to some extent: the real potential of EO lies in combining all sort of data from different EO sensors. Most research so far happens between combining different open data sources, but especially the combination of open data with various commercial sources has the potential to solve many monitoring challenges currently faced. Researching these types of combinations is currently mostly done at companies, who then focus on combining their commercial source with open sources. This is too limiting, the academic world should become involved as well, with the necessary funds to acquire and combine commercial data from different supplier to exploit the full potential of all that is already out there observing the earth.
- End User License Agreements outdated approach with respect to licensing/right to use imagery
- Current methane detection efforts focus on (1) large scale (global) emissions and (2) very small individual emitters. Research should be done to bridge the gap between large and small, to focus on screening country-sized area for medium-sized emissions with a focus on detection rather than precise quantification.
- Increasing spatial resolution for key energy variables (e.g., wind speed, wave height, wave period and ocean current speeds). Current resolution does not allow for accurate representation of

localised patterns where tidal energy deployments might be planned (i.e., in narrow channels and sounds).

### 2.2.3 Main User Communities

International associations and agencies represent and support various stakeholders in the energy value chain. The main user communities are listed below, which partly shape the energy users' needs and requirements.

- **The International Energy Association (IEA)**
  - The IEA is at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations, and real-world solutions to help countries provide secure and sustainable energy for all.
  - The IEA drives user needs and requirements through their wide reach, their various published analyses, reports, and recommendations
- **International Renewable Energy Agency (IRENA)**
  - IRENA is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource, and financial knowledge on renewable energy.
  - IRENA, like IEA, drives user needs and requirements through published roadmaps to help accelerate the green energy transition (see e.g., REmaps [RD52]).
- **International Association of Oil & Gas Producers (IOGP)**
  - The IOGP is the voice of the global upstream industry. Oil and gas continue to provide a significant proportion of the world's energy to meet growing demands for heat, light and transport. Their members produce 40% of the world's oil and gas.
  - Their **Geomatics subcommittee** is a major stakeholder when it comes to the use of EO in energy and strongly drives user needs and requirements.

Various sector- and region-specific associations exist for both the fossil and renewable energy sources and related infrastructure.

- **Solar Power Europe**
  - Solar power Europe provides the link between policymakers and the solar PV value chain. Their mission is to ensure solar becomes Europe's leading energy source by 2030.
  - Solar Power Europe drives user needs and requirements through their various work streams (e.g., on sustainability and digitalisation).
- **Wind Europe**
  - Wind Europe is the voice of the wind industry, actively promoting wind energy across Europe, with over 400 members from across the value chain: wind turbine manufacturers, component suppliers, power utilities and wind farm developers, financial institutions, research institutes and national wind energy associations.
  - Wind Europe drives user needs and requirements through their recommendations (e.g., on acceleration of permitting and related site selection criteria).
- **Ocean Energy Europe**
  - Ocean Energy Europe's mission is to create a strong environment for the development of ocean energy, improve access to funding, and enhance business opportunities for its members. It is the largest network of ocean energy professionals in the world. Over 120 organisations, including Europe's leading utilities, industrialists, and research institutes, and widely represents the interests of Europe's ocean energy sector.

- **European Pipeline Research Group (EPRG)**
  - The EPRG addresses issues of common interest concerning the technical integrity of oil & gas transmission pipelines, in the areas of pipe manufacture, pipeline design, construction, operation and maintenance.
  - EPRG has a track record of supplying guidance to the industry, especially in the area of pipeline safety and integrity, and thus drives user needs and requirements.
- **Pipeline Research Council International (PRCI)**
  - PRCI is a community of the world's leading pipeline companies, and the vendors, service providers, equipment manufacturers, and other organizations supporting the industry.
- **European Network of Transmission System Operators for Gas and Electricity (ENTSO-G/E)**
  - ENTSO for Gas (ENTSO-G) facilitates and enhances cooperation between (currently 43) national gas transmission system operators (TSOs) across Europe, to ensure the development of a pan-European transmission system in line with European Union energy and climate goals. ENTSO for Electricity (ENTSO-E) represents 39 TSOs for electricity and plays a central role in enabling Europe to become the first climate-neutral continent by 2050.

### 2.2.4 Main Market Players

Some of the main players involved in EO and GNSS are depicted the value chains[1] below.

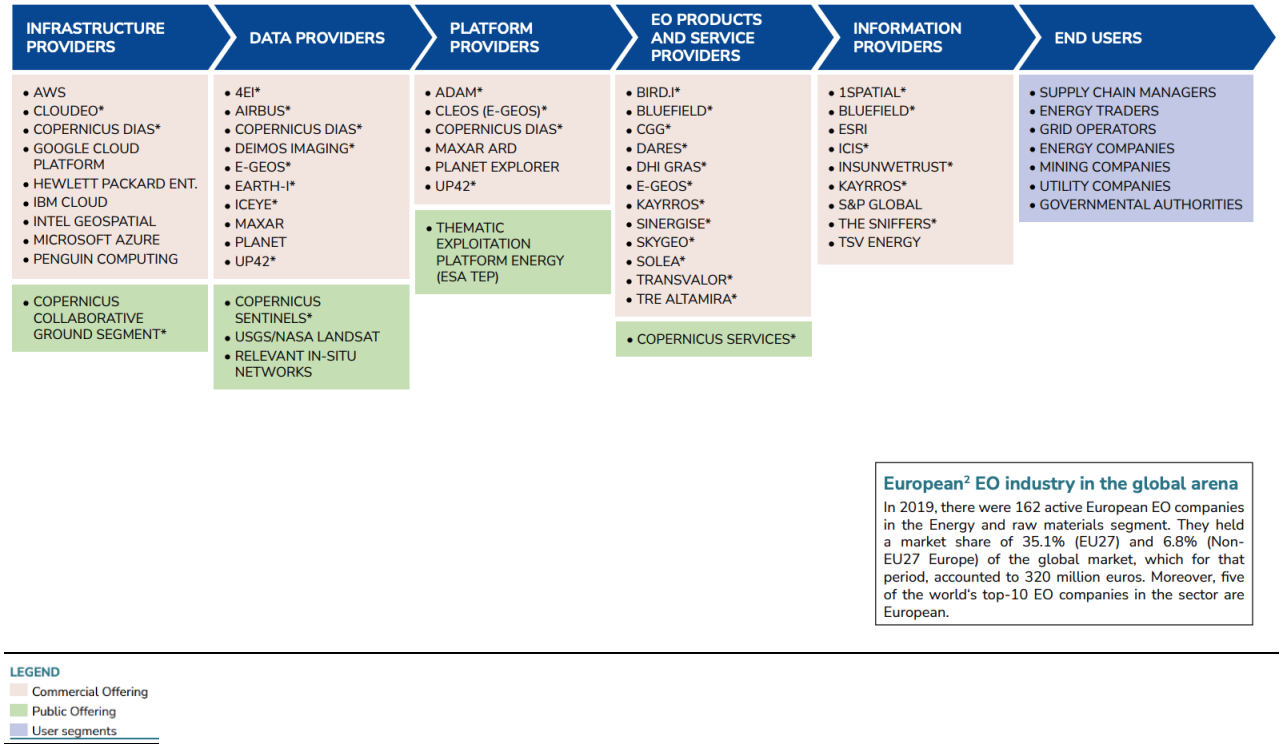


**Figure 2: Energy & Raw Materials Value Chain (EO)**

[1] Please consult the EUSPA EO and GNSS Market Report (issue 1, 2022) for more details

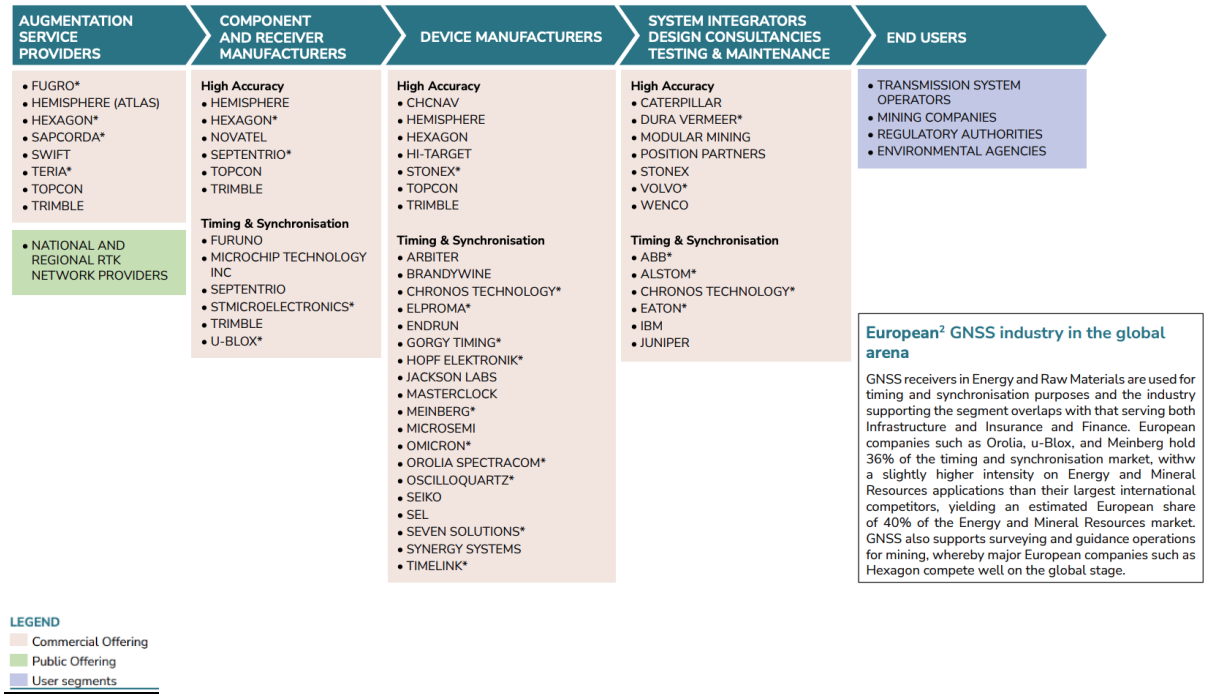


**Figure 3: Energy & Raw Materials Value Chains (GNSS)**

## 2.3 Policy, Regulation and Standards

The below policies, regulations, and standards drive user needs and requirements in the energy sector.

- **Policy: REPowerEU Plan**
  - The recent REPowerEU plan [RD1] is a direct response to the hardships and global energy market disruption caused by Russia's invasion of Ukraine. There is a double urgency to transform Europe's energy system: ending the EU's dependence on Russian fossil fuels, which are used as an economic and political weapon and cost European taxpayers nearly €100 billion per year, as well as tackling the climate crisis.
  - The further acceleration of the renewables roll-out is key to realising the plan's goals. It outlines the need to massively scale-up and speed-up renewable energy in power generation, industry, buildings, and transport to accelerate the EU's independence, give a boost to the green transition, and reduce prices over time. The headline 2030 target for renewables is also to be increased from 40% to 45% under the Fit for 55 package.
  - For the solar industry, there exists a dedicated EU Solar Energy Strategy [RD30] that aims to double solar photovoltaic capacity by 2025 and install 600GW by 2030. Specifically relevant for solar PV farms, but also for other large energy sites such as wind farms, the European Commission has made a recommendation [RD31] to tackle slow and complex permitting for major renewables projects, as well as a targeted amendment to the Renewable Energy Directive [RD32] to recognise renewable energy as an overriding public interest. Dedicated 'go-to' areas for renewables should be put in place by Member States with shortened and simplified permitting processes in areas with lower environmental risks.
  - **To help quickly identify such 'go-to' areas, services powered by EO data can play a major role** where furthermore the Commission is making available datasets on environmentally sensitive areas as part of its digital mapping tool for geographic data related to energy, industry, and infrastructure.

- **Regulation: EU Taxonomy for Sustainable Activities**
    - (Renewable) energy investors/operators now have increased interest in climate impact information, as the European Taxonomy of Sustainable Commercial Activities obliges such investors and operators to look at climate risks and to identify them in their current/future investments. For example, to install a new solar PV energy site, the project developer must perform an Environmental Impact Assessment (EIA) or screening that has been done in accordance with Directive 2011/92/EU.
    - For sites/operations located in or near biodiversity-sensitive areas (including the Natura 2000 network of protected areas, UNESCO World Heritage sites and Key Biodiversity Areas, as well as other protected areas), an appropriate assessment, where applicable, should be conducted and based on its conclusions the necessary mitigation measures should be implemented.
    - Another example for offshore wind is that the activity should not hamper the achievement of good environmental status, as set out in Directive 2008/56/EC, requiring that the appropriate measures are taken to prevent or mitigate impacts in relation to that Directive's Descriptors 1 (biodiversity) and 6 (seabed integrity), laid down in Annex I to that Directive, and as set out in Decision (EU) 2017/848 in relation to the relevant criteria and methodological standards for those descriptors.
    - **EO-data-powered solutions can specifically aid in these assessments (e.g., biodiversity assessment and impact monitoring).**

There is also current legislation that limits the uptake of specific EO applications, such as for example safety monitoring tasks when detecting third party activity around pipelines. Some countries' legislation prescribes this specific activity to be done from the air using helicopters, while EO solutions may provide an equally adequate service to address this need.

## 2.4 User Requirements Analysis

This chapter aims at providing a detailed analysis of user needs and requirements pertaining to the energy applications. The chapter furthermore aims to describe the different roles and needs covered by GNSS and EO and identify the corresponding requirements from a user perspective.

Table 1 below depicts the main applications making use of GNSS and/or EO technologies in energy. The list of applications is non-exhaustive and is expected to potentially grow and adapt according to the expected adoption of space technologies in the coming years and the innovations that should come with it. The current report is the first version of the energy and raw materials report on User Needs and Requirements, and thus considered a living and evolving document that will periodically be updated and expanded by EUSPA in its next releases.

While each one of the applications addressed in this document can benefit from GNSS and/or EO, the current issue of this report does not cover in detail the needs and requirements for all these applications. A categorisation was performed prioritising some applications based on their maturity level and relevance to the market trends and drivers. Other applications are foreseen to be covered in more detail in future versions of this RUR.

The following applications categorisation reflects the depth of information available in section 5:

**Application Type A:** these applications correspond to those for which an in-depth investigation is presented, and for which needs and requirements relevant to GNSS and EO have been identified and validated with *the energy* user community at the UCP.

**Application Type B:** these applications correspond to those not selected for in-depth investigation in the current version of the RUR, for which a partial specification of needs and requirements is provided, limited at this stage to the ones relevant to GNSS.

**Application Type C:** these applications correspond to EO-based applications, not selected for in-depth investigation in the current version of the document. A high-level description of the application is included considering that they will be further analysed and developed in next versions of the RURs.

The table below maps the seven **energy-related** applications to the three above-mentioned types. The following list of applications and their categorisation are **expected to evolve in the next versions of the document.**

**Legend**

EO only application

GNSS only application

Hybrid/synergetic application (combined use of EO and GNSS)

**Table 1: Energy applications, definitions, and categorisation**

| Segment | Sub-segment | Application | Type of application/ Level of Investigation | |
|---|---|---|---|---|
| **Energy** | **Energy Network Fidelity** | Energy network conditions monitoring | A | |
| | | Phasor measurement units (PMU) | B | |
| | **Environmental Impact Monitoring** | Environmental impact assessment of renewable energy plants | C | |
| | **Renewable energy** | Renewable energy plant design optimisation | C | |
| | | Renewable energy assessment potential and forecast | A | |
| | | Risk assessment for renewable energy assets | C | |
| | | Renewable energy site selection, planning and monitoring | C | |

The next section first addresses "type A" applications, then "type B" applications and finally "type C" applications, for which the level of provided information is currently the least developed.

Each EO-based "Type A" application will cover the needs and requirements for potentially several operational scenarios. For each scenario, a table summarises the EO related needs and requirements. The table template is illustrated below in Table 2 and explains the various inputs.

**Table 2: Description of needs and requirements relevant to EO**

| | |
|---|---|
| IFS | Identifier |
| **Application** | Application covered. |
| **Users** | Common users of the product/service. |
| **User Needs** | |
| **Operational scenario** | **Describes the operational scenario faced by the user, which requires a solution.** |

| | |
|---|---|
| **Size of area of interest** | Describes the area of interest (e.g., a miner is interested in a new mining site of 5Km$^2$). |
| **Scale** | Describes the scale of interest (e.g., a miner is interested to see at mm level the ground subsidence for the mining pit slopes). |
| **Frequency of information** | How often the user requires the information. |
| **Other (if applicable)** | Other user needs such as contextual information (weather data) or file formatting requirements. |
| **Service Provider Offer** | |
| **What the service does** | Description of the service that satisfies the user's needs. |
| **How does the service work** | (Technical) description of how the service works. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | Spatial resolution of the satellite imagery/data required by the service provider to realise the service |
| **Temporal resolution** | Frequency of satellite data (revisit time) over the area of interest. |
| **Data type / Spectral range** | Type of data (e.g., RGB, SAR) and spectral range (if relevant). |
| **Other (if applicable)** | Other data requirements. |
| **Service Inputs** | |
| **Satellite data sources** | Type of required data and examples of operational satellites that can provide these data. |
| **Other data sources** | Other sources of data that the service provider uses to realise the service. |

**Disclaimer:** The EO-related requirements presented in the next section should be considered as "work-in-progress". They must be seen as a first attempt to specify requirements relevant to EO and are likely to evolve throughout the UCP process.

Future versions of the RUR may consider additional parameters, such as data quality control and validation.

### 2.4.1 Energy network conditions monitoring

The situational awareness and monitoring capabilities of EO contribute through application such as monitoring the structural integrity of assets, monitoring land subsidence around energy infrastructure such as pipeline and plants, assessment of vegetation encroachments; and allowing for asset condition management damages, degradation, corrosion, etc.

The following operational scenarios and the related user needs and requirements will be covered in this section:

- **Pipelines**
  - Monitor third party activity around energy corridor (pipeline safety)
  - Detect and report suspicious activity around critical infrastructure that can indicate sabotage, vandalism and/or theft from (oil, gasoline) pipelines.
  - Critical pipeline infrastructure external stress assessment (subsidence induced network stress)
  - Monitor changes in above-ground pipeline assets
  - Monitor PV installations around pipelines
  - Risk-class assessments for pipelines
  - *Scenario for future evaluations: methane leak detection*

- **Powerlines**
  - Vegetation encroachment/management around powerlines
  - Flood risk and mapping
  - Landslide risk-assessment by providing input data for slope stability assessments
  - Storm damage assessment
  - Transmission line mapping
  - Monitor ground surface for subsurface powerlines

**Table 3: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Pipelines) - Monitor third party activity**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0021 |
| **Application** | Energy network conditions monitoring (pipelines) |
| **Users** | Critical linear infrastructure operators |
| **User Needs** | |
| **Operational scenario** | **Monitor third party activity around energy corridor (pipeline safety)** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | Daily - weekly - biweekly - triweekly - monthly (depending on regulatory requirements) |
| **Other (if applicable)** | Need to comply with legislation requiring minimum monitoring frequency. Reliable thus weather independent service required. Service to be delivered based on ready to use information in the hands of both office as field staff. Needs satellites that always collect (like Copernicus program) and NOT only collect on tasking orders. |
| **Service Provider Offer** | |
| **What the service does** | Identify and report potential third party activities in and around a linear infrastructure corridor |
| **How does the service work** | Detect construction activities/infrastructure changes/excavating activities/heavy machinery/tree felling activities/site preparation or any irregular activity |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | SAR: 1-10m, MS: 1-10m, Optical: <50cm |
| **Temporal resolution** | SAR: At least once every "**Frequency of information**" interval. MS: At least once every "Frequency of information" interval. Optical: Multiple collection options per day -> one successful collection per activity per "**Frequency of information**" interval. |
| **Data type / Spectral range** | SAR/MS/Optical |
| **Other (if applicable)** | Latency SAR < 8hrs, Latency MS < 8hrs, Optical < 8hrs |
| **Service Inputs** | |
| **Satellite data sources** | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. |
| **Other data sources** | Pipeline-network definition, corridor definition, land use data. |

**Table 4: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Pipelines) - Detect and report suspicious activity**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0022 |
| **Application** | Energy network conditions monitoring (pipelines) |
| **Users** | Critical linear infrastructure operators and security contractors |
| **User Needs** | |
| **Operational scenario** | **Detect and report suspicious activity around critical infrastructure that can indicate sabotage, vandalism and/or theft from (oil, gasoline) pipelines.** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | Multiple times per day (and night) |
| **Other (if applicable)** | Frequent and timely info on suspicious activities. |
| **Service Provider Offer** | |
| **What the service does** | Detect and report suspicious activity near critical infrastructure possibly associated with vandalism, sabotage and/or theft |
| **How does the service work** | Detect with SAR day-and-night activities around the corridor. Assess risk using all available context info and alert in case of suspicious activity. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | SAR: 1-10m<br>MS: 1-10m |
| **Temporal resolution** | SAR: At least once every "**Frequency of information**" interval. Optical: Periodically updated base layer for human interpretation. |
| **Data type / Spectral range** | SAR/Optical |
| **Other (if applicable)** | Latency SAR < 1hr, Optical < 8hrs |
| **Service Inputs** | |
| **Satellite data sources** | ICEYE, Capella, SkySat, Pleiades, etc |
| **Other data sources** | Pipeline-network definition, corridor definition, land use data. |

**Table 5: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Pipelines) – External stress assessment**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0023 |
| **Application** | Energy network conditions monitoring (pipelines) |
| **Users** | Critical linear infrastructure operators/owners |
| **User Needs** | |
| **Operational scenario** | **Critical pipeline infrastructure external stress assessment (subsidence induced network stress)** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | Monthly, Quarterly, Yearly |
| **Other (if applicable)** | Ground subsidence can be unevenly distributed in areas with an energy network. This gives rise to hotspots in the network where mechanical stress builds up that can eventually lead to snapping cables and powerlines or rupturing pipelines. Operators need subsidence data to be combined with network models to determine these points and take mitigating measures. |
| **Service Provider Offer** | |
| **What the service does** | Periodically deliver subsidence information as input to models to calculate stress in the network. |
| **How does the service work** | InSAR is used to generate millimetre-precise subsidence rates across large areas efficiently. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-10m |
| **Temporal resolution** | weekly-monthly |
| **Data type / Spectral range** | SAR: X/C band for urbanized areas, L/P band preferred for heavily vegetated areas. |
| **Other (if applicable)** | long timeseries required for delivering a good and reliable service (ideally also historical). Thus, should ideally not be dependent on tasking but on always collecting constellations. |
| **Service Inputs** | |
| **Satellite data sources** | Sentinel-1 (currently the only always collecting constellation), but in principle any SAR-constellation in intended for InSAR use, with the note that they are tasking based so do require long-term commitments to be used for this use case. |
| **Other data sources** | DEM models |

**Table 6: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Pipelines) - Monitor changes in above-ground pipeline assets**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0024 |
| **Application** | Energy network conditions monitoring (pipelines) |
| **Users** | Oil & gas companies, pipeline operators |
| **User Needs** | |
| **Operational scenario** | **Monitor changes in above-ground pipeline assets** |
| **Size of area of interest** | Pipeline corridors, 10 m wide |
| **Scale** | N/A |
| **Frequency of information** | Annual |
| **Other (if applicable)** | Asset location data |
| **Service Provider Offer** | |
| **What the service does** | Validate presence of above ground assets along pipeline infrastructure. |
| **How does the service work** | Detect missing or 'displaced' above ground assets (poles, technical installations), provide call-to-action to operator. The operator can effectively initiate survey work for asset inspection. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <0.5m |
| **Temporal resolution** | Annual, quarterly |
| **Data type / Spectral range** | Multispectral |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | VHR optical satellite imagery |
| **Other data sources** | Aerial imagery (=<10 cm spatial resolution) |

**Table 7: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Pipelines) - Monitor PV installations around pipelines**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0025 |
| **Application** | Energy network conditions monitoring (pipelines) |
| **Users** | Oil & gas companies, pipeline operators |
| **User Needs** | |
| **Operational scenario** | **Monitor PV installations around pipelines** |
| **Size of area of interest** | Pipeline corridors, 500 m wide |
| **Scale** | N/A |
| **Frequency of information** | Quarterly |
| **Other (if applicable)** | Asset location data |
| **Service Provider Offer** | |
| **What the service does** | The service provides information on solar panels: location, estimate of power and yield |
| **How does the service work** | PV panels are inventoried based on aerial imagery and satellite imagery. Object information is provided as a service to operators. The operator wants to know these locations as the PV installations (transformers) may influence the pipeline integrity through negative impact on the process of active cathodic protection systems. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 0.5-10m |
| **Temporal resolution** | Monthly, weekly |
| **Data type / Spectral range** | Multispectral |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | VHR optical satellite imagery<br>HR optical imagery: Sentinel-2 |
| **Other data sources** | Aerial imagery |

**Table 8: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Pipelines) - Risk-class assessments for pipelines**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0026 |
| **Application** | Energy network conditions monitoring (pipelines) |
| **Users** | Pipeline operators (mainly gas and hazardous chemicals) |
| **User Needs** | |
| **Operational scenario** | **Risk-class assessments for pipelines** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | quarterly, 6-monthly, yearly, bi-yearly |
| **Other (if applicable)** | Periodic updates of human activities and inhabited structures around their network to fulfil regulatory requirements to keep their risk profiles up to date. |
| **Service Provider Offer** | |
| **What the service does** | Governmental regulators require that every pipeline segment has an associated risk-class that will determine the required risk mitigating measures required for that segment during operations. This risk-class is among other things, determined based on the number of structures and expected human presence within a certain distance from the pipeline. The assessment of the amount and distance of structures, and the periodic update of changes therein, can be efficiently done using satellite data. |
| **How does the service work** | Use high-res optical data to find and register all structures within the prescribed distance of the pipe to serve as input to the risk models. Repeat this exercise periodically to provide updated info to the risk-models. For the updates also a combination of SAR (to find persistent changes == new building) and optical (to classify type of structure) can be used to reduce costs. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | Optical: <50cm<br>SAR: 1-10m |
| **Temporal resolution** | At least same as Frequency of information requirements: quarterly, 6-monthly, yearly, bi-yearly |
| **Data type / Spectral range** | Optical, optionally supplemented by SAR |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Optical satellites with 50cm or better resolution. Optionally open SAR data (Sentinel-1). |
| **Other data sources** | Provided information service based on EO is input to a risk-class service that requires additional models, domain knowledge and field data. |

**Table 9: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Powerlines) – Vegetation encroachment/management**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0027 |
| **Application** | Energy network conditions monitoring (powerlines) |
| **Users** | Network operators |
| **User Needs** | |
| **Operational scenario** | **Vegetation encroachment/management around powerlines** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | several times per year |
| **Other (if applicable)** | Operators want to know where vegetation needs clearing but also want to monitor progress of those contracted to do the clearing. Also, corridor accessibility is a topic here. |
| **Service Provider Offer** | |
| **What the service does** | Classify vegetation type, height, and its proximity to the energy network infrastructure |
| **How does the service work** | Analyse multi-spectral, high-res optical satellite and aerial image data to extract vegetation parameters and distance with respect to assets. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-10m |
| **Temporal resolution** | monthly |
| **Data type / Spectral range** | Optical (SAT and/or aerial), MS |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview etc... |
| **Other data sources** | Pipeline-network definition, corridor definition, land use data. |

**Table 10: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Powerlines) - Flood risk and mapping**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0028 |
| **Application** | Energy network conditions monitoring (powerlines) |
| **Users** | Network operators |
| **User Needs** | |
| **Operational scenario** | **Flood risk and mapping** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | Periodic baseline once per year, ad hoc at flood event |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess flood risk and impact. Determine flood extent at flooding event |
| **How does the service work** | Provide flood risk maps that are updated yearly based on DEM combined with subsidence measurements (Input from InSAR). Provide exact flood extent info in case of a flooding event. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-10m |
| **Temporal resolution** | at least weekly |
| **Data type / Spectral range** | SAR optionally supplemented with high res optical. |
| **Other (if applicable)** | long timeseries required for delivering a good and reliable service (ideally also historical). Thus, should ideally not be dependent on tasking but on always collecting constellations. |
| **Service Inputs** | |
| **Satellite data sources** | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. |
| **Other data sources** | Pipeline-network definition, corridor definition, land use data, DEM |

**Table 11: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Powerlines) - Landslide risk-assessment**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0029 |
| **Application** | Energy network conditions monitoring (powerlines) |
| **Users** | Network operators/owners |
| **User Needs** | |
| **Operational scenario** | **Landslide risk-assessment by providing input data for slope stability assessments** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | several times per year |
| **Other (if applicable)** | Landslides are one of the biggest risks for pipeline failures, so slope stability data is crucial info for pipeline operators. |
| **Service Provider Offer** | |
| **What the service does** | Establish slope stability parameters like slope creep speed. Also soil moisture data can be derived from sat data to serve as input to slope stability models. |
| **How does the service work** | Periodic updates of model input data. Requires InSAR analysis. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-10m |
| **Temporal resolution** | weekly-monthly |
| **Data type / Spectral range** | Optical, MS, SAR |
| **Other (if applicable)** | long timeseries required for delivering a good and reliable service (ideally also historical). Thus, should ideally not be dependent on tasking but on always collecting constellations. |
| **Service Inputs** | |
| **Satellite data sources** | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. |
| **Other data sources** | Pipeline-network definition, corridor definition, land use data, DEM |

**Table 12: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Powerlines) - Storm damage assessment**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0030 |
| **Application** | Energy network conditions monitoring (powerlines) |
| **Users** | Grid operators |
| **User Needs** | |
| **Operational scenario** | **Storm damage assessment** |
| **Size of area of interest** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor |
| **Scale** | N/A |
| **Frequency of information** | Ad hoc after large storm |
| **Other (if applicable)** | Assess damage to above ground power grid lines and energy towers. Fast damage overview is crucial to restore possible power outings. |
| **Service Provider Offer** | |
| **What the service does** | Provide damage overview for large areas in one go. |
| **How does the service work** | Periodic baseline update, with ad hoc initiated analysis triggered by a storm. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | SAR: 1-10m<br>MS: 1-10m<br>Optical: <50cm |
| **Temporal resolution** | Baseline quarterly/yearly, damage analysis ad hoc. |
| **Data type / Spectral range** | SAR supplemented with high res optical. |
| **Other (if applicable)** | long timeseries required for delivering a good and reliable service (ideally also historical). Thus, should ideally not be dependent on tasking but on always collecting constellations. |
| **Service Inputs** | |
| **Satellite data sources** | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. |
| **Other data sources** | Pipeline-network definition, corridor definition, land use data, DEM |

**Table 13: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Powerlines) - Transmission line mapping**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0031 |
| **Application** | Energy network conditions monitoring (powerlines) |
| **Users** | Government, financial institutions, investors |
| **User Needs** | |
| **Operational scenario** | **Transmission line mapping** |
| **Size of area of interest** | Country |
| **Scale** | N/A |
| **Frequency of information** | One-time, repetition optional |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Mapping transmission line infrastructure: network, towers, stations |
| **How does the service work** | Using a variety of public sources and VHR imagery powerline infrastructure is mapped on a national scale. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <0.5m |
| **Temporal resolution** | Event driven |
| **Data type / Spectral range** | Multispectral |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview etc… |
| **Other data sources** | PMUS topographic data<br>Night-time satellite imagery<br>open data on power stations, power sources |

**Table 14: Main Requirements Relevant to EO for Energy Network Conditions Monitoring (Powerlines) - Monitor ground surface for subsurface powerlines**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0032 |
| **Application** | Energy network conditions monitoring (powerlines) |
| **Users** | Grid operators, contractors |
| **User Needs** | |
| **Operational scenario** | **Monitor ground surface for subsurface powerlines** |
| **Size of area of interest** | Grid corridors, 10 m wide (urban areas: full areas) |
| **Scale** | N/A |
| **Frequency of information** | Quarterly |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Monitor ground surface types |
| **How does the service work** | Using a baseline object-based inventory of ground surface types (based on satellite data, aerial imagery, topography maps) the grid operator has a base for designing and planning costs for maintenance and repair works on subsurface infrastructure: surface needs to be restored to original state when placing or accessing subsurface grid infrastructure. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <0.5m |
| **Temporal resolution** | Annual, quarterly |
| **Data type / Spectral range** | Multispectral |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | VHR optical satellite imagery for monitoring |
| **Other data sources** | Aerial imagery (=<10 cm spatial resolution)<br>Topographic (digital) maps |

### 2.4.2 Renewable energy assessment potential and forecast

Renewable energy project developers and investors identify the most suitable areas for the exploitation of renewable energy sources (solar parks, wind parks, etc.), plan their development and monitor their integrity/status. Jobs to be done include decision support for renewable energy project developers and investors by providing understanding of basic characteristics of solar radiation and wind speeds/shears in certain locations, estimating Annual Energy Production (AEP) for onshore and offshore projects, mapping hydrological networks and monitoring water resources (reservoirs), providing infrastructure monitoring support.

The following operational scenarios and the related user needs and requirements will be covered in this section:

- **Solar**
  - Assess (1) rooftop PV Annual Energy Potential in kWh/kWp for single rooftops or rooftops across municipalities - solar cadastre, (2) industrial PV farm Annual Energy Potential in kWh per unit of surface
  - Assess rooftop PV Energy production at sub-hourly temporal resolution for single rooftops or rooftops across municipalities - analyse the fit for one or several years between production and consumption (from a typical consumption time series depending on the building type) to optimize the PV system for self-consumption or a battery storage if planned
  - Monitoring, nowcasting and forecasting of energy potential for grid balancing and solar energy trading at urban scale
  - *Scenario for future evaluations: floating PV site selection*
- **Wind**
  - Assess offshore wind farm Energy Potential in MWh/year
  - Assess offshore wind energy resource (MWh/year) for a particular country
  - Forecast wind energy at a specific offshore wind site for days/week ahead (also for O&M activities)
  - Assess onshore wind farm Energy Potential and provide wind energy forecasts
  - Assess the impact of blockage/wake effects on wind energy production
  - Impact of waves on floating turbines
- **Ocean**
  - Assess wave energy resource within a country's maritime area or at a specific area of interest
  - Assess tidal energy resource within a country's maritime area or at a specific area of interest
  - Assess wave energy resource at a specific site of interest for days/week ahead. Assess possibility of O&M activities over days/week ahead (wind, wave and tidal)
  - Assess Ocean Current Energy Potential and provide current forecasts
  - Assess Ocean Temperature Conversion Energy Potential and provide temperature forecasts

**Table 15: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Solar) – PV energy potential**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0001 |
| **Application** | Renewable energy assessment potential and forecast (solar) |
| **Users** | Individual citizens, companies, municipalities. Project developers, investors |
| **User Needs** | |
| **Operational scenario** | **Assess rooftop PV Annual Energy Potential in kWh/kWp for single rooftops or rooftops across municipalities – solar cadastre. Assess industrial PV farm Annual Energy Potential in kWh per unit of surface** |
| **Size of area of interest** | 50m2-100km2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | Aerosol information, meteo data |
| **Service Provider Offer** | |
| **What the service does** | Assess rooftop PV annual energy production potential |
| **How does the service work** | Multiply the area suitable for PV installations by the average solar irradiation and rooftop slant/azimuth based on 3D data and shadow analysis to assess energy production potential. Irradiation is assessed by combining imagery from five geostationary weather satellites, which image the globe at a spatial resolution as fine as 1 kilometre, and geo-code, quality control and compute estimates. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <1m (surface area assessment), 1KM (irradiance assessment), 10-100m (distant horizon assessment), 1KM (irradiance assessment) |
| **Temporal resolution** | annual (RGB) and hourly or sub-hourly (irradiance and air temperature at 2m) |
| **Data type / Spectral range** | RGB 400-700nm (rooftop surface area and slope), 0.3–3.0 µm (solar irradiance), Air temperature at 2m from Numerical Weather Model |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | VHR (stereo) satellite data (e.g., Worldview) for rooftop surface area/slope, with a minimum resolution of 0,25 m which may not be available yet. Geostationary satellite data (e.g., GOES, HIMAWARI, METEOSAT) for solar irradiance. CAMS IFS meteo data |
| **Other data sources** | Aerial, drones (RGB & LiDAR), SRTM Digital Terrain Model data |

**Table 16: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Solar) – PV energy production**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0002 |
| **Application** | Renewable energy assessment potential and forecast (solar) |
| **Users** | Individual citizens, companies, municipalities |
| **User Needs** | |
| **Operational scenario** | **Assess rooftop PV Energy production at sub-hourly temporal resolution for single rooftops or rooftops across municipalities - analyse the fit for one or several years between production and consumption (from a typical consumption time series depending on the building type) to optimize the PV system for self-consumption or a battery storage if planned** |
| **Size of area of interest** | 50m2-10km2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | Aerosol information, meteo data |
| **Service Provider Offer** | |
| **What the service does** | Assess rooftop PV energy production time series to optimize PV system (potentially with battery storage) and self-consumption potential for residential, commercial, and industrial buildings |
| **How does the service work** | Multiply the area suitable for PV installations by the solar irradiation sub-hourly time series and rooftop slant/azimuth based on 3D data and shadow analysis to assess energy production vs. typical consumption time series. Irradiation is assessed by combining imagery from five geostationary weather satellites, which image the globe at a spatial resolution as fine as 1 kilometre, and geo-code, quality control and compute estimates. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <1m (surface area assessment), 1KM (irradiance assessment) |
| **Temporal resolution** | annual (RGB) and hourly or sub-hourly (irradiance and air temperature at 2m) |
| **Data type / Spectral range** | RGB 400-700nm (rooftop surface area and slope), 0.3–3.0 µm (solar irradiance), air temperature at 2m from Numerical Weather Model |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | VHR (stereo) satellite data (e.g., Worldview) for rooftop surface area/slope, with a minimum resolution of 0,25 m which may not be available yet. Geostationary satellite data (e.g., GOES, HIMAWARI, METEOSAT) for solar irradiance. CAMS IFS meteo data |
| **Other data sources** | Aerial, drones (RGB & LiDAR) |

**Table 17: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Solar) – Monitoring, nowcasting, and forecasting for grid balancing and solar energy trading**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0003 |
| **Application** | Renewable energy assessment potential and forecast (solar) |
| **Users** | Energy companies, grid operators, urban planning decision makers |
| **User Needs** | |
| **Operational scenario** | **Monitoring, nowcasting and forecasting of energy potential for grid balancing and solar energy trading at urban scale** |
| **Size of area of interest** | 50m2-10km2 |
| **Scale** | N/A |
| **Frequency of information** | daily or sub-daily |
| **Other (if applicable)** | Aerosol information, meteo data |
| **Service Provider Offer** | |
| **What the service does** | Monitor and nowcast the temporal and spatial variability of the generated electricity for grid operators and aggregators for grid balancing and solar energy trading |
| **How does the service work** | Compute, for a single or a group of PV systems in urban environment the current, near future and optionally the next day electricity output, considering the systems characteristics (slopes and azimuth of panels) with shadow analysis. Irradiation is assessed in near real-time by combining imagery from five geostationary weather satellites, which image the globe at a spatial resolution as fine as 1 kilometre, and geo-code, quality control and compute estimates. Cloud Motion Vectors or Deep Learning methods are used to estimate the clouds movement for the irradiance nowcasting in the same day. Machine Learning methods are applied to forecast the next day sub-hourly solar irradiance curve. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <1m (surface area assessment), 1KM (irradiance assessment) |
| **Temporal resolution** | annual (RGB) and hourly or sub-hourly (irradiance and air temperature at 2m) |
| **Data type / Spectral range** | RGB 400-700nm (Digital Terrain Model), 0.3–3.0 µm (solar irradiance), Air temperature at 2m from Numerical Weather Model |
| **Other (if applicable)** | Numerical Weather Model hindcast historical data together with the past solar irradiance data is needed to train the Machine Learning model for the next day forecast |
| **Service Inputs** | |
| **Satellite data sources** | Geostationary satellite data (e.g., GOES, HIMAWARI, METEOSAT) for solar irradiance. CAMS IFS meteo data. CAMS IFS hindcast meteo data if next day solar irradiance forecast is needed |
| **Other data sources** | Aerial, drones (RGB & LiDAR). A report named "Non-commercial Light Detection and Ranging (LiDAR) data in Europe" has been published by the JRC in 2021 doi:10.2760/212427 |

**Table 18: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Wind) – Offshore wind farm potential**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0004 |
| **Application** | Renewable energy assessment potential and forecast (wind) |
| **Users** | Offshore wind farm developers, offshore wind farm operators, consultants for offshore wind farm siting and resource assessment |
| **User Needs** | |
| **Operational scenario** | **Assess offshore wind farm Energy Potential in MWh/year** |
| **Size of area of interest** | up to 1000KM2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess offshore wind farm annual energy production potential |
| **How does the service work** | Use satellite data (SAR/ASCAT) to derive wind speeds at 10m above surface, then extrapolate to 30-300m above surface to assess production potential of wind farms, complemented by other data provided using meteorological masts/radars/lidars |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | hundreds of meters (wind farm assessment), KM (wide coastal areas assessment) |
| **Temporal resolution** | mean annual values (mean wind, wind power, wind rose, Weibull fit estimates) and wind time series |
| **Data type / Spectral range** | SAR & ASCAT |
| **Other (if applicable)** | meso-scale model outputs for long-term stability correction |
| **Service Inputs** | |
| **Satellite data sources** | SAR data (e.g., by Sentinel-1, ICEYE, TerraSAR-X satellites), ASCAT data (e.g., by METEOSAT, MetOp satellites) |
| **Other data sources** | In-situ meteorological masts/Doppler Radars/LiDARs (on turbines) |

**Table 19: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Wind) – Offshore wind potential country-wide**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0005 |
| **Application** | Renewable energy assessment potential and forecast (wind) |
| **Users** | Researchers, project developers, government |
| **User Needs** | |
| **Operational scenario** | **Assess offshore wind energy resource (MWh/year) for a particular country** |
| **Size of area of interest** | Up to 1,000,000 Km2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess the wind speed (m/s) within a country's maritime area (or specific site) to derive potential power production in MWh |
| **How does the service work** | Hourly wind speeds are given for each geographical grid of the study area. The user downloads a given geographical and temporal subset of the data product and then applies a power curve to these wind speed values (or uses the theoretical wind power equation) to get the corresponding power output. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-5km |
| **Temporal resolution** | hourly values |
| **Data type / Spectral range** | NetCDF |
| **Other (if applicable)** | 20 year hindcast of data minimum |
| **Service Inputs** | |
| **Satellite data sources** | SAR (e.g., Sentinel 1 and 6), ASCAT data, other |
| **Other data sources** | In-situ met-ocean buoys (UK Met Office, Irish Marine Institute, etc.) |

**Table 20: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Wind) – Offshore wind site energy forecasting**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0006 |
| **Application** | Renewable energy assessment potential and forecast (wind) |
| **Users** | Project developers, energy companies |
| **User Needs** | |
| **Operational scenario** | **Forecast wind energy at a specific offshore wind site for days/week ahead (also for O&M activities)** |
| **Size of area of interest** | Up to 100 Km2 |
| **Scale** | N/A |
| **Frequency of information** | updated every 3 - 6 hours with a forecast of >5 days |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess the wind speed (m/s) to ultimately derive potential power production in MWh for the days/week ahead and assess weather windows for operations & maintenance activities |
| **How does the service work** | Hourly wind speed (m/s) values are given for each geographical grid of the study area. For energy forecast assessment, user downloads a given geographical subset of the data product and then applies a power curve to these wind speed values to derive the power output expected over coming days/week. For O&M weather window assessment, user downloads the wind speed data and applies it to a weather windows threshold matrix to assess the possibility of wind, wave, or tidal energy farm visit for O&M over coming days/week. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-5km |
| **Temporal resolution** | hourly values |
| **Data type / Spectral range** | NetCDF |
| **Other (if applicable)** | 5 - 10 days forecast |
| **Service Inputs** | |
| **Satellite data sources** | Sentinel 1, 3, 6, other |
| **Other data sources** | In-situ met-ocean buoys (UK Met Office, Irish Marine Institute, etc.) |

**Table 21: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Wind) – Onshore wind farm energy potential**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0007 |
| **Application** | Renewable energy assessment potential and forecast (wind) |
| **Users** | Energy companies, project developers, investors |
| **User Needs** | |
| **Operational scenario** | **Assess onshore wind farm Energy Potential in MWh/year** |
| **Size of area of interest** | up to 1000KM2 |
| **Scale** | N/A |
| **Frequency of information** | one-off for energy assessment to 3 hourly for forecasts |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess onshore wind farm annual energy production potential and provide wind energy forecasts |
| **How does the service work** | 5 different EO-based high-quality and high-resolution data products on land cover, key forest characteristics, historical and future changes, topography, and surface roughness Surface roughness data is directly compatible with modelling methods (windPRO, WaSP and CFD tools). |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 10 to 20 m |
| **Temporal resolution** | mean annual values (mean wind, wind power, wind rose, Weibull fit estimates) and wind time series |
| **Data type / Spectral range** | Copernicus Global Land Service (LAI, NDVI) from Sentinel 3 OLCI, SAR (Sentinel 1), optical data (Sentinel 2), ASCAT |
| **Other (if applicable)** | meso-scale model outputs for long-term stability correction, very high-resolution elevation layer (1 m) |
| **Service Inputs** | |
| **Satellite data sources** | SAR data (e.g., by Sentinel-1, ICEYE, TerraSAR-X satellites), ASCAT data (e.g., by METEOSAT, MetOp satellites), existing datasets from Copernicus Global Land Service (CGLS) |
| **Other data sources** | In-situ meteorological masts/Doppler Radars/LiDARs (on turbines)/Met Stations |

**Table 22: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Wind) – Assess impact of blockage/wake effects on wind energy production**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0008 |
| **Application** | Renewable energy assessment potential and forecast (wind) |
| **Users** | Energy companies, project developers, investors |
| **User Needs** | |
| **Operational scenario** | **Assess the impact of blockage/wake effects on wind energy production** |
| **Size of area of interest** | up to 1000KM2 |
| **Scale** | N/A |
| **Frequency of information** | Hourly to daily |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Analyse the wakes and blockage effects between turbines and between two wind farms |
| **How does the service work** | Use of SAR data to detect, measure and monitor the effects of wakes from individual turbines and blockage between wind farms that impact the wind speed and energy reaching the turbines |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 10m-1km |
| **Temporal resolution** | Daily |
| **Data type / Spectral range** | SAR |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | SAR data (Sentinel-1, Envisat, Radarsat 2, Terrasar X, Cosmo Skymed, ICEYE) |
| **Other data sources** | Microscale atmospheric numerical models |

**Table 23: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Wind) – Impact of waves on floating turbines**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0009 |
| **Application** | Renewable energy assessment potential and forecast (wind) |
| **Users** | Energy companies, project developers |
| **User Needs** | |
| **Operational scenario** | **Impact of waves on floating turbines** |
| **Size of area of interest** | up to 1000KM2 |
| **Scale** | N/A |
| **Frequency of information** | Hourly |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Analyse and forecast the impact of the wave effects on the floating structures |
| **How does the service work** | Altimetric and radar data to provide wave data fields that can be directly used for wave climatology analysis or indirectly as boundary conditions or data assimilations on numerical models providing wave forecasts |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1km |
| **Temporal resolution** | Daily |
| **Data type / Spectral range** | SAR, Altimetry |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | SAR data (Sentinel-1 and 6, Envisat, Radarsat 2, Terrasar X, Cosmo Skymed, ICEYE) & altimetry data (Jason2-3,Sentinel-3,Cryosat-2,Saral,HY-2,Jason-1,ENVISAT,ERS-1/2,GFO,Topex/Poseidon) |
| **Other data sources** | In-situ metocean buoys/wave gauges and numerical models |

**Table 24: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Ocean) – Assess wave energy resource**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0010 |
| **Application** | Renewable energy assessment potential and forecast (ocean) |
| **Users** | Project developers, energy companies, government, researchers |
| **User Needs** | |
| **Operational scenario** | **Assess wave energy resource within a country's maritime area or at a specific area of interest** |
| **Size of area of interest** | Up to 1,000,000 Km2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess the significant wave height (Hs) and wave period (T) to ultimately derive potential power production in MWh |
| **How does the service work** | Hourly significant wave height (Hs) and wave period (T) values are given for each geographical grid of the study area. The user downloads a given geographical and temporal subset of the data product and then applies a power matrix to these wind speed values (or uses the theoretical wave power equation) to derive the power output. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-5km |
| **Temporal resolution** | hourly values |
| **Data type / Spectral range** | NetCDF, SAR, altimetry |
| **Other (if applicable)** | 20 year hindcast of data minimum |
| **Service Inputs** | |
| **Satellite data sources** | Sentinel 1, 3, 6 |
| **Other data sources** | In-situ metocean buoys/wave gauges and numerical models |

**Table 25: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Ocean) – Assess tidal energy resource**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0011 |
| **Application** | Renewable energy assessment potential and forecast (ocean) |
| **Users** | Energy companies, project developers, investors, governments (ministries, regulation agencies) |
| **User Needs** | |
| **Operational scenario** | **Assess tidal energy resource within a country's maritime area or at a specific area of interest** |
| **Size of area of interest** | Up to 1,000,000 Km2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess current speeds (m/s) to ultimately derive potential power production in MWh for short and long-term forecasts |
| **How does the service work** | Hourly current speed (m/s) values are given for each geographical grid of the study area. The user downloads a given geographical and temporal subset of the data product and then applies a tidal energy device power matrix to these current speed values (or uses the theoretical tidal power equation) to derive the power output. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <1km2 |
| **Temporal resolution** | hourly values |
| **Data type / Spectral range** | NetCDF, altimetry |
| **Other (if applicable)** | 1 year hindcast is sufficient |
| **Service Inputs** | |
| **Satellite data sources** | NOAA, METOP-A, Oceansat 2, AQUA, SNPP, NOAA-20, ENVISAT, Sentinel 3 and 6, MSG, GOES, DMSP, TRMM, Jason 1,2,3, Topex/Poseidon, Cryosat, Saral, ERS 1,2, GFO |
| **Other data sources** | In-site ADCP data (availability may be an issue) |

**Table 26: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Ocean) – Forecast wave energy resource & assess possibility of operations/maintenance activities**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0012 |
| **Application** | Renewable energy assessment potential and forecast (ocean) |
| **Users** | ORE Project developers, energy companies |
| **User Needs** | |
| **Operational scenario** | **Assess wave energy resource at a specific site of interest for days/week ahead. Assess possibility of operations and maintenance activities over days/week ahead (wind, wave and tidal)** |
| **Size of area of interest** | Up to 100 Km2 |
| **Scale** | N/A |
| **Frequency of information** | updated every 3 - 6 hours with a forecast of >5 days |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess the significant wave height (Hs) and wave period (T) to ultimately derive potential power production in MWh for the days/week ahead and assess weather windows for O&M |
| **How does the service work** | Hourly significant wave height (Hs) and wave period (T) values are given for each geographical grid of the study area. For energy forecast assessment (wave energy only), user downloads a given geographical subset of the data product and then applies a power matrix to these values to derive the power output expected over coming days/week. For O&M weather window assessment, user downloads only wave height data at a given geographical subset and then applies it to a weather windows threshold matrix to assess the possibility of wind, wave, or tidal energy farm visit for O&M over coming days/week. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1 km2 |
| **Temporal resolution** | hourly values |
| **Data type / Spectral range** | NetCDF |
| **Other (if applicable)** | 5 - 10 days |
| **Service Inputs** | |
| **Satellite data sources** | Sentinel 1, 3, 6 |
| **Other data sources** | In-situ met-ocean buoys (UK Met Office, Irish Marine Institute, etc.) |

**Table 27: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Ocean) – Current energy potential and forecasts**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0013 |
| **Application** | Renewable energy assessment potential and forecast (ocean) |
| **Users** | Energy companies, project developers, investors, governments (ministries, regulation agencies) |
| **User Needs** | |
| **Operational scenario** | **Assess Ocean Current Energy Potential and provide current forecasts** |
| **Size of area of interest** | up to 10000KM2 |
| **Scale** | N/A |
| **Frequency of information** | Daily |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess ocean currents annual energy production potential and provide short to long term wave forecasts |
| **How does the service work** | Altimetric, Sea Surface Colour and radar data to provide ocean currents data fields that can be directly used for current climatology analysis or indirectly as boundary conditions or data assimilations on numerical models providing currents forecasts |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-100km |
| **Temporal resolution** | N/A |
| **Data type / Spectral range** | SST, SSC, altimetry |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | NOAA, METOP-A, Oceansat 2, AQUA, SNPP, NOAA-20, ENVISAT, Sentinel-3, MSG, GOES, DMSP, TRMM, Jason 1,2,3, Topex/Poseidon, Cryosat, Saral, ERS 1,2, GFO |
| **Other data sources** | In-situ metocean buoys, drifters, and numerical models |

**Table 28: Main Requirements Relevant to EO for Renewable Energy Assessment Potential and Forecast (Ocean) – Ocean temperature conversion energy potential**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0014 |
| **Application** | Renewable energy assessment potential and forecast (ocean) |
| **Users** | Energy companies, project developers, investors, governments (ministries, regulation agencies) |
| **User Needs** | |
| **Operational scenario** | **Assess Ocean Temperature Conversion Energy Potential and provide temperature forecasts** |
| **Size of area of interest** | up to 10000KM2 |
| **Scale** | N/A |
| **Frequency of information** | Daily |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Assess ocean temperature energy conversion potential |
| **How does the service work** | Altimetric and Sea Surface Temperature data to provide ocean temperature data fields data that can be directly used for sea temperature climatology analysis or indirectly as boundary conditions or data assimilations on numerical models providing temperature forecasts |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-100km |
| **Temporal resolution** | N/A |
| **Data type / Spectral range** | SST, altimetry |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | NOAA, METOP-A, Oceansat 2, AQUA, SNPP, NOAA-20, ENVISAT, Sentinel-3, MSG, GOES, DMSP, TRMM, Jason 1,2,3, Topex/Poseidon, Cryosat, Saral, ERS 1,2, GFO |
| **Other data sources** | In-situ metocean buoys, drifters, and numerical models |

### 2.4.3 Phasor measurement units (PMU)

GNSS provides accurate timing and synchronisation for PMUs, which are deployed across remote locations of the power network (nodes), improving the reliability of power systems. PMUs measure voltage and current phasors and timestamp those measurements using a GPS receiver and a phase-lock oscillator. They should be installed at strategic places of the power grid to create a global picture of a grid's dynamics for power system planning, control, and post-incident analysis. For instance, PMUs can be deployed at main substations and power plants. **The relevant GNSS requirements are presented in section 2.6.1.**

### 2.4.4 Renewable energy plant design optimisation

EO can help optimising the design of renewable energy power plants (e.g., optimisation of the positioning of solar panels, onshore and offshore wind turbines, etc.). Relevant EO-based products include terrain elevation models, solar irradiance, wind speed, precipitation, and climate conditions.

### 2.4.5 Risk assessment for renewable energy assets

Energy assets are exposed to a variety of natural risks which can put at danger the people working on site or, damage equipment or negatively impact production. EO can contribute to the assessment of the level of risk to prevent/mitigate the effects of adverse events on the exploitation of energy (incl. the protection of workers maintaining offshore wind platforms for instance). Relevant EO-based products and services include the monitoring of dangerous sub-surface currents, iceberg detection and tracking, etc.

### 2.4.6 Environmental impact assessment of renewable energy plants

To reach the goals set for the green energy transition, a major acceleration is foreseen in the deployment of renewable energy sites such as solar and wind farms. These sites have an impact on their surroundings, affecting biodiversity and even weather patterns. In this light, new obligations have been imposed on EU Member States to identify "go-to areas" for the installation of renewable energy sites as part of the REPowerEU plan. For this application, EO data and services will play a critical role in the identification of such sites, considering key parameters such as the energy generation potential using satellite-measured solar irradiance or wind data as well as measuring potential impact on nature and biodiversity.

### 2.4.7 Renewable energy site selection, planning and monitoring

EO can provide a large variety of products and information supporting the identification of the most suitable areas for the exploitation of renewable energy sources. These products and information include for instance data on relevant environmental parameters influencing the production of energy, data on the status of the power plants, geological evaluation, topography mapping, etc.

GNSS can enable geomatics applications such as plant and construction surveying, mapping and GIS, photogrammetry, laser scanning and remote sensing, as well as route planning and augmented reality visualization. The GNSS devices that are used for those applications include high-accuracy GNSS receivers (geodetic-grade smart antennas, all-in-one integrated mapping/GIS devices or

infrastructure/CORS) and embedded chipsets. On the other hand, several CORS networks operate receivers that are powered by renewable energy sources (e.g., solar panels or wind turbines), so the utilization of GNSS for renewable energy operations brings mutual benefits.

## 2.5 Limitations of GNSS & EO

### 2.5.1 GNSS Limitations

GNSS is an integral enabling technology used across the wide range of surveying applications presented previously. However, several limitations apply, which are typically overcome by employing the complementary technologies described in the previous section or by following best practices regarding the type of GNSS equipment used.

| Limitation | Description |
|---|---|
| **Operating Environment Limitations** | These are mostly related to constraints related to the environment in which survey operations are carried out. Thus, in dense urban environments, in sites where there are natural (e.g., tree canopy, deep open pit mines) or artificial (e.g. buildings or highly-reflective surfaces in construction sites) obstructions, and in areas with complex topographies, interference and multipath effects as well as limited GNSS signal availability, should be overcome by deploying complementary technologies.<br><br>For example, even though GNSS has been proven to work under vegetation cover, there may a significant loss of signal depending on the type and moisture content of the vegetation. In such cases, tertiary or secondary control should be established on the edges of the vegetation, whereas for detail surveys traditional methods should be deployed. |
| **Demanding Data Point Collection** | When there is a need of collecting a vast number of data points per second, typically to construct 3D models or digital terrain models, laser scanner and LIDAR technologies need to be deployed. In addition, when the access to certain areas is difficult or safety considerations apply, surveying from a distance is ensured with RPAS or aircraft. |
| **Vertical Position Determination** | When there is a need for highly accurate vertical position determination (e.g., in control surveys) considerations related to antenna phase centre variations should be considered. These are a function of the elevation and azimuth angle between the antenna and a given satellite. For short baselines, and where the same antenna is used (between rover and base), the variations cancel out. But as the baseline length increases, and even more if different antennas are used, the variations pertain and there is a significant deterioration in height determination accuracy. Advanced software methodologies are deployed to model these variations and improve the outcome. However, it is typically recommended that traditional spirit levelling is deployed to accurately determine the orthometric height of a given site. |
| **Susceptibility to Interference** | Radio interference can be defined as the reception of a mix of multiple signals with one signal being the desired signal to be received and processed and the other signals being undesired. If the undesired signals degrade, obstructs, or repeatedly interrupts the reception of the desired signal it is referred to harmful interference. The origin of the radio interference can be intentional (e.g., GNSS |

| Limitation | Description |
|---|---|
| | jammers) or unintentional (e.g., malfunctioning equipment in wireless telecom networks creating in-band spurious emissions). GNSS interference is critical for ground CORS infrastructure receivers, as well as RPAS applications. Innovative dedicated mitigation techniques within the receiver chipsets are capable to overall limit its negative effects. |
| **RTK - Transmission of Corrections from Base Stations** | The RTK solutions depend on a safe, stable, and sufficient transmission of corrections from base stations to calculate a precise position. This transmission is often performed by radio or over the telecommunication network. In the latter case, data transmission is often a lower priority over ordinary telecommunications (especially at peak times), thus reducing GNSS surveying equipment's uptime. Today, this issue is mitigated by SiS correction dissemination when internet is down (e.g., Trimble service, future HAS, etc.). |
| **Sensibility To Ambient Humidity** | Additional errors are detected when surveyors perform measurements in extreme conditions and/or with big fluctuations in ambient humidity, such as in Antarctica, or at high altitudes in mountainous areas (e.g., when installing telecom antennas, repeaters) when measurements are taken at points with height difference between the reference station and the rover of orders of 600 m. If such meteorological conditions exist, one practical approach for high-precision surveying is to choose the days for GNSS observations with minimal moisture content (no higher than 12 g/m3)57. |

### 2.5.2 EO Limitations

To assess the solar energy potential for individual rooftops, most satellite-generated data do not have the required spatial resolution for surface area assessments. For this, often high-resolution aerial, or UAV data (<10cm) is used.

For wind energy assessment and forecasting, EO datasets do not always have the required time-series data, as some operational scenarios require data going back 20 years. Furthermore, when using SAR data in wind energy assessments, often some data is missing due to the relatively small swath of the SAR satellites and relatively few SAR satellites in operation, which then requires averaging methods to fill the gaps, which in turn leads to less precise estimates.

The take-away is that for many EO applications, a single source of EO data does not always match the required needs. Some sensors, such as those producing RGB or multispectral data, are weather dependant. Others may not have the required spatial or temporal resolution. Instead, rather than focussing on the shortcomings of a single sensor (suite), EO sensors and data should be combined into solutions, where the full potential of EO lies in combining sensors in a smart way.

## 2.6 User Requirements Specification

The chapter provides a synthesis of the requirements described in section 2.4 respectively on GNSS in section 2.6.1 and on EO in section 2.6.2.

### 2.6.1 Synthesis of Requirements Relevant to GNSS

**Table 29 Cross-sector GNSS requirements relevant to Energy**

| Cross-Sector GNSS requirements relevant to Phasor Measurement Units | | | |
|---|---|---|---|
| **ID** | **Description** | **Type** | **Sources** |
| EUSPA-GN-UR-TSC-0070 | The Timing & Sync system shall provide continuity of service | Functional | [RD28][RD29][RD34] |
| EUSPA-GN-UR-TSC-0110 | The Timing & Sync system shall be trustable | Functional | [RD28][RD29][RD34] [RD32][RD33][RD42] |
| EUSPA-GN-UR-TSC-0130 | The Timing & Sync system shall be resilient | Functional | [RD28][RD29][RD34] [RD32][RD33][RD42] |
| EUSPA-GN-UR-TSC-0140 | The Timing & Sync system shall be able to detect and characterization GNSS interference | Functional | [RD28][RD29] |
| EUSPA-GN-UR-TSC-0150 | The Timing & Sync system shall provide service commitment | Functional | [RD28][RD29] |
| EUSPA-GN-UR-TSC-0160 | The Timing & Sync system shall get access to integrity information with a certain level of confidence | Functional | [RD28][RD29][RD43] |
| EUSPA-GN-UR-TSC-0176 | The Timing & Sync system shall provide robustness against "synchronised" GNSS spoofing attacks for Electricity transmission applications | Functional | [RD28][RD29][RD34] [RD32][RD43] |
| EUSPA-GN-UR-TSC-0190 | The Timing & Sync system shall be preferably provided worldwide and regionally as a minimum | Functional | [RD44] |
| EUSPA-GN-UR-TSC-0268 | The Timing & Sync system shall provide an update rate of 1Hz to 10 Hz | Performance | [RD44] |
| EUSPA-GN-UR-TSC-0200 | The Timing & Sync system shall be able to demonstrate traceability to UTC | Functional | [RD44] |
| EUSPA-GN-UR-TSC-0210 | The Timing & Sync system shall be able to provide an authentication capability at User Equipment level | Functional | [RD44] |
| EUSPA-GN-UR-TSC-0220 | The Timing & Sync system shall be able to provide an authentication capability on a continuous basis | Functional | [RD44] |
| EUSPA-GN-UR-TSC-0230 | The Timing & Sync system shall be able to provide an authentication capability with a duration between successive authentications of 5 to 10 seconds | Functional | [RD44] |
| EUSPA-GN-UR-TSC-0240 | The Timing & Sync system shall be able to provide an authentication capability with no degradation of the time accuracy | Functional | [RD44] |
| EUSPA-GN-UR-TSC-0250 | The Timing & Sync system shall be able to provide an authentication capability with a key management procedure as transparent as possible | Functional | [RD44] |

**Table 30 GNSS requirements relevant to Phasor Measurement Units**

| GNSS requirements relevant to Phasor Measurement Units | | | |
|---|---|---|---|
| **ID** | **Description** | **Type** | **Sources** |
| EUSPA-GN-UR-TSC-0050 | The Timing & Sync system shall provide an accuracy of 1 µs for PMU applications (Time tagging with accuracy better than 1 µs with a magnitude accuracy of 0.1% or better). | Performance | [RD28][RD29][RD30] [RD31][RD32][RD33] [RD34] |
| EUSPA-GN-UR-TSC-0060 | The Timing & Sync system shall not only be dependent on GPS | Functional | [RD28][RD29][RD34] [RD35] |
| EUSPA-GN-UR-TSC-0105 | The Timing & Sync system shall provide a high level of availability (99.9%) | Performance | [RD41] |
| EUSPA-GN-UR-TSC-0235 | The Timing & Sync system shall have an availability "Desirable" in urban canyons | Functional | [RD41] |
| EUSPA-GN-UR-TSC-0245 | The Timing & Sync system shall have an availability "desirable" indoors | Performance | [RD41] |

## 2.6.2 Synthesis of Requirements Relevant to EO

**Table 31: Requirements Synthesis – Network Conditions Monitoring (Pipelines)**

| | ID | Application | Users | User Needs | | | | | Service Provider Offer | | Service Provider Satellite EO Requirements | | | | Service Inputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Operational Scenario | Size of Area of Interest | Scale | Frequency of Information | Other (if applicable) | What the service does | How does the service work | Spatial Resolution | Temporal Resolution | Data Type / Spectral Range | Other (if applicable) | Satellite Data Sources | Other Data Sources |
| PIPELINES | EUSPA-EO-UR-ERM-0021 | Energy network conditions monitoring (pipelines) | Critical linear infrastructure operators | **Monitor third party activity around energy corridor (pipeline safety)** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor | N/A | Daily - weekly - biweekly - triweekly - monthly (depending on regulatory requirements) | Need to comply with legislation requiring minimum monitoring frequency. Reliable thus weather independent service required. Service to be delivered based on ready to use information in the hands of both office as field staff. Needs satellites that always collect (like Copernicus program) and NOT only collect on tasking orders. | Identify and report potential third party activities in and around a linear infrastructure corridor | Detect construction activities/infrastructure changes/excavating activities/heavy machinery/tree felling activities/site preparation or any irregular activity | SAR: 1-10m<br>MS: 1-10m<br>Optical: <50cm | SAR: At least once every "**Frequency of information**" interval.<br>MS: At least once every "Frequency of information" interval.<br>Optical: Multiple collection options per day -> one successful collection per activity | SAR/MS/Optical | Latency SAR < 8hrs, Latency MS < 8hrs, Optical < 8hrs | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview etc... | Pipeline-network definition, corridor definition, land use data. |
| | EUSPA-EO-UR-ERM-0022 | Energy network conditions monitoring (pipelines) | Critical linear infrastructure operators and security contractors | **Detect and report suspicious activity around critical infrastructure that can indicate sabotage, vandalism and/or theft from (oil, gasoline) pipelines.** | 10-100000km energy networks -> 10-100000km2 energy corridors to | N/A | Multiple times per day (and night) | Frequent and timely info on suspicious activities. | Detect and report suspicious activity near critical infrastructure possibly associated with vandalism, sabotage and/or theft | Detect with SAR day and night activities around the corridor. Assess risk using all available context info and alert in case of suspicious activity. | SAR: 1-10m<br>MS: 1-10m | SAR: At least once every "**Frequency of information**" interval.<br>Optical: Periodically updated base layer for human interpretation. | SAR/Optical | Latency SAR < 1hr, Optical < 8hrs | ICEYE, Capella, SkySat, Pleiades, etc | Pipeline-network definition, corridor definition, land use data. |
| | EUSPA-EO-UR-ERM-0023 | Energy network conditions monitoring (pipelines) | Critical linear infrastructure operators/owners | **Critical pipeline infrastructure external stress assessment (subsidence induced network stress)** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor | N/A | Monthly, Quarterly, Yearly | Ground subsidence can be unevenly distributed in areas with an energy network. This gives rise to hotspots in the network where mechanical stress builds up that can eventually lead to snapping cables and powerlines or rupturing pipelines. Operators need subsidence data to be combined with network models to determine these point and take mitigating measures. | Periodically deliver subsidence information as input to models to calculate stress in the network. | InSAR is used to generate millimeter-precise subsidence rates across large areas efficiently. | 1-10m | weekly-monthly | SAR: X/C band for urbanized areas, L/P band preferred for heavily vegetated areas. | long timeseries required for delivering a good and reliable service (ideally also historical). Thus should ideally not be dependent on tasking but on always collecting constellations. | Sentinel-1 (currently the only always collecting constellation), but in principle any SAR-constellation in intended for InSAR use, with the note that they are tasking based so do require long-term commitments to be used for this use case. | DEM models |
| | EUSPA-EO-UR-ERM-0024 | Energy network conditions monitoring (pipelines) | Oil & gas companies, pipeline operators | **Monitor changes in above-ground pipeline assets** | Pipeline corridors, 10 m wide | N/A | Annual | Asset location data | Validate presence of above ground assets along pipeline infrastructure. | Detect missing or 'displaced' above ground assets (poles, technical installations) , provide call-to-action to operator. The operator can effectively initiate survey work for asset inspection. | <0.5m | Annual, quarterly | Multispectral | N/A | VHR optical satellite imagery | Aerial imagery (=<10 cm spatial resolution) |
| | EUSPA-EO-UR-ERM-0025 | Energy network conditions monitoring (pipelines) | Oil & gas companies, pipeline operators | **Monitor PV installations around pipelines** | Pipeline corridors, 500 m wide | N/A | Quarterly | Asset location data | The service provides information on solar panels: location, estimate of power and yield | PV panels are inventoried based on aerial imagery and satellite imagery. Object information is provided as a service to operators. The operator wants to know these locations as the PV installations (transformers) may influence the pipeline integrity through negative impact on the process of active cathodic protection systems. | 0.5-10m | Monthly, weekly | Multispectral | N/A | VHR optical satellite imagery<br>HR optical imagery: Sentinel-2 | Aerial imagery |
| | EUSPA-EO-UR-ERM-0026 | Energy network conditions monitoring (pipelines) | Pipeline operators (mainly gas and hazardous chemicals) | **Risk-class assessments for pipelines** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor | N/A | quarterly, 6-monthly, yearly, bi-yearly | Periodic updates of human activities and inhabited structures around their network to fulfil regulatory requirements to keep their risk profiles up to date. | Governmental regulators require that every pipeline segment has an associated risk-class that will determine the required risk mitigating measures required for that segment during operations. This risk-class is among other things, determined based on the amount of structures and expected human presence within a certain distance from the pipeline. The assessment of the amount and distance of structures, and the periodic update of changes therein, can be efficiently done using satellite data. | Use high-res optical data to find and register all structures within the prescribed distance of the pipe to serve as input to the risk models. Repeat this exercise periodically to provide updated info to the risk-models. For the updates also a combination of SAR (to find persistent changes == new building) and optical (to classify type of structure) can be used to reduce costs. | Optical: <50cm<br>SAR: 1-10m | At least same as Frequency of information requirements: quarterly, 6-monthly, yearly, bi-yearly | Optical, optionally supplemented by SAR | N/A | Optical satellites with 50cm or better resolution. Optionally open SAR data (sentinel-1). | Provided information service based on EO is input to a risk-class service that requires additional models, domain knowledge and field data. |

## Table 32: Requirements Synthesis – Network Conditions Monitoring (Powerlines)

| | ID | Application | Users | User Needs | | | | | Service Provider Offer | | Service Provider Satellite EO Requirements | | | | Service Inputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Operational Scenario | Size of Area of Interest | Scale | Frequency of Information | Other (if applicable) | What the service does | How does the service work | Spatial Resolution | Temporal Resolution | Data Type / Spectral Range | Other (if applicable) | Satellite Data Sources | Other Data Sources |
| POWERLINES | EUSPA-EO-UR-ERM-0027 | Energy network conditions monitoring (powerlines) | Network operators | **Vegetation encroachment/management around powerlines** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor | N/A | several times per year | Operators want to know where vegetation needs clearing but also want to monitor progress of those contracted to do the clearing. Also corridor accessibility is a topic here. | Classify vegetation type, height and its proximity to the energy network infrastructure | Analyse multi-spectral, high res optical satellite and aerial image data to extract vegetation parameters and distance wrt assets. | 1-10m | monthly | Optical (SAT and/or aerial), MS | N/A | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. | Pipeline-network definition, corridor definition, land use data. |
| | EUSPA-EO-UR-ERM-0028 | Energy network conditions monitoring (powerlines) | Network operators | **Flood risk and mapping** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor | N/A | Periodic baseline once per year, ad hoc at flood event | N/A | Assess flood risk and impact..... Determine flood extent at flooding event | Provide flood risk maps that are updated yearly based on DEM combined with subsidence measurements (Input from InSAR). Provide exact flood extent info in case of a flooding event. | 1-10m | at least weekly | SAR optionally supplemented with high res optical. | long timeseries required for delivering a good and reliable service (ideally also historical). Thus should ideally not be dependent on tasking but on always collecting constellations. | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. | Pipeline-network definition, corridor definition, land use data, DEM |
| | EUSPA-EO-UR-ERM-0029 | Energy network conditions monitoring (powerlines) | Network operators/owners | **Landslide risk-assessment by providing input data for slope stability assessments** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor | N/A | several times per year | Landslides are one of the biggest risk for pipeline failures, so slope stability data is crucial info for pipeline operators. | Establish slope stability parameters like slope creep speed. Also soil moisture data can be derived from sat data to serve as input to slope stability models. | Periodic updates of model input data. Requires InSAR analysis. | 1-10m | weekly-monthly | Optical, MS, SAR | long timeseries required for delivering a good and reliable service (ideally also historical). Thus should ideally not be dependent on tasking but on always collecting constellations. | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. | Pipeline-network definition, corridor definition, land use data, DEM |
| | EUSPA-EO-UR-ERM-0030 | Energy network conditions monitoring (powerlines) | Grid operators | **Storm damage assessment** | 10-100000km energy networks -> 10-100000km2 energy corridors to monitor | N/A | Ad hoc after large storm | Asses damage to above ground power grid lines and energy towers. Fast damage overview is crucial to restore possible power outings. | Provide damage overview for large areas in one go. | Periodic baseline update, with ad hoc initiated analysis triggered by a storm. | SAR: 1-10m<br>MS: 1-10m<br>Optical: <50cm | Baseline quarterly/yearly, damage analysis ad hoc. | SAR supplemented with high res optical. | long timeseries required for delivering a good and reliable service (ideally also historical). Thus should ideally not be dependent on tasking but on always collecting constellations. | Monitoring constellations like the Sentinels. Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. | Pipeline-network definition, corridor definition, land use data, DEM |
| | EUSPA-EO-UR-ERM-0031 | Energy network conditions monitoring (powerlines) | Government, financial institutions, investors | **Transmission line mapping** | Country | N/A | One-time, repetition optional | N/A | Mapping transmission line infrastructure: network, towers, stations | Using a variety of public sources and VHR imagery powerline infrastructure is mapped on an national scale. | <0.5m | Event driven | Multispectral | N/A | Commercial high res optical (<=50cm) providers like Planet, Pleiades, Superview, etc. | OSM topographic data<br>Night-time satellite imagery<br>open data on power stations, power sources |
| | EUSPA-EO-UR-ERM-0032 | Energy network conditions monitoring (powerlines) | Grid operators, contractors | **Monitor ground surface for subsurface powerlines** | Grid corridors, 10 m wide (urban areas: full areas) | N/A | Quarterly | N/A | Monitor ground surface types | Using a baseline object-based inventory of ground surface types (based on satellite data, aerial imagery, topography maps) the grid operator has a base for designing and planning costs for maintenance and repair works on subsurface infrastructure: surface needs to be restored to original state when placing or accessing subsurface grid infrastructure . | <0.5m | Annual, quarterly | Multispectral | N/A | VHR optical satellite imagery for monitoring | Aerial imagery (=<10 cm spatial resolution)<br>Topographic (digital) maps |

## Table 33: Requirements Synthesis – Renewable Energy Assessment Potential and Forecast (Solar)

| | ID | Application | Users | User Needs | | | | | Service Provider Offer | | Service Provider Satellite EO Requirements | | | | Service Inputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Operational Scenario | Size of Area of Interest | Scale | Frequency of Information | Other (if applicable) | What the service does | How does the service work | Spatial Resolution | Temporal Resolution | Data Type / Spectral Range | Other (if applicable) | Satellite Data Sources | Other Data Sources |
| SOLAR | EUSPA-EO-UR-ERM-0001 | Renewable energy assessment potential and forecast (solar) | Individual citizens, companies, municipalities<br><br>Project developers, investors | **Assess rooftop PV Annual Energy Potential in kWh/kWp for single rooftops or rooftops across municipalities - solar cadaster.**<br><br>**Assess industrial PV farm Annual Energy Potential in kWh per unit of surface** | 50m2-100km2 | N/A | one-off | Aerosol information, meteo data | Assess rooftop PV annual energy production potential | Multiply the area suitable for PV installations by the average solar irradiation and rooftop slant/azimuth based on 3D data and shadow analysis to assess energy production potential. Irradiation is assessed by combining imagery from five geostationary weather satellites, which image the globe at a spatial resolution as fine as 1 kilometer, and geo-code, quality control and compute estimates. | <1m (surface area assessment), 1KM (irradiance assessment)<br><br>10-100m (distant horizon assessment), 1KM (irradiance assessment) | annual (RGB) and hourly or sub-hourly (irradiance and air temperature at 2m) | RGB 400-700nm (rooftop surface area and slope)<br><br>0.3–3.0 µm (solar irradiance)<br><br>Air temperature at 2m from Numerical Weather Model | N/A | VHR (stereo) satellite data (e.g. Worldview) for rooftop surface area/slope, with a minimum resolution of 0,25 m which may not be available yet<br><br>geostationary satellite data (e.g. GOES, HIMAWARI, METEOSAT) for solar irradiance<br><br>CAMS IFS meteo data | Aerial, drones (RGB & LiDAR), SRTM Digital Terrain Model data |
| | EUSPA-EO-UR-ERM-0002 | Renewable energy assessment potential and forecast (solar) | Individual citizens, companies, municipalities | **Assess rooftop PV Energy production at sub-hourly temporal resolution for single rooftops or rooftops across municipalities - analyse the fit for one or several years between production and consumption (from a typical consumption time series depending on the building type) to optimize the PV system for self-consumption or a battery storage if planned** | 50m2-10km2 | N/A | one-off | Aerosol information, meteo data | Assess rooftop PV energy production time series to optimize PV system (potentially with battery storage) and self-consumption potential for residential, commercial and industrial buildings | Multiply the area suitable for PV installations by the solar irradiation sub-hourly time series and rooftop slant/azimuth based on 3D data and shadow analysis to assess energy production vs. typical consumption time series.<br><br>Irradiation is assessed by combining imagery from five geostationary weather satellites, which image the globe at a spatial resolution as fine as 1 kilometer, and geo-code, quality control and compute estimates. | <1m (surface area assessment), 1KM (irradiance assessment) | annual (RGB) and hourly or sub-hourly (irradiance and air temperature at 2m) | RGB 400-700nm (rooftop surface area and slope)<br><br>0.3–3.0 µm (solar irradiance)<br><br>Air temperature at 2m from Numerical Weather Model | N/A | VHR (stereo) satellite data (e.g. Worldview) for rooftop surface area/slope, with a minimum resolution of 0.25 m which may not be available yet<br><br>geostationary satellite data (e.g. GOES, HIMAWARI, METEOSAT) for solar irradiance<br><br>CAMS IFS meteo data | Aerial, drones (RGB & LiDAR) |
| | EUSPA-EO-UR-ERM-0003 | Renewable energy assessment potential and forecast (solar) | Energy companies, grid operators, urban planning decision makers | **Monitoring, nowcasting and forecasting of energy potential for grid balancing and solar energy trading at urban scale** | 50m2-10km2 | N/A | daily or sub-daily | Aerosol information, meteo data | Monitor and nowcast the temporal and spatial variability of the injected electic energy for grid operators and aggregators for grid balancing and solar energy trading | Compute, for a single or a group of PV systems in urban environment the current, near future and optionally the next day electricity output, taking into account the systems characteristics (slopes and azimuth of panels) with shadow analysis.<br><br>Irradiation is assessed in near real-time by combining imagery from five geostationary weather satellites, which image the globe at a spatial resolution as fine as 1 kilometre, and geo-code, quality control and compute estimates. Cloud Motion Vectors or Deep Learning methods are used to estimate the clouds movement for the irradiance nowcasting in the same day. Machine Learning methods are applied to forecast the next day sub-hourly solar irradiance curve. | <1m (surface area assessment), 1KM (irradiance assessment) | annual (RGB) and hourly or sub-hourly (irradiance and air temperature at 2m) | RGB 400-700nm (Digital Terrain Model)<br><br>0.3–3.0 µm (solar irradiance)<br><br>Air temperature at 2m from Numerical Weather Model | Numerical Weather Model hindcast historical data together with the past solar irradiance data is needed to train the Machine Learning model for the next day forecast | Geostationary satellite data (e.g. GOES, HIMAWARI, METEOSAT) for solar irradiance<br><br>CAMS IFS meteo data<br><br>CAMS IFS hindcast meteo data if next day solar irradiance forecast is needed | Aerial, drones (RGB & LiDAR)<br><br>A report named "Non-commercial Light Detection and Ranging (LiDAR) data in Europe" has been published by the JRC in 2021 doi:10.2760/212427 |

## Table 34: Requirements Synthesis – Renewable Energy Assessment Potential and Forecast (Wind)

| | ID | Application | Users | User Needs | | | | | Service Provider Offer | | Service Provider Satellite EO Requirements | | | | Service Inputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Operational Scenario | Size of Area of Interest | Scale | Frequency of Information | Other (if applicable) | What the service does | How does the service work | Spatial Resolution | Temporal Resolution | Data Type / Spectral Range | Other (if applicable) | Satellite Data Sources | Other Data Sources |
| WIND | EUSPA-EO-UR-ERM-0004 | Renewable energy assessment potential and forecast (wind) | Offshore wind farm developers, offshore wind farm operators, consultants for offshore wind farm siting and resource assessment | **Assess offshore wind farm Energy Potential in MWh/year** | up to 1000KM2 | N/A | one-off | N/A | Assess off-shore wind farm annual energy production potential | Use satellite data (SAR/ASCAT) to derive wind speeds at 10m above surface, then extrapolate to 30-300m above surface to assess production potential of wind farms, complemented by other data provided using meteorological masts/radars/lidars | hundreds of meters (wind farm assessment), KM (wide coastal areas assessment) | mean annual values (mean wind, wind power, wind rose, Weibull fit estimates) and wind time series | SAR & ASCAT | meso-scale model outputs for long-term stability correction | SAR data (e.g. by Sentinel-1, ICEYE, TerraSAR-X satellites), ASCAT data (e.g. by METEOSAT, MetOp satellites) | In-situ meteorological masts/Doppler Radars/LiDARs (on turbines) |
| | EUSPA-EO-UR-ERM-0005 | Renewable energy assessment potential and forecast (wind) | Researchers, project developers, government | **Assess offshore wind energy resource (MWh/year) for a particular country** | Up to 1,000,000 Km2 | N/A | one-off | N/A | Assess the wind speed (m/s) within a country's maritime area (or specific site) to derive potential power production in MWh | Hourly wind speeds are given for each geographical grid of the study area. The user downloads a given geographical and temporal subset of the data product and then applies a power curve to these wind speed values (or uses the theoretical wind power equation) to get the corresponding power output. | 1-5km | hourly values | NetCDF | 20 year hindcast of data minimum | SAR (e.g. Sentinel 1 and 6), ASCAT data, other | In-situ met-ocean buoys (UK Met Office, Irish Marine Institute, etc.) |
| | EUSPA-EO-UR-ERM-0006 | Renewable energy assessment potential and forecast (wind) | Project developers, energy companies | **Forecast wind energy at a specific offshore wind site for days/week ahead (also for O&M activities)** | Up to 100 Km2 | N/A | updated every 3 6 hours with a forecast of >5 days | N/A | Assess the wind speed (m/s) to ultimately derive potential power production in MWh for the days/week ahea and also assess weather windows for operations & maintenance activities | Hourly wind speed (m/s) values are given for each geographical grid of the study area. For energy forecast assessment, user downloads a given geographical subset of the data product and then applies a power curve to these wind speed values to derive the power output expected over coming days/week. For O&M weather window assessment, user downloads the wind speed data and applies it to a weather windows threshold matrix to assess the possibility of wind, wave or tidal energy farm visit for O&M over coming days/week. | 1-5km | hourly values | NetCDF | 5 - 10 days forecast | Sentinel 1, 3, 6, other | In-situ met-ocean buoys (UK Met Office, Irish Marine Institute, etc.) |
| | EUSPA-EO-UR-ERM-0007 | Renewable energy assessment potential and forecast (wind) | Energy companies, project developers, investors | **Assess onshore wind farm Energy Potential in MWh/year** | up to 1000KM2 | N/A | one-off for energy assessment to 3 hourly for forecasts | N/A | Assess onshore wind farm annual energy production potential and provide wind energy forecasts | 5 different EO-based high-quality and high-resolution data products on land cover, key forest characteristics, historical and future changes, topography and surface roughness Surface roughness data is directly compatible with modelling methods (windPRO, WaSP and CFD tools). | 10 to 20 m | mean annual values (mean wind, wind power, wind rose, Weibull fit estimates) and wind time series | Copernicus Global Land Service (LAI, NDVI) from Sentinel 3 OLCI, SAR (Sentinel 1), optical data (Sentinel 2), ASCAT | meso-scale model outputs for long-term stability correction, very high-resolution elevation layer (1 m) | SAR data (e.g. by Sentinel-1, ICEYE, TerraSAR-X satellites), ASCAT data (e.g. by METEOSAT, MetOp satellites), existing datasets from Copernicus Global Land Service (CGLS) | In-situ meteorological masts/Doppler Radars/LiDARs (on turbines)/Met Stations |
| | EUSPA-EO-UR-ERM-0008 | Renewable energy assessment potential and forecast (wind) | Energy companies, project developers, investors | **Assess the impact of blockage/wake effects on wind energy production** | up to 1000KM2 | N/A | Hourly to daily | N/A | Analyse the wakes and blockage effects between turbines and between two wind farms | Use of SAR data to detect, measure and monitor the effects of wakes from individual turbines and blockage between wind farms that impact the wind speed and energy reaching the turbines | 10m-1km | Daily | SAR | N/A | SAR data (Sentinel-1, Envisat, Radarsat 2, Terrasar X, Cosmo Skymed, ICEYE ) | Microscale atmospheric numerical models |
| | EUSPA-EO-UR-ERM-0009 | Renewable energy assessment potential and forecast (wind) | Energy companies, project developers | **Impact of waves on floating turbines** | up to 1000KM2 | N/A | Hourly | N/A | Analyze and forecast the impact of the wave effects on the floating structures | Altimetric and radar data to provide wave data fields that can be directly used for wave climatology analysis or indirectly as boundary conditions or data assimilations on numerical models providing wave forecasts | 1km | Daily | SAR, Altimetry | N/A | SAR data (Sentinel-1 and 6, Envisat, Radarsat 2, Terrasar X, Cosmo Skymed, ICEYE ) & altimetry data (Jason2-3,Sentinel-3,Cryosat-2,Saral,HY-2,Jason-1,ENVISAT,ERS-1/2,GFO,Topex/Poseidon) | In-situ metocean buoys/wave gauges and numerical models |

## Table 35: Requirements Synthesis – Renewable Energy Assessment Potential and Forecast (Ocean)

| | ID | Application | Users | User Needs | | | | | Service Provider Offer | | Service Provider Satellite EO Requirements | | | | Service Inputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Operational Scenario | Size of Area of Interest | Scale | Frequency of Information | Other (if applicable) | What the service does | How does the service work | Spatial Resolution | Temporal Resolution | Data Type / Spectral Range | Other (if applicable) | Satellite Data Sources | Other Data Sources |
| OCEAN | EUSPA-EO-UR-ERM-0010 | Renewable energy assessment potential and forecast (ocean) | Project developers, energy companies, government, researchers | **Assess wave energy resource within a country's maritime area or at a specific area of interest** | Up to 1,000,000 Km2 | N/A | one-off | N/A | Assess the significant wave height (Hs) and wave period (T) to ultimately derive potential power production in MWh | Hourly significant wave height (Hs) and wave period (T) values are given for each geographical grid of the study area. The user downloads a given geographical and temporal subset of the data product and then applies a power matrix to these wind speed values (or uses the theoretical wave power equation) to derive the power output. | 1-5km | hourly values | NetCDF, SAR, altimetry | 20 year hindcast of data minimum | Sentinel 1, 3, 6 | In-situ metocean buoys/wave gauges and numerical models |
| | EUSPA-EO-UR-ERM-0011 | Renewable energy assessment potential and forecast (ocean) | Energy companies, project developers, investors, governments (ministries, regulation agencies) | **Assess tidal energy resource within a country's maritime area or at a specific area of interest** | Up to 1,000,000 Km2 | N/A | one-off | N/A | Assess current speeds (m/s) to ultimately derive potential power production in MWh for short and long-term forecasts | Hourly current speed (m/s) values are given for each geographical grid of the study area. The user downloads a given geographical and temporal subset of the data product and then applies a tidal energy device power matrix to these current speed values (or uses the theoretical tidal power equation) to derive the power output. | <1km2 | hourly values | NetCDF, altimetry | 1 year hindcast is sufficient | NOAA, METOP-A, Oceansat 2, AQUA, SNPP, NOAA-20, ENVISAT, Sentinel 3 and 6, MSG,GOES, DMSP, TRMM, Jason 1,2,3, Topex/Poseidon, Cryosat, Saral, ERS 1,2, GFO | In-site ADCP data (availability may be an issue) |
| | EUSPA-EO-UR-ERM-0012 | Renewable energy assessment potential and forecast (ocean) | ORE Project developers, energy companies | **Assess wave energy resource at a specific site of interest for days/week ahead. Assess possibility of operations & maintenance activities over days/week ahead (wind, wave and tidal)** | Up to 100 Km2 | N/A | updated every 3 - 6 hours with a forecast of >5 days | N/A | Assess the significant wave height (Hs) and wave period (T) to ultimately derive potential power production in MWh for the days/week ahead and also assess weather windows for O&M | Hourly significant wave height (Hs) and wave period (T) values are given for each geographical grid of the study area. For energy forecast assessment (wave energy only), user downloads a given geographical subset of the data product and then applies a power matrix to these values to derive the power output expected over coming days/week. For O&M | 1 km2 | hourly values | NetCDF | 5 - 10 days | Sentinel 1, 3, 6 | In-situ met-ocean buoys (UK Met Office, Irish Marine Institute, etc.) |
| | EUSPA-EO-UR-ERM-0013 | Renewable energy assessment potential and forecast (ocean) | Energy companies, project developers, investors, governments (ministries, regulation agencies) | **Assess Ocean Current Energy Potential and provide current forecasts** | up to 10000KM2 | N/A | Daily | N/A | Assess ocean currents annual energy production potential and provide short to long term wave forecasts | Altimetric, Sea Surface Colour and radar data to provide ocean currents data fields that can be directly used for current climatology analysis or indirectly as boundary conditions or data assimilations on numerical models providing currents forecasts | 1-100km | N/A | SST, SSC, altimetry | N/A | NOAA, METOP-A, Oceansat 2, AQUA, SNPP, NOAA-20, ENVISAT, Sentinel-3, MSG,GOES, DMSP, TRMM, Jason 1,2,3, Topex/Poseidon, Cryosat, Saral, ERS 1,2, GFO | In-situ metocean buoys, drifters and numerical models |
| | EUSPA-EO-UR-ERM-0014 | Renewable energy assessment potential and forecast (ocean) | Energy companies, project developers, investors, governments (ministries, regulation agencies) | **Assess Ocean Temperature Conversion Energy Potential and provide temperature forecasts** | up to 10000KM2 | N/A | Daily | N/A | Assess ocean temperature energy conversion potential | Altimetric and Sea Surface Temperature data to provide ocean temperature data fields data that can be directly used for sea temperature climatology analysis or indirectly as boundary conditions or data assimilations on numerical models providing temperature forecasts | 1-100km | N/A | SST, altimetry | N/A | NOAA, METOP-A, Oceansat 2, AQUA, SNPP, NOAA-20, ENVISAT, Sentinel-3, MSG,GOES, DMSP, TRMM, Jason 1,2,3, Topex/Poseidon, Cryosat, Saral, ERS 1,2, GFO | In-situ metocean buoys, drifters and numerical models |

# 3 RAW MATERIALS

## 3.1 Executive Summary

This report aims to enhance the understanding of market evolution, strongpoints, limitations, key technological trends, and main drivers related to the uptake of GNSS and EO data and services across the different raw materials application domains. These elements are essential to frame the appropriate technology and service offering development against the requirements of the respective users.

**Market Evolution & Key Trends**

An overview of the raw materials market evolution is presented in section 3.2. Key trends include:

- **Legislation and Environmental, Social and Governance (ESG) expectations drive environmental monitoring needs and requirements**
- **New protocols and standards for monitoring tailings dams drive safety monitoring needs and requirements**
- **Increased responsibility and transparency in the supply of minerals drive value chain (emission) monitoring needs and requirements**
- **Depletion of the number of 'easy' mining deposits which haven't already been developed drive exploration needs and requirements**
- **More performant upstream solutions tailored for specific market needs**

The 2020 European Commission's Action Plan on Raw Materials contains 30 materials and charts out a plan towards greater security and sustainability of their supply. One of the ten proposed actions is to "**Deploy Earth-observation programs and remote sensing for resource exploration, operations and post-closure environmental management**", highlighting the importance of space-based infrastructure to the sector.

**Current and Prospective Use of GNSS and EO in Raw Materials**

EO and GNSS powered services have a multitude of applications within the Raw Materials segment. Mining companies can use services enabled by EO and GNSS data to ensure better safety around the mining operations, by assessing stability of pit slopes of tailings dams. Mining site closure and aftercare operations can also benefit from EO data to ensure rapid response and minimal impact on the environment in case of an event. Miners furthermore use sophisticated GNSS-powered solutions to fully remote-control trucks moving around iron ore in mines, a world's first back in 2015 [RD47]. Static and dynamic GNSS-based solutions are also used for exploration and mine site surveying, to coordinate survey control and the development of the basic geodetic base, maintaining and updating maps of the surface layout as the mining operations progress, or to conduct progressive ground model surveys during construction to assist in the volumetric surveys for contractor payment.

While maturity is improving, the EO sector does not yet offer fit-for-purpose, turn-key solutions for the mining industry and the data products available on the market do not integrate well with the industry's workflows and systems. Moreover, EO solutions are losing the competition to the current way of working because of the high cost-of-change barrier that needs to be overcome. Given the increasing demand for critical raw materials, but also the societal and environmental challenges related to mining, there is a growing need for EO solutions that can enable new exploration, planning, operations, and monitoring capabilities.

In the next years, the following applications of earth observation are expected to become generally available and widely used, driven by the overall market trends, the specific needs of actors in the sector, and the advances in technological capabilities:

- Geological mapping to explore and select new potential extraction sites, including the assessment of terrain features and surface composition.
- Comprehensive monitoring of the environmental impact of mining activities both at the mining site and in the surrounding areas.
- Monitoring and detection of geological and hydrological changes to reduce safety risks, in particular tailings dam and pit slope stability monitoring.
- Remote stockpile measurements to improve mining operations, and to enable material flow analysis for supply chain and market intelligence on a global scale.
- Use of satellite data in permitting, licensing, and regulatory compliance processes.
- Detection of illegal mining activities based on satellite data.

**Drivers for users' requirements**

In addition to the key market trends mentioned above, user requirements are furthermore driven by policy, regulation and standards as covered in section 3.3, mainly:

- **Policy: Action Plan for Critical Raw Materials**
- **Regulations related to Mining Waste**
- **Regulations related to Water Protection**
- **Standard: Global Industry Standard on Tailings Management**

## 3.2 Market Overview & Trends

### 3.2.1 Market Evolution

Mining companies can use services enabled by EO and GNSS data for various applications, for instance to identify the most suitable areas for the extraction of raw materials, aid in the permitting process, plan their development and monitor their operations (fleet tracking, ground stability, water monitoring), and use EO solutions in site closure and aftercare. As illustrated in EUSPA's Market Report 7, the revenues from the sale of both EO data and services to both the energy and raw materials sectors in 2020 amounted to €305m. *Site exploration, planning and monitoring for raw materials* is the largest segment in the market, holding 34% of the market share. *Environmental impact assessment of energy and mineral resources plants* is in third place with a share of 17%.

EO lends itself very well to site exploration, planning and monitoring for raw materials since many sites are being developed in more and more isolated parts of the world. The large market share held by the environmental impact assessment of energy and mineral resources plants application reflects the focus on sustainability in the sector. The substantial market shares for both reflect the efficacy and efficiency of EO in remotely and cost-effectively enabling discovery, planning and management of sites.

Government authorities/regulatory agencies furthermore want to monitor remote sites and detect/stop illegal mining activities, where EO data enables the detection and monitoring of the progression of disturbance caused by illegal mining. GNSS, like EO, is also used for planning and operational activities for raw materials. High-accuracy GNSS is used to survey sites and safely guide earth movers, bulldozers, or other machinery – in recent years many of these are operated fully autonomously thanks to GNSS guidance. Moreover, satellite data is invaluable in the post-operational phase for the mining industry, especially in site clean-up, rehabilitation, and waste management.

Role of Copernicus Data & Services – In the Raw Materials market segment, Copernicus data and services provide specific value for the assessment of environmental impact of mining activities as well as ground stability monitoring. For example, Sentinel 2 data (e.g., Red-Edge, NDVI, etc.) can be used to provide a baseline vegetation study prior to the start of mining activities and continuously monitor the stress on vegetation over time. Copernicus data also sees use in ground deformation assessments around mining sites, e.g., to monitor (in)stability of tailings dams or pit slopes, through Interferometric Synthetic Aperture

Radar (inSAR) techniques enabled by Sentinel 1 data. Overall, the value of Copernicus Data and Services comes from the fact that it is open, reliable, free-to-use and can be used for any study and in any model, which levels the playing field in terms of modelling.

### 3.2.2 Key Market Trends

- **Legislation and Environmental, Social and Governance (ESG) expectations drive environmental monitoring needs and requirements**
    - Legislation and ESG expectations drive the trend of **ambitious decarbonization and environmental targets for miners**. In line with the ESG trend, EO data specifically allows miners to monitor the environmental impact of their activity (mining, processing, storage, etc.) on the immediate areas surrounding the mines and to avoid waste of resources through leakage. Such EO data may also be used in support of environmental impact certification [RD51]. Mining companies can use EO-enabled services to monitor or certify the environment around a mine, plant, or other site, identify potential environmental impacts which can then be investigated further manually or through more precise data, as well as use historic time series to confirm compliance to legislation and standards. Site remediation efforts may equally be monitored using EO data.
- **New protocols and standards for monitoring tailings dams drive safety monitoring needs and requirements**
    - EO may play an increasingly large role in ensuring the safety of mining operations. Specifically, to monitor the **stability of tailings dams**: an earth-fill embankment dam used to store by-products of mining operations after separating the ore, which are inherently unstable structures. The International Council on Mining and Metals (ICMM) and the United Nations Environment Programme have agreed protocols on how to deal with tailings dam safety, where EO solutions can provide insights into subsidence and a dams' instability [RD18]. **Pit slope stability** is another application where the trend towards the use of EO solutions is apparent: as a major safety and production risk for the industry, pit slopes' stability requires continuous monitoring, where today traditional survey techniques or drones are primarily used. Recent high-profile failures (e.g., Bingham Canyon Failure in 2013) drive the need for better and more frequent monitoring practices where EO can provide added value by highlighting the need for preventative actions and provide early warning for imminent failure in a cost-effective manner [RD18].
- **Increased responsibility and transparency in the supply of minerals drive value chain (emission) monitoring needs and requirements**
    - The changing needs of consumers, suppliers, investors, and governments are partly responsible for this disruption. In the case of mining companies, EO data can provide insights into the emissions of mines, with a recent example of a group of Dutch scientists at TNO revealing that Australian coal mines emit far more methane than expected based on national reporting [RD20]. It is these kinds of insights that allow stakeholders to monitor performance of supply chains against legal or quality standards or assess total carbon footprint. Mining companies themselves can benefit from EO data used to assess stockpile volumes, as much of the mined materials (e.g., iron ore, coal) are stored at the surface and their volumes can be measured from space. With certain stockpiles worth millions of euros, having insights into the change in volumes is considered critical supply chain information.

- **Depletion of the number of 'easy' mining deposits which haven't already been developed drive exploration needs and requirements**
    - Mining exploration projects are forced to explore the most remote parts of the globe, making manual surveys expensive and time consuming, where EO data and services can provide cost-effective alternatives.
- **More performant upstream solutions tailored for specific market needs**
    - Recently deployed and future planned high performance (high resolution and high frequency) satellite constellations are better capable to address the stringent needs of the raw materials sector.

Technology trends include:

- Hyperspectral sensors for mineral exploration
- Need for full-range solution: VIS/NIR/SWIR/LWIR spectral ranges
- Hyperspectral data vs. multispectral bands with adjusted wavelength position and width
- More EO data, more satellites, more missions with different configurations and features for complete monitoring and more service opportunities
- Background missions with continuous and automatic acquisition modes for ensuring EO data over strategic areas
- More frequent EO data for more reliable monitoring and service opportunities
- CHIME will be a game-changer thanks to increased capacity and continuous monitoring/capturing of global data
- 3D representations for volumetric monitoring

Research gaps include:

- Data fusion / interoperability: efficient ways to combine radar and optical data from the current Copernicus portfolio as well as (future) hyperspectral missions (CHIME, EnMAP) for Raw Materials needs
- Need for real time monitoring and development of digital twins allowing 4D monitoring
- Integration of ancillary data: integrating other sources of information such as geophysical, UAV (hyperspectral, LiDAR) and geo-localisation data
- Scalable solution for Data Processing: need for innovative processing methodologies making use of Artificial Intelligence, for optimally exploiting the data acquired by different platforms [close-range, UAV, aerial, orbital] and at multiple spatial and temporal scales
- Need for tools allowing object-oriented analysis

### 3.2.3 Main User Communities

A critical role is played by associations in raising awareness for the mining industry, as the industry's biggest advocate helping to promote and maximise the contribution of mining, minerals, and metals to sustainable development. Their role is to provide leadership and opportunities to their members while driving social, economic, and environmental progress.

- **International Council on Mining and Metals (ICMM)**
    - One of the largest global user communities in Raw Materials is that of the which brings together approximately a third of the global metals and mining industry to "to drive leadership, action and innovation for a safe, just and sustainable world" [RD26].
    - The ICMM drives user needs and requirements by promoting sustainable development for miners, to strengthen social and environmental requirements, as well as address issues like mine closure, pollution, and waste.

- **Euromines**
    - Euromines plays a key role in Europe's mining industry, acting primarily as an interface between the extractive industry of Europe and the European authorities and international or intergovernmental bodies
    - Euromines drives environmental user needs and requirements through their focus on environmental sustainability, including reducing carbon emissions, reducing energy intensity, reducing discharges to water, reducing emissions to air.
- **European Raw Materials Alliance (ERMA)**
    - ERMA was recently announced in September of 2022 as part of the Action Plan on Critical Raw Materials [RD44] with a vision to secure access to critical and strategic raw materials, advanced materials, and processing know-how for EU Industrial Ecosystems.
    - ERMA, with its mission to "bolster the creation of environmentally sustainable and socially equitable innovations and infrastructure" is expected to drive innovation uptake among miners
- **EIT Raw Materials**
    - EIT Raw Materials is the largest consortium in the raw materials sector worldwide, with a mission is to enable sustainable competitiveness of the European minerals, metals, and materials sector along the value chain by driving innovation, education, and entrepreneurship. It unites more than 120 core and associate partners and 180+ project partners from leading industry, universities, and research institutions.
    - Its wide reach and strong focus on innovation and entrepreneurship showcases their clear link to the mining industry's needs and requirements

### 3.2.4 Main Market Players

Please refer to section 2.2.4 for EO and GNSS value chains and market players for both Energy and Raw Materials.

## 3.3 Policy, Regulation and Standards

The below policies, regulations, and standards drive user needs and requirements in the mining sector.

- **Policy: Action Plan for Critical Raw Materials [RD45]**
    - The most prominent EU policy for mining: it primarily aims to develop resilient value chains for EU industrial ecosystems, reduce dependency on primarily critical raw materials through circular use of re-sources, sustainable products, and innovation, strengthen domestic sources of raw materials in the EU, and diversify sourcing from third countries.
    - Ten concrete actions were outlined. One of the actions is to "**deploy Earth-observation programs and remote sensing for resource exploration, operations and post-closure environmental management**" – highlighting the importance of EO data and services in achieving the goals set out in the Action Plan.

Regulations primarily affect two types of environmental concerns that arise for mining operations: depletion of resources and harm to the environment. For the environment, this includes pollution of air, soil, water, and noise, with potential negative impact on natural habitats, visual impact on the landscape and altering ground water levels.

- **Regulation: Mining Waste**
    - The mining waste stream is one of the largest in the EU, where some of it is dangerous [RD41]. The EU legislative framework for managing mining waste safely comprises:

- The Mining Waste Directive [RD35], introducing obligatory permits and setting requirements for building or modifying an extractive waste facility. If potential risk to the environment or public health exists, operators need to provide a financial guarantee and draw up emergency plans, a policy for prevention of major accidents, and develop safety management systems. **EO-data driven services can help with the fast identification of potential leakages or other events are required to enable a speedy response and can furthermore monitor site remediation efforts following an event and provide a historic baseline in support of further investigations into the cause of the event.**
- The Seveso-III directive [RD36] covers risks arising from storage and processing activities in mining, particularly tailing ponds and dams used in mineral processing of ores. **EO-data has been proven to help assess the stability of tailings dams over time and can be used as an early indicator of instability. SAR imagery is used furthermore to identify where exactly the waste changes on large sites have occurred. Subsequently optical imagery is acquired for the specific locations where changes have been notified.** The optical imagery allows for quantitative estimations of bulk material volumes and material classes.

- **Regulation: Water Protection**
  - Operational mines discharge poor quality water which impacts the environment, but also closed mines can leak contaminated water and should be monitored. Mine water is covered in the Water Framework Directive [RD37] which introduces river-basin management and requires that a "good" status must be achieved for all EU water. It is furthermore complemented by the Groundwater Directive [RD38] which sets quality standards for underground waters and introduces measures to prevent or limit the pollution of ground water.
  - It is a challenge to meet these needs with remote sensing data. **Remote sensing may indirectly address those issues by providing several indicators using gravimetry as well as interferometry techniques [RD39]. Satellite SAR data however is capable of accurately assessing the extent of surface water within a mining site as well as water gains and losses in a tailings dam, surface run-off, or any other water body within the area of interest [RD40].**

Mining associations work together with Programmes and other stakeholders to develop standards that support the continual improvement in the safe and transparent management of mining activities.

- **Standard: Global Industry Standard on Tailings Management**
  - The United Nations Environment Programme (UNEP) together with Principles for Responsible Investment (PRI), a United Nations-supported international network of investors, closely cooperated with ICMM to create the Global Industry Standard on Tailings Management [RD27]. This standard will drive the needs and requirements of miners that aim to implement the safety and monitoring standards outlined in this standard. EO has been proven to provide valuable insights for this activity [RD50]. In addition to the standard, ICMM also developed a conformance protocol to help operators and independent third parties assess the implementation of the standard's requirements, and ultimately demonstrate conformance [RD43].

## 3.4 User Requirements Analysis

This chapter aims at providing a detailed analysis of user needs and requirements pertaining to the raw materials applications. The chapter furthermore aims to describe the different roles and needs covered by GNSS and EO and identify the corresponding requirements from a user perspective.

Table 1 below depicts the main applications making use of GNSS and/or EO technologies in raw materials. The list of applications is non-exhaustive and is expected to potentially grow and adapt according to the expected adoption of space technologies in the coming years and the innovations that should come with it. The current report is the first version of the energy and raw materials report on User Needs and Requirements, and thus considered a living and evolving document that will periodically be updated and expanded by EUSPA in its next releases.

While each one of the applications addressed in this document can benefit from GNSS and/or EO, the current issue of this report does not cover in detail the needs and requirements for all these applications. A categorisation was performed prioritising some applications based on their maturity level and relevance to the market trends and drivers. Other applications are foreseen to be covered in more detail in future versions of this RUR.

The following applications categorisation reflects the depth of information available in section 5:

**Application Type A:** these applications correspond to those for which an in-depth investigation is presented and for which needs and requirements relevant to GNSS and EO have been identified and validated with the raw materials user community at the UCP.

**Application Type B:** these applications correspond to those not selected for in-depth investigation in the current version of the RUR, for which a partial specification of needs and requirements is provided, limited at this stage to the ones relevant to GNSS.

**Application Type C:** these applications correspond to EO-based applications, not selected for in-depth investigation in the current version of the document. A high-level description of the application is included considering that they will be further analysed and developed in next versions of the RURs.

The table below maps the seven **raw materials-related** applications to the three above-mentioned types. The following list of applications and their categorisation are **expected to evolve in the next versions of the document**.

**Legend**

EO only application

GNSS only application

Hybrid/synergetic application (combined use of EO and GNSS)

**Table 36: Raw Materials applications, definitions, and categorisation**

| Segment | Subsegment | Application | Type of application/ Level of Investigation | |
|---|---|---|---|---|
| **Raw Materials** | **Environmental Impact Monitoring** | Environmental impact assessment of mines | A |  |
| | **Market intelligence** | Supply chain insights | C |  |
| | **Mining** | Illegal mining monitoring | C |  |
| | | Mining machinery control | B |  |
| | | Mining vehicle tracking & asset management | B |  |
| | | Mining site exploration, planning and monitoring | A |  |

The next section first addresses "type A" applications, then "type B" applications and finally "type C" applications, for which the level of provided information is currently the least developed.

Each EO-based "Type A" application will cover the needs and requirements for potentially several operational scenarios. For each scenario, a table summarises the EO related needs and requirements. The table template is illustrated below in Table 2 and explains the various inputs.

**Table 37: Description of needs and requirements relevant to EO**

| | |
|---|---|
| **ID** | Identifier |
| **Application** | Application covered. |
| **Users** | Common users of the product/service. |
| **User Needs** | |
| **Operational scenario** | **Describes the operational scenario faced by the user, which requires a solution.** |
| **Size of area of interest** | Describes the area of interest (e.g., a miner is interested in a new mining site of 5Km$^2$). |
| **Scale** | Describes the scale of interest (e.g., a miner is interested to see at mm level the ground subsidence for the mining pit slopes). |
| **Frequency of information** | How often the user requires the information. |
| **Other (if applicable)** | Other user needs such as contextual information (weather data) or file formatting requirements. |
| **Service Provider Offer** | |
| **What the service does** | Description of the service that satisfies the user's needs. |
| **How does the service work** | (Technical) description of how the service works. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | Spatial resolution of the satellite imagery/data required by the service provider to realise the service. |
| **Temporal resolution** | Frequency of satellite data (revisit time) over the area of interest. |

| | |
|---|---|
| **Data type / Spectral range** | Type of data (e.g., RGB, SAR) and spectral range (if relevant). |
| **Other (if applicable)** | Other data requirements. |
| **Service Inputs** | |
| **Satellite data sources** | Type of required data and examples of operational satellites that can provide these data. |
| **Other data sources** | Other sources of data that the service provider uses to realise the service. |

**Disclaimer:** The EO-related requirements presented in the next section should be considered as "work-in-progress". They must be seen as a first attempt to specify requirements relevant to EO and are likely to evolve throughout the UCP process.
Future versions of the RUR may consider additional parameters, such as data quality control and validation.

### 3.4.1 Environmental impact assessment of mines

EO can support the mitigation of mining effects of the environment through continuous monitoring of relevant environmental characteristics and through the capacity of EO to detect changes. Jobs to be done include monitoring or certifying the environment around a mine, plant, or other site, identify potential environmental impacts which can then be investigated further manually or through more precise data, use historic time series to confirm compliance to legislation and standards, or monitor site remediation efforts.

Relevant products and services include coastal ecosystems monitoring, water quality monitoring, air quality monitoring, erosion monitoring, pollution monitoring, vegetation monitoring, etc. In some cases, EO-based products could also include the production of environmental impact assessment "certificate"[2].

The following operational scenarios and the related user needs and requirements will be covered in this section:

- **Document surface infrastructure, disturbances of surface, current land use, erosion, landslides.**
- **Geotechnical analysis**
- **Baseline vegetation study & monitoring vegetation: stress due to drought; stress due to pollution, wildfires**
- **Monitoring: ground- and near surface water regime, soil moisture and drought**
- **Prediction & monitoring of direct extraction effects: dust, acid drainage, spills, waste movement**
- **Mining site post-closure monitoring**

**Table 38: Main Requirements Relevant to EO for Environmental impact assessment of mines – Document surface infrastructure, disturbances, land use, erosion, landslides**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0015 |
| **Application** | Environmental impact assessment of mines |
| **Users** | Mining companies, oil & gas companies |
| **User Needs** | |
| **Operational scenario** | **Document surface infrastructure, disturbances of surface, current land use, erosion, landslides.** |
| **Size of area of interest** | Site-scale, usually order of < 10 km2 |

[2] https://www.citizensinformation.ie/en/environment/climate_change/environmental_impact_assessment.html

| | |
|---|---|
| **Scale** | N/A |
| **Frequency of information** | once |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | The service registers existing land use and surface conditions, including man-made objects and natural phenomena. |
| **How does the service work** | Digital analysis and pattern recognition techniques can be used to classify and categorize the relevant features. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-5m |
| **Temporal resolution** | once |
| **Data type / Spectral range** | standard natural colour, multispectral |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | WV3, GeoEye, Pleiades, Spot, Geosat |

Note: the accompanying operational scenario (which monitors changes to the documented surface infrastructure, disturbances, etc. is listed in Table 47).

**Table 39: Main Requirements Relevant to EO for Environmental impact assessment of mines – Geotechnical analysis**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0016 |
| **Application** | Environmental impact assessment of mines |
| **Users** | Mining companies, oil & gas companies |
| **User Needs** | |
| **Operational scenario** | **Geotechnical analysis** |
| **Size of area of interest** | Site-scale, usually order of < 10 km2 |
| **Scale** | N/A |
| **Frequency of information** | once |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | The service provides generation of high-resolution DEMs, geologic maps, structural analysis |
| **How does the service work** | Stereo imagery is used for generation of DEMs. Combined with those DEMs, satellite imagery can be used for lithologic/structural mapping |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-5m |
| **Temporal resolution** | once |
| **Data type / Spectral range** | standard natural colour, multispectral, Panchromatic stereo |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | WV3, GeoEye, Pleiades, Spot, Geosat |
| **Other data sources** | ground and drillhole data, drone imagery |

**Table 40: Main Requirements Relevant to EO for Environmental impact assessment of mines – Baseline vegetation study & vegetation monitoring**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0017 |
| **Application** | Environmental impact assessment of mines |
| **Users** | National authorities, NGOs, mining companies, oil & gas companies |
| **User Needs** | |
| **Operational scenario** | **Baseline vegetation study & monitoring vegetation: stress due to drought; stress due to pollution, wildfires** |
| **Size of area of interest** | Site-scale, usually order of < 10 km2. Regional scale, usually order of < 100 km2 |
| **Scale** | N/A |
| **Frequency of information** | once, monthly-quarterly |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | The service records the important parameters related to the health of vegetation and the seasonal variations. |
| **How does the service work** | Recommended is to use imagery to automatically detect changes in vegetation health using indicators such as: Red-Edge, NDVI, LAI, Chlorophyll-a |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 10-30m |
| **Temporal resolution** | quarterly, monthly |
| **Data type / Spectral range** | VNIR and SWIR (400nm - 2500nm), SAR (soil moisture) |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Landsat, Sentinel-2, Planet, WV3 |
| **Other data sources** | Land-use maps, field spectroscopy, drone imagery |

**Table 41: Main Requirements Relevant to EO for Environmental impact assessment of mines – Water regime, soil moisture and drought monitoring**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0018 |
| **Application** | Environmental impact assessment of mines |
| **Users** | National authorities, NGOs, mining companies, oil & gas companies |
| **User Needs** | |
| **Operational scenario** | **Monitoring: ground- and near surface water regime, soil moisture and drought** |
| **Size of area of interest** | Site-scale, usually order of < 10 km2 |
| **Scale** | N/A |
| **Frequency of information** | monthly-quarterly |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | The service monitors the behaviour of ground- and near-surface water, drainage, runoff, flooding |
| **How does the service work** | recommended is to use imagery to automatically can monitor indicators for soil-moisture content, to map the drainage characteristics, and predict (model) changes in ground water level because of mine-drainage. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 10-30m |
| **Temporal resolution** | monthly-quarterly |
| **Data type / Spectral range** | UV-VNIR (350 - 1000nm), SAR |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Sentinel-2, NISAR, Aster, ICEYE, Sentinel-1 |
| **Other data sources** | Geologic maps, structural data, in situ data, ground water data. Drone Thermal IR. |

**Table 42: Main Requirements Relevant to EO for Environmental impact assessment of mines – Prediction and monitoring of direct extraction effects**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0019 |
| **Application** | Environmental impact assessment of mines |
| **Users** | Mining companies, oil & gas companies |
| **User Needs** | |
| **Operational scenario** | **Prediction & monitoring of direct extraction effects: dust, acid drainage, spills, waste movement** |
| **Size of area of interest** | Site-scale, usually order of < 10 km2 |
| **Scale** | N/A |
| **Frequency of information** | monthly-quarterly |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | The service monitors identifies where the potential hazards and affected zones are located |
| **How does the service work** | recommended is to use imagery to automatically detect spread of dust, acid drainage and other hazardous spills that are a direct result of the mining activities |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 10-300m |
| **Temporal resolution** | monthly (VNIR), annually (SWIR) |
| **Data type / Spectral range** | VNIR (400-1000nm) and SWIR (2000-2500), SAR |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | MODIS, CALIPSO, GeoEye, Sentinel-1&2, TerraSAR-X, Spot, WV3 |
| **Other data sources** | N/A |

**Table 43: Main Requirements Relevant to EO for Environmental impact assessment of mines – Mining site post-closure monitoring**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0020 |
| **Application** | Environmental impact assessment of mines |
| **Users** | Mining companies, service providers to competent authorities |
| **User Needs** | |
| **Operational scenario** | **Mining site post-closure monitoring** |
| **Size of area of interest** | Site-scale, usually order of < 10 km2 |
| **Scale** | N/A |
| **Frequency of information** | Monthly, quarterly, yearly (regulation dependent) |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Provide a low-cost remote monitoring of mines post-exploitation to ensure 1. compliance with environmental recovery plans, 2. they are not causing harm (subsidence, damage to ecosystem, water etc.) |
| **How does the service work** | Provides reports on the status of the mine for mining company + competent authority. The service can also be referred to in the planning phase / when applying for permits as a feasible, low-cost and credible solution for the end-of-life period of a site. |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 10m |
| **Temporal resolution** | weekly |
| **Data type / Spectral range** | Optical, SAR |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Sentinel-1, sentinel-2, ICEYE, TerraSAR-X, Planet |
| **Other data sources** | N/A |

### 3.4.2 Mining site exploration, planning and monitoring

Mining companies identify the most suitable areas for the extraction of raw materials, plan their development and monitor their integrity/status (also after abandonment). Jobs to be done include identifying field intensity and the probability of the substances existing at the surface or below hundreds of meters of overburden, geomorphological studies: mapping structures and faults driving mineralization, preliminary delineation of commercial minerals and metals deposits, regional geological trends and structures, combination of remote sensing and subsurface imagery (geophysics) to identify the depth to basement, and domain creations to optimise sampling strategies and drilling campaigns.

EO data complements and enhances traditional detection methods by reducing location errors and providing faster, more accurate information on asset concentration and commercial yields.

The following operational scenarios and the related user needs and requirements will be covered in this section:

- **Geological mapping to explore for new minerals and metals commercial deposits through proxies visible at the surface**
- **Re-mining of mining waste and tailings**
- **Site exploration and planning for mine, stockpiles, tailings reservoir and related infrastructure**
- **Monitor changes in surface infrastructure, disturbances of surface, current land use, erosion, landslides**
- **Monitor ground (in)stability in prospective, active, and closed mining areas**

**Table 44: Main Requirements Relevant to EO for Mining site exploration, planning and monitoring – Geological mapping to explore for new minerals and metals**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0033 |
| **Application** | Mining site exploration, planning, monitoring |
| **Users** | Mining companies |
| **User Needs** | |
| **Operational scenario** | **Geological mapping to explore for new minerals and metals commercial deposits through proxies visible at the surface** |
| **Size of area of interest** | regional scale, up to 1,000,000 km2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Mapping of favourable indicators for the occurrence of mineral resources. |
| **How does the service work** | Map lithological features, lithology, and surficial geology (soils) to assess mineral composition (surface outcrops) of the areas of interest, using digital elevation models (DEM) and spectral/textural surface characteristics |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-15m |
| **Temporal resolution** | n/a - one off |
| **Data type / Spectral range** | Multispectral |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Multispectral data (e.g., from WV3, Aster, Landsat, Sentinel-2), Hyperspectral data (EnMAP), other (GOCE) |
| **Other data sources** | UAVs, Geophysics, geochemistry, drillholes/in-situ samples to validate mapping and build spectral library, surface mapping, etc., |

**Table 45: Main Requirements Relevant to EO for Mining site exploration, planning and monitoring - Re-mining of mining waste and tailings**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0034 |
| **Application** | Mining site exploration, planning, monitoring |
| **Users** | Mining companies, governmental institutions |
| **User Needs** | |
| **Operational scenario** | **Re-mining of mining waste and tailings** |
| **Size of area of interest** | national level (the EU wants to do this at the EU level) |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | Provides a geological mapping of abandoned waste/tailings/ stockpiles to identify potential for remining (plus cleaning up of the waste) |
| **How does the service work** | Provides geological mapping |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-15m |
| **Temporal resolution** | n/a - one off |
| **Data type / Spectral range** | Multispectral |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | Multispectral data (e.g., from WV3, Aster, Landsat, Sentinel-2), Hyperspectral data (EnMAP), other (GOCE) |
| **Other data sources** | UAVs |

**Table 46: Main Requirements Relevant to EO for Mining site exploration, planning and monitoring – Site exploration and planning for mine, stockpiles, tailings reservoir and related infrastructure**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0035 |
| **Application** | Mining site exploration, planning, monitoring |
| **Users** | Mining companies |
| **User Needs** | |
| **Operational scenario** | **Site exploration and planning for mine, stockpiles, tailings reservoir and related infrastructure** |
| **Size of area of interest** | Mine-scale, usually order of < 10 km2 |
| **Scale** | N/A |
| **Frequency of information** | one-off |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | The service uses satellite data for site exploration, mine planning and associated risk analysis, terrain & watershed analysis |
| **How does the service work** | Stereo imagery is used for generation of DEMs. Combined with those DEMs, satellite imagery is used for terrain analysis |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | <1m |
| **Temporal resolution** | once |
| **Data type / Spectral range** | Standard natural colour, multispectral, panchromatic stereo |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | WV3, GeoEye, Pleiades, Spot, Geosat |
| **Other data sources** | Cadastral data, land use maps, soil maps, Digital elevation models, Drone imagery |

**Table 47: Main Requirements Relevant to EO for Mining site exploration, planning and monitoring - Monitor changes in surface infrastructure, disturbances of surface, current land use, erosion, landslides**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0036 |
| **Application** | Mining site exploration, planning, monitoring |
| **Users** | Mining companies, oil & gas companies |
| **User Needs** | |
| **Operational scenario** | **Monitor changes in surface infrastructure, disturbances of surface, current land use, erosion, landslides** |
| **Size of area of interest** | Mine-scale, usually order of < 10 km2 |
| **Scale** | N/A |
| **Frequency of information** | annual |
| **Other (if applicable)** | N/A |
| **Service Provider Offer** | |
| **What the service does** | The service registers changes in land use and surface conditions, including man-made objects and natural phenomena. |
| **How does the service work** | Digital analysis and pattern recognition techniques can be used to classify and categorize the relevant features, and monitor changes |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-5m |
| **Temporal resolution** | annual |
| **Data type / Spectral range** | Standard natural colour, multispectral, SAR |
| **Other (if applicable)** | N/A |
| **Service Inputs** | |
| **Satellite data sources** | WV3, GeoEye, Pleiades, Spot, Geosat, ICEYE, Sentinel-1 |
| **Other data sources** | Cadastral data, land use maps, soil maps, digital elevation models, drone imagery, LIDAR (drone/aerial) |

**Table 48: Main Requirements Relevant to EO for Mining site exploration, planning and monitoring – Monitor ground (in)stability in mining sites**

| | |
|---|---|
| **ID** | EUSPA-EO-UR-ERM-0037 |
| **Application** | Mining site exploration, planning, monitoring |
| **Users** | Mining companies |
| **User Needs** | |
| **Operational scenario** | **Monitor ground (in)stability in prospective, active, and closed mining areas** |
| **Size of area of interest** | 30x30 km |
| **Scale** | N/A |
| **Frequency of information** | weekly to daily |
| **Other (if applicable)** | 3D GIS compatible sources |
| **Service Provider Offer** | |
| **What the service does** | Identify areas with ground displacements for risk assessment based on mining activities and avoid potential geotechnical failures (creeping slopes, slopes failures, collapses, etc.) |
| **How does the service work** | Provide recurrent map highlighting areas with significant ground displacements |
| **Service Provider Satellite EO Requirements** | |
| **Spatial resolution** | 1-10m |
| **Temporal resolution** | daily |
| **Data type / Spectral range** | SAR - C or X band data with dual modes, ascending and descending view |
| **Other (if applicable)** | Important to have data archives for back-analysis, service demos |
| **Service Inputs** | |
| **Satellite data sources** | Sentinel-1 |
| **Other data sources** | in-situ stability and inclination measurements such as GPS devices, inclinometers etc. |

**NOTE: The GNSS requirements relevant to mining site exploration, planning, and monitoring are presented in section 3.6.1.**

### 3.4.3 Mining machinery control

GNSS machine control refers to the control and semi-automatic guidance of vehicles; this entails mainly earth-moving machines, i.e., dozers, diggers, graders. Using RTK corrections machine operations can be undertaken at centimetre level accuracy, with increased productivity (fewer passes needed to achieve grade specifications) and at significantly less cost (reduced labour, fuel, and maintenance). For example, it is estimated that in large-scale projects such as mines, earthworks and transportation may account for up to 50% of total operational costs.

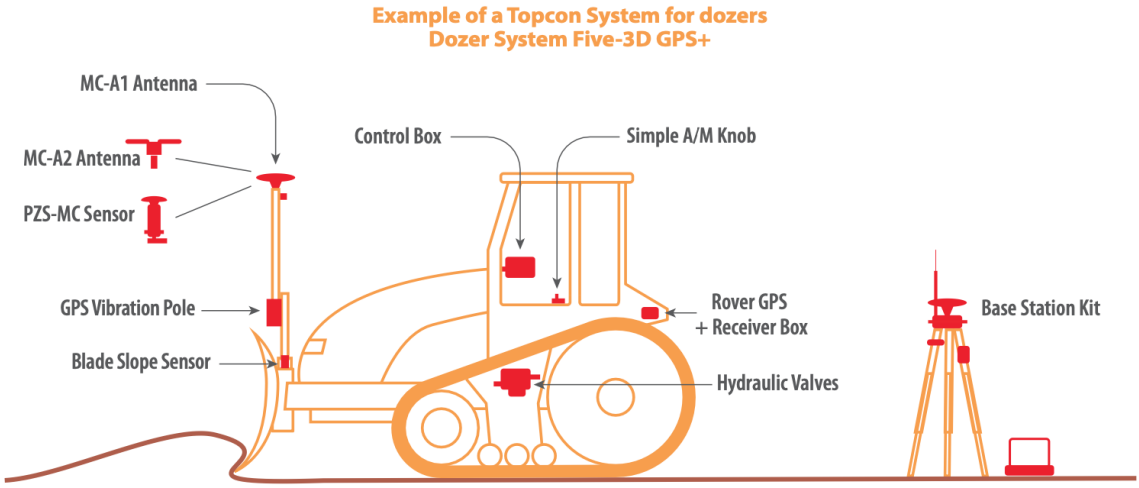


**Figure 4 Example of a Topcon System for dozers (Dozer System Five-3D GPS+)**

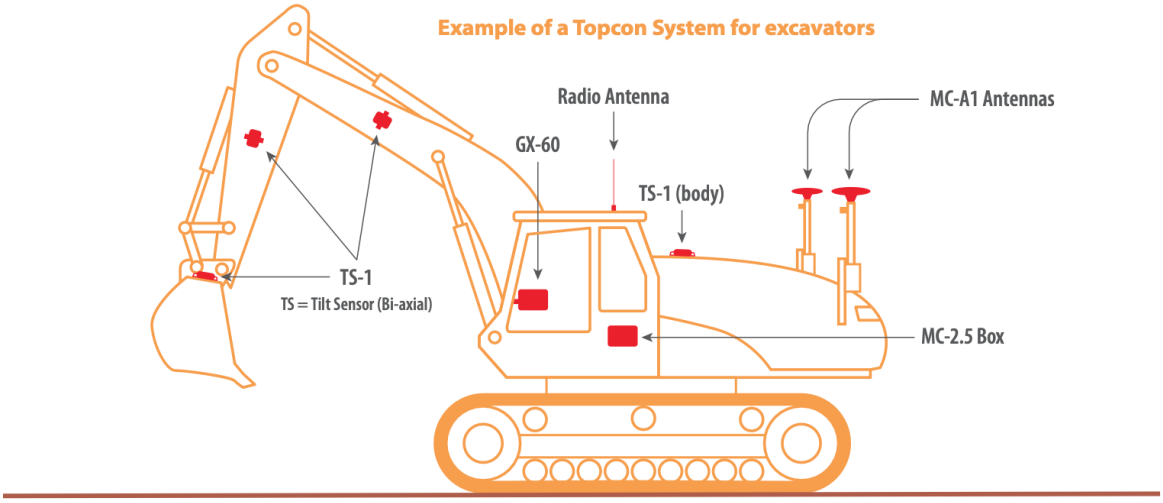


**Figure 5 Example of a Topcon System for excavators**

The mining sector heavily benefits from and heavily invests in increased automation and operations control. Here too, the availability of reliable, real-time positioning information at cm level provided by GNSS-RTK or DGNSS (and frequently augmented by additional sensors) is growingly recognised and exploited, especially in open pit mines. Machine guidance in the context of mining operations includes (semi-)automated drilling and excavator control, allowing for cost savings due to reduced passes and machine wear and tear. It also involves the automatic guidance of haulage trucks.

**The relevant GNSS requirements are presented in section 3.6.1.**

### 3.4.4 Mining vehicle tracking & asset management

By tracking the locations of mining vehicles and other mining assets, mining operators can see what is happening versus what is planned. GPS-driven data regarding the location and status can allow operators to manage issues and make effective decisions, boosting production rates while enhancing safety and minimising downtime.

**The relevant GNSS requirements are presented in section 3.6.1.**

### 3.4.5 Supply chain insights

Market analysts, traders, investors, energy operators and regulators, governments and international banking institutions all need to better understand the new energy dynamics shifting under the pressure of climate change. Applications such as reservoir monitoring, heavy oil production mapping, underground gas storage, sophisticated methane-detection technologies, etc., all help to give insights into the underlying business.

EO data helps support monitoring of key components of the supply chain infrastructure to understand their status. Service providers combine these with non-EO data and apply AI/ML methods to obtain insights into the production, supply, and demand of key commodities, and integrate these to obtain insights into the likely future market for these commodities.

### 3.4.6 Illegal mining monitoring

Government authorities/regulatory agencies want to monitor remote sites and detect/stop illegal mining activities. Due to its capacity to detect landscape changes through the analysis of satellite imagery, EO can support the detection and monitoring of the evolution of illegal mining activities (including in remote areas). Sentinel 2 data allows the mapping in near-real time deforestation potentially caused by illegal (e.g., gold) mining or, using S1 data, detect new open-pit excavations. Specifically, this information helps governments to manage risks that originate from illegal mining activities, such as deadly operational failures, or social environmental threats for the surrounding ecosystem. EO enables the production of actionable information on time, allowing governments to efficiently manage national natural resources and reduce economic losses from illegal mining activities.

## 3.5 Limitations of GNSS & EO

### 3.5.1 GNSS Limitations

See section 2.5.1.

### 3.5.2 EO Limitations

Air quality (particulate matter) monitoring is an important factor when assessing the environmental impact of mineral plants. For this application, satellite data are however dependent on clear-sky conditions, meaning that particulate matter assessments under cloudy conditions, or over bright surfaces such as snow/ice, cannot be performed. LiDAR and radar sensors (e.g., CALIPSO, CLOUDSAT) are however effective for this case. Spatial resolutions for methane/CH4 retrievals from satellite-based payloads are relatively coarse/low resolution, which means most existing satellites are unable to identify or track methane emissions of individual sites. However, new satellites are being launched (e.g., GHGsat) that provide higher resolution – although to widely monitor methane at small scales, many more satellites will be required.

To monitor the stability of mining infrastructure (tailings dams, pit slope stability) using space-based platforms, radar satellites are the go-to. However, the frequency, or revisit time, of these satellites are often once every few days, which could be too low for certain applications. Furthermore, the ability of the satellite to measure ground deformations is dependent on the reflectivity characteristics of the surface, meaning the satellite may not always be able to produce the requested measurements.

In the pursuit of mineral sites, mining companies need to establish the likelihood of minerals being present. Magnetic and gravitational field data can aid in the assessments, however the remote sensing missions (e.g., GRACE, GRACE-FO, GOCE) for these types of data provide coarse resolution (100-300km), limiting the usefulness, and are not always covering the areas of interest.

## 3.6 User Requirements Specification

The chapter provides a synthesis of the requirements described in section 3.4 respectively on GNSS in section 3.6.1 and on EO in section 3.6.2. The content of this section will be updated, completed, and expanded by EUSPA in the next releases of the RUR based on the results of further investigations discussed and validated in the frame of the UCP.

### 3.6.1 Synthesis of Requirements Relevant to GNSS

**Table 49 Cross-sector GNSS requirements relevant to Raw Materials**

| Cross-sector GNSS requirements relevant to Raw Materials | | | |
|---|---|---|---|
| **ID** | **Description** | **Type** | **Sources** |
| EUSPA-GN-UR-SURV-0040 | The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be high (>95%), including in harsh environments | Performance | [RD36][RD39] |
| EUSPA-GN-UR-SURV-0080 | The PNT information shall be based on signals transmitted in two or more bands (E1, E5, E6) thus enabling dual or triple frequency RTK and PPP solutions. | Functional | [RD37] |
| EUSPA-GN-UR-SURV-0130 | Galileo precise orbit and clock corrections shall be available in a similar way as GPS/Glonass are provided in the IGS Real Time Service | Functional | [RD40] |
| EUSPA-GN-UR-SURV-0150 | Documentation related to reference systems, needed data for the compliance to the INSPIRE directive (transformation from GTRF to ETRF2000) shall be available at the GSC portal. | Functional | [RD40] |

**Table 50 GNSS requirements relevant to Mining Site Exploration, Planning, and Monitoring**

| GNSS requirements relevant to Mining Site Exploration, Planning, and Monitoring | | | |
|---|---|---|---|
| **ID** | **Description** | **Type** | **Sources** |
| EUSPA-GN-UR-SURV-3601 | The PNT solution shall provide 20 - 80 mm horizontal accuracy | Performance | [RD36][RD41] |
| EUSPA-GN-UR-SURV-3602 | The PNT solution shall provide mm to cm level vertical accuracy | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3607 | The PNT solution shall be available regionally or locally | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3608 | The PNT solution shall be available in urban canyon with a 95% probability | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3609 | The PNT solution shall be available under canopy with a 95% probability | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3610 | The PNT solution shall be available with a TTFF of 5 min or less | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3612 | The PNT solution shall be provided with low integrity requirements | Functional | [RD41] |

**Table 51 GNSS requirements relevant to Mining Machinery Control**

| GNSS requirements relevant to Mining Machinery Control | | | |
|---|---|---|---|
| **ID** | **Description** | **Type** | **Sources** |
| EUSPA-GN-UR-SURV-3701 | The PNT solution shall provide 20 - 80 mm horizontal accuracy | Performance | [RD36][RD41] |
| EUSPA-GN-UR-SURV-3702 | The PNT solution shall provide mm to cm level vertical accuracy | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3707 | The PNT solution shall be available regionally or locally | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3708 | The PNT solution shall be available in urban canyon with a 95% probability | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3709 | The PNT solution shall be available under canopy with a 95% probability | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3710 | The PNT solution shall be available with a TTFF of 10 s or less | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3711 | The PNT solution shall be available with an update rate of 10 Hz min | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3712 | The PNT solution shall be provided with high integrity requirements | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3715 | The solution shall provide PNT information that is trustable Medium level (see comment) | Functional | [RD37] |

**Table 52 GNSS requirements relevant to Mining Vehicle Tracking & Asset Management**

| GNSS requirements relevant to Mining Vehicle Tracking & Asset Management | | | |
|---|---|---|---|
| **ID** | **Description** | **Type** | **Sources** |
| EUSPA-GN-UR-SURV-3801 | The PNT solution shall provide 1 - 5 m horizontal accuracy | Performance | [RD36][RD41] |
| EUSPA-GN-UR-SURV-3802 | The PNT solution shall provide m level vertical accuracy when applicable | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3807 | The PNT solution shall be available regionally or locally | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3808 | The PNT solution shall be available in urban canyon with a 95% probability | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3809 | The PNT solution shall be available under canopy with a 95% probability | Functional | [RD41] |
| EUSPA-GN-UR-SURV-3810 | The PNT solution shall be available with a TTFF of 10 s or less | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3811 | The PNT solution shall be available with an update rate of 1 Hz min | Performance | [RD41] |
| EUSPA-GN-UR-SURV-3812 | The PNT solution shall be provided with low integrity requirements | Functional | [RD41] |

## 3.6.2 Synthesis of Requirements Relevant to EO

**Table 53: Requirements Synthesis – Environmental Impact Assessment of Mines**

| ID | Application | Users | User Needs | | | | | Service Provider Offer | | Service Provider Satellite EO Requirements | | | | Service Inputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Operational Scenario | Size of Area of Interest | Scale | Frequency of Information | Other (if applicable) | What the service does | How does the service work | Spatial Resolution | Temporal Resolution | Data Type / Spectral Range | Other (if applicable) | Satellite Data Sources | Other Data Sources |
| EUSPA-EO-UR-ERM-0015 | Environmental impact assessment of mines | Mining companies, oil & gas companies | **Document surface infrastructure, disturbances of surface, current land use, erosion, landslides.** | Site-scale, usually order of < 10 km2 | N/A | once | N/A | The service registers existing land use and surface conditions, including man-made objects and natural phenomena. | Digital analysis and pattern recognition techniques can be used to classify and categorize the relevant features. | 1-5m | once | standard natural colour, multispectral | N/A | WV3, GeoEye, Pleiades, Spot, Geosat | Cadastral data, land use maps, soil maps, Digital elevation models, Drone imagery |
| EUSPA-EO-UR-ERM-0016 | Environmental impact assessment of mines | Mining companies, oil & gas companies | **Geotechnical analysis** | Site-scale, usually order of < 10 km2 | N/A | once | N/A | The service provides generation of high-resolution DEMs, geologic maps, structural analysis | Stereo imagery is used for generation of DEMs. Combined with those DEMs, satellite imagery can be used for lithologic/structural mapping | 1-5m | once | standard natural colour, multispectral, Panchromatic stereo | N/A | WV3, GeoEye, Pleiades, Spot, Geosat | ground and drillhole data, drone imagery |
| EUSPA-EO-UR-ERM-0017 | Environmental impact assessment of mines | National authorities, NGOs, mining companies, oil & gas companies | **Baseline vegetation study & monitoring vegetation: stress due to drought; stress due to pollution, wildfires** | Site-scale, usually order of < 10 km2<br><br>Regional scale, usually order of < 100 km2 | N/A | once<br><br>monthly-quarterly | N/A | The service records the important parameters related to the health of vegetation and the seasonal variations. | recommended is to use imagery to automatically detect changes in vegetation health using indicators such as: Red-Edge, NDVI, LAI, Chlorophyll-a | 10-30m | quarterly<br><br>monthly | VNIR and SWIR( 400nm - 2500nm)<br><br>SAR (soil moisture) | N/A | Landsat, Sentinel-2, Planet, WV3 | Land-use maps, field spectroscopy, drone imagery |
| EUSPA-EO-UR-ERM-0018 | Environmental impact assessment of mines | National authorities, NGOs, mining companies, oil & gas companies | **Monitoring: ground- and near surface water regime, soil moisture and drought** | Site-scale, usually order of < 10 km2 | N/A | monthly-quarterly | N/A | The service monitors the behaviour of ground- and near-surface water, drainage, runoff, flooding | recommended is to use imagery to automatically can monitor indicators for soil-moisture content, to map the drainage characteristics, and predict (model) changes in ground water level as a result of mine-drainage. | 10-30m | monthly-quarterly | UV-VNIR (350 - 1000nm), SAR | N/A | Sentinel-2, NISAR, Aster, ICEYE, Sentinel-1 | Geologic maps, structural data, in situ data, ground water data. Drone Thermal IR. |
| EUSPA-EO-UR-ERM-0019 | Environmental impact assessment of mines | Mining companies, oil & gas companies | **Prediction & monitoring of direct extraction effects: dust, acid drainage, spills, waste movement** | Site-scale, usually order of < 10 km2 | N/A | monthly-quarterly | N/A | The service monitors identifies where the potential hazards and affected zones are located | recommended is to use imagery to automatically detect spread of dust, acid drainage and other hazardous spills that are a direct result of the mining activities | 10-300m | monthly (VNIR), annually (SWIR) | VNIR (400-1000nm) and SWIR (2000-2500), SAR | N/A | MODIS, CALIPSO, GeoEye, Sentinel-1&2, TerraSAR-X, Spot, WV3 | N/A |
| EUSPA-EO-UR-ERM-0020 | Environmental impact assessment of mines | Mining companies, service providers to competent authorities | **Mining site post-closure monitoring** | Site-scale, usually order of < 10 km2 | N/A | Monthly, quarterly, yearly (regulation dependent) | N/A | Provide a low-cost remote monitoring of mines post-exploitation to ensure 1. compliance with environmental recovery plans, 2. they are not causing harm (subsidence, damage to ecosystem, water etc.) | Provides reports on the status of the mine for mining company + competent authority. The service can also be referred to in the planning phase / when applying for permits as a feasible, low-cost and credible solution for the end of life period of a site. | 10m | weekly | Optical, SAR | N/A | Sentinel-1, sentinel-2, ICEYE, TerraSAR-X, Planet | N/A |

## Table 54: Requirements Synthesis – Mining Site Exploration, Planning, and Monitoring

| ID | Application | Users | User Needs | | | | | Service Provider Offer | | Service Provider Satellite EO Requirements | | | | Service Inputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Operational Scenario | Size of Area of Interest | Scale | Frequency of Information | Other (if applicable) | What the service does | How does the service work | Spatial Resolution | Temporal Resolution | Data Type / Spectral Range | Other (if applicable) | Satellite Data Sources | Other Data Sources |
| EUSPA-EO-UR-ERM-0033 | Mining site exploration, planning, monitoring | Mining companies | **Geological mapping to explore for new minerals and metals commercial deposits through proxies visible at the surface** | regional scale, up to 1,000,000 km2 | N/A | one-off | N/A | Mapping of favourable indicators for the occurrence of mineral resources. | Map lithological features, lithology and surficial geology (soils) to assess mineral composition (surface outcrops) of the areas of interest, using digital elevation models (DEM) and spectral/textural surface characteristics | 1-15m | n/a - one off | Multispectral | N/A | Multispectral data (e.g. from WV3, Aster, Landsat, Sentinel-2), Hyperspectral data (EnMAP), other (GOCE) | UAVs, Geophysics, geochemistry, drillholes/in-situ samples to validate mapping and build spectral library, surface mapping, etc., |
| EUSPA-EO-UR-ERM-0034 | Mining site exploration, planning, monitoring | Mining companies, governmental institutions | **Re-mining of mining waste and tailings** | national level (the EU wants to do this at the EU level) | N/A | one-off | N/A | Provides a geological mapping of abandoned waste/tailings/ stockpiles to identify potential for remining (plus cleaning up of the waste) | Provides geological mapping | 1-15m | n/a - one off | Multispectral | N/A | Multispectral data (e.g. from WV3, Aster, Landsat, Sentinel-2), Hyperspectral data (EnMAP), other (GOCE) | UAVs |
| EUSPA-EO-UR-ERM-0035 | Mining site exploration, planning, monitoring | Mining companies | **Site exploration and planning for mine, stockpiles, tailings reservoir and related infrastructure** | Mine-scale, usually order of < 10 km2 | N/A | one-off | N/A | The service uses satellite data for site exploration, mine planning and associated risk analysis, terrain & watershed analysis | Stereo imagery is used for generation of DEMs. Combined with those DEMs, satellite imagery is used for terrain analysis | <1m | once | Standard natural colour, multispectral, panchromatic stereo | N/A | WV3, GeoEye, Pleiades, Spot, Geosat | Cadastral data, land use maps, soil maps, Digital elevation models, Drone imagery |
| EUSPA-EO-UR-ERM-0036 | Mining site exploration, planning, monitoring | Mining companies, oil & gas companies | **Monitor changes in surface infrastructure, disturbances of surface, current land use, erosion, landslides** | Mine-scale, usually order of < 10 km2 | N/A | annual | N/A | The service registers changes in land use and surface conditions, including man-made objects and natural phenomena. | Digital analysis and pattern recognition techniques can be used to classify and categorize the relevant features, and monitor changes | 1-5m | annual | Standard natural colour, multispectral, SAR | N/A | WV3, GeoEye, Pleiades, Spot, Geosat, ICEYE, Sentinel-1 | Cadastral data, land use maps, soil maps, digital elevation models, drone imagery, LIDAR (drone/aerial) |
| EUSPA-EO-UR-ERM-0037 | Mining site exploration, planning, monitoring | Mining companies | **Monitor ground (in)stability in prospective, active and closed mining areas** | 30x30 km | N/A | weekly to daily | 3D GIS compatible sources | Identify areas with ground displacements for risk assessment based on mining activities and avoid potential geotechnical failures (creeping slopes, slopes failures, collapses, etc.) | Provide recurrent map highlighting areas with significant ground displacements | 1-10m | daily | SAR - C or X band data with dual modes, ascending and descending view | Important to have data archives for back-analysis, service demos | Sentinel-1 | in-situ stability and inclination measurements such as GPS devices, inclinometers etc. |

# 4 ANNEXES

## A1.1 Definition of key GNSS performance parameters

This annex provides a definition of the most used GNSS performance parameters, taken from [RD49].

**Availability:** the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%. There are two classes of availability:

- System availability: the percentage of time the system allows the user to compute a position - this is what GNSS Interface Control Documents (ICDs) refer to.
- Overall availability: considers the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.

**Accuracy** is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion – usually 95% – of samples would fall if measured. This report refers to positioning accuracy using the following convention: centimetre-level: 0-10cm; decimetre level: 10-100cm; metre-level: 1-10 metres.

**Continuity** is the ability of a system to perform its function (deliver PNT services with the required performance levels) without interruption once the operation has started. It is usually expressed as the risk of discontinuity and depends entirely on the timeframe of the application. A typical value is around 1*10-4 over the course of the procedure where the system is in use.

**Indoor penetration** is the ability of a signal to penetrate inside buildings (e.g., through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of Wi-Fi base stations for Wi-Fi-based positioning).

**Integrity** is a term used to express the ability of the system to provide warnings to users when it should not be used. It is the probability of a user being exposed to an error larger than the alert limits without timely warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to users are highly application dependent. Throughout this report, the "integrity concept" is to be understood at large, i.e., not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used in other applications and sectors.

**Latency** is the difference between the reference time of the solution and the time this solution is made available to the end user or application (i.e., including all delays). Latency is typically accounted for in a receiver but presents a potential problem for integration (fusion) of multiple positioning solutions, or for high dynamics mobile devices.

**Robustness** relates to spoofing and jamming and how the system can cope with these issues. It is a more qualitative than quantitative parameter and depends on the type of attack or interference the receiver is capable of mitigating. Robustness can be improved by authentication information and services.

**Authentication** gives a level of assurance that the data provided by a positioning system has been derived from real signals. Radio frequency spoofing may affect the positioning system, resulting in false data as output of the system itself.

**Power consumption** is the amount of power a device uses to provide a position. It will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to

identify signals (cold start) than when computing a position. Typical values are in the order of tens of milliwatts (for smartphone chipsets).

**Time To First Fix (TTFF)** is a measure of time between activation of a receiver and the availability of a solution, including any power on self-test, acquisition of satellite signals and navigation data and computation of the solution. It mainly depends on data that the receiver has access to before activation: cold start (the receiver has no knowledge of the current situation and must thus systematically search for and identify signals before processing them – a process that can take up to several minutes.); warm start (the receiver has estimates of the current situation – typically taking tens of seconds) or hot start (the receiver understands the current situation – typically taking a few seconds).

## A1.2 Definition of key EO performance parameters

This annex provides a definition of the most used EO performance parameters and includes additional details which are relevant for the Energy and Raw Materials community.

### Key EO performance parameters

**Spatial resolution** relates to the level of detail that can be retrieved from a scene. In the case of a satellite image, which consists of an array of pixels, it corresponds to the smallest feature that can be detected on the image. A common way of characterising the spatial resolution is to use the Ground Sample Distance (GSD) which corresponds to the distance measured on the ground between the centres of two adjacent pixels. Thus, a spatial resolution of 1 meter means that each pixel corresponds to a 1 by 1 meter area on the ground.

**Spectral resolution** refers to the ability of a sensor to differentiate electromagnetic radiation of different wavelengths. In other words, it refers to the number and "bandwidth" of wavelength intervals that the sensor can measure. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. In remote sensing, features (e.g., water, vegetation) can be characterised by comparing their "response" in different spectral bands.
**Spectral range** refers to the wavelength range of a particular channel or band over in which remote sensing data must be collected.

**Radiometric resolution** expresses the sensitivity of the sensor, its ability to differentiate between different magnitudes of the electromagnetic energy. The finer the radiometric resolution, the more sensitive it is to small differences in the energy emitted or reflected by an object. The radiometric resolution is generally expressed in bit, a resolution of 8 bit meaning that the "brightness" of the image is measured with a scale of 28=256 nuances.

**Temporal resolution** relates to the time elapsed between two consecutive observations of the same area on the ground. The higher the temporal resolution, the shorter the time between the acquisitions of two consecutive observations of the same area. In absolute terms, the temporal resolution of a remote sensing system corresponds to the time elapsed between two consecutive passes of the satellite over the exact same point on the ground (generally referred to as "revisit time" or "orbit cycle"). However, several parameters like the overlap between the swaths of adjacent passes, the agility of the satellites and in case of a constellation, the number of satellites mean that some areas of the Earth can be reimaged more frequently. For a given system, the temporal resolution can therefore be better than the revisit time of the satellite(s).

**Latency** is the difference between the reference time of the satellite measurement and the time the final product is made available to the user (here the service provider).

**Geolocation accuracy** refers to the ability of an EO remote sensing platform to assign an accurate geographic position on the ground to the features captured in a scene. An accurate geolocation makes easier the combination of several images (e.g., combination of a Synthetic Aperture Radar image with a cadastral map and a map on fishing grounds or aquafarming).

### Other performance parameters

**Agility** corresponds to the ability of a satellite to modify its attitude and to point rapidly in any direction to observe areas of interest outside its ground trace. High agility can improve the temporal resolution compared with the revisit time of the satellite.

**Swath** corresponds to width of the portion of the ground that the satellite "sees" at each pass. The larger the swath, the bigger the observed area at each pass.

**Off-nadir angle** corresponds to the angle at which images are acquired compared with the “nadir”, i.e., looking straight down at the target. In practice, objects located directly below the sensor only have their tops visible, thus making it impossible to represent the three-dimensional surface of the Earth. High resolution images are therefore generally not collected at nadir but at an angle. A large off-nadir angle enables a wider ground coverage at each pass and the identification of features not visible at nadir, but it reduces the spatial resolution. For optical imagery, typical off-nadir angles are in the range of 25-30 degrees.

**Sun-elevation angle** corresponds to the angle of the sun above the horizon at the time an image is collected. High elevation angles can lead to bright spots on the imagery while low elevation angles lead to darker images and longer shadows. The most appropriate angle depends on the type of application: a high sun elevation is appropriate for spectral analysis since the objects to be observed are well illuminated while a lower elevation angle is better suited to interpretation of surface morphology (e.g., the projected shadows can enable a better image interpretation)

## A1.3 List of Acronyms

**Table 55: List of acronyms and abbreviations**

| Acronym | Definition |
|---|---|
| ADCP | Acoustic Doppler Current Profiler |
| AEP | Annual Energy Production |
| AI | Artificial Intelligence |
| ASCAT | Advanced Scatterometer |
| CAMS | Copernicus Atmosphere Monitoring Service |
| CDF | Cumulative Distribution Function |
| CFD | Computational Fluid Dynamics |
| CGLS | Copernicus Global Land Service |
| CH4 | Methane |
| CHIME | Copernicus Hyperspectral Imaging Mission for the Environment |
| CORS | Continuously Operating Reference Stations |
| CSP | Concentrated Solar Power |
| DEM | Digital Elevation Model |
| DGNSS | Differential Global Navigation Satellite System |
| DMSP | Defense Meteorological Satellite Program |
| EARSC | European Association of Remote Sensing Companies |
| EC | European Commission |
| EEA | European Environmental Agency |
| EGNOS | European Geostationary Navigation Overlay Service |
| EIA | Environmental Impact Assessment |
| EIT | European Institute of Innovation & Technology |
| ENRAW | Energy and Raw Materials |
| ENTSO | European Network of Transmission System Operators |
| EO | Earth Observation |
| EPRG | European Pipeline Research Group |
| ERA | European Reanalysis |
| ERM | Energy and Raw Materials |
| ERMA | European Raw Materials Alliance |
| ERS | European Remote Sensing Satellite |
| ESG | Environment, Social and Governance |
| EU | European Union |
| EUSPA | European Agency for the Space Programme |

| | |
|---|---|
| GFO | Geosat Follow On |
| GHG | Greenhouse Gas |
| GIS | Geographic Information System |
| GNSS | Global Navigation Satellite System |
| GOCE | Gravity Field and Steady-State Ocean Circulation Explorer |
| GOES | Geostationary Operational Environmental Satellite |
| GOVSATCOM | European Union Governmental Satellite Communications |
| GPS | Global Positioning System |
| GSA | European Global Navigation Satellite Systems Agency (now EUSPA) |
| GSC | GNSS Service Centre |
| GSD | Ground Sampling Distance |
| HR | High Resolution |
| ICD | Interface Control Documents |
| ICMM | International Council on Mining and Metals |
| ID | Identifier |
| IEA | International Energy Agency |
| IFS | Integrated Forecasting System |
| IGS | International GNSS Service |
| IOGP | International Association of Oil & Gas Producers |
| IR | Infrared |
| IRENA | International Renewable Energy Agency |
| JRC | Joint Research Centre |
| LAI | Leaf Area Index |
| LIDAR | Light Detection And Ranging |
| LWIR | Long-wave Infrared |
| ML | Machine Learning |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MOM | Minutes of Meeting |
| MS | Multispectral |
| MSG | Meteosat Second Generation |
| MW | Megawatt |
| NDVI | Normalized Difference Vegetation Index |
| NGO | Non-Government Organisation |
| NIR | Near Infrared |
| NOAA | National Oceanic and Atmospheric Administration |

| | |
|---|---|
| OLCI | Ocean and Land Colour Instrument |
| ORE | Offshore Renewable Energy |
| OSM | Open Street Map |
| PMU | Phasor Measurement Unit |
| PNT | Positioning, Navigation, Timing |
| PPP | Precise of Point Positioning |
| PRCI | Pipeline Research Council International |
| PRI | Principles for Responsible Investment |
| PV | Photovoltaic |
| RD | Reference Document |
| RE | Renewable Energy |
| RGB | Red Green Blue |
| RICS | Royal Institution of Chartered Surveyors |
| RPAS | Remotely Piloted Aircraft System |
| RTK | Real Time Kinematics |
| RUR | Report on User Needs and Requirements |
| SAR | Synthetic Aperture Radar |
| SAT | Satellite |
| SNPP | Suomi National Polar-orbiting Partnership |
| SP | Service Provider |
| SRTM | Shuttle Radar Topography Mission |
| SSC | Sea Surface Chlorophyll |
| SST | Sea Surface Temperature |
| SWIR | Short-wave Infrared |
| TBC | To be confirmed |
| TBD | To be determined |
| TBU | To be updated |
| TNO | Netherlands Organisation for Applied Scientific Research |
| TRMM | The Tropical Rainfall Measuring Mission |
| TSO | Transmission System Operator |
| TTFF | Time To First Fix |
| UAV | Unmanned Aerial Vehicle |
| UCP | User Consultation Platform |
| UNEP | UN Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |

| | |
|---|---|
| UR | User Requirement |
| UV | Ultraviolet |
| VHR | Very High Resolution |
| VIS | Visible |
| VNIR | Visible and Near-Infrared |
| WV | Worldview |

## A1.4 Reference Documents

| RD | Reference | Title | Date |
|---|---|---|---|
| 1 | EU Commission Article | REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition | 18/05/2022 |
| 2 | Deloitte NL | 2022 renewable energy industry outlook | 2022 |
| 3 | McKinsey | Global Energy Perspective 2022 | 04/2022 |
| 4 | BBC News | Wind farms can affect local weather patterns | 05/10/2010 |
| 5 | EARSC | EOcafe: Earth Observation & the Raw Materials Sector | 09/02/2021 |
| 6 | TNO | SATELLITE REVEALS AUSTRALIAN COAL MINES EMIT MUCH MORE METHANE THAN EXPECTED BASED ON NATIONAL REPORTING | 29/11/2021 |
| 7 | ICMM | Our Members | 2022 |
| 8 | UNEP & ICMM & PRI | GLOBAL INDUSTRY STANDARD ON TAILINGS MANAGEMENT | 08/2022 |
| 9 | European Commission | EU Solar Energy Strategy | 2022 |
| 10 | European Commission | COMMISSION RECOMMENDATION on speeding up permit-granting procedures for renewable energy projects and facilitating Power Purchase Agreements | 2022 |
| 11 | European Commission | amending Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency | 2022 |
| 12 | European Commission | Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC | 2006 |
| 13 | European Commission | Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC Text with EEA relevance | 2012 |
| 14 | European Commission | Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy | 2000 |
| 15 | European Commission | Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration | 2006 |
| 16 | EO4RM | Product Sheet: Ground Water Monitoring | 2022 |
| 17 | ICEYE | PERSISTENT MONITORING OF SURFACE WATER EXTENT IN REMOTE AREAS WITH SAR DATA | 2022 |
| 18 | Library of the European Parliament | Mining in the EU: Regulation and the way forward | 2012 |
| 19 | UNEP & ICMM & PRI | Conformance Protocols: Global Industry Standard on Tailings Management | 06/05/2021 |
| 20 | ERMA | About Us | 2022 |
| 21 | European Commission | Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability | 03/09/2020 |
| 22 | Bloomberg | EU Countries Call for 1,000 Gigawatts of Solar Energy by 2030 | 05/05/2022 |
| 23 | ABC News | Driverless trucks move all iron ore at Rio Tinto's Pilbara mines, in world first | 18/10/2022 |
| 24 | EUSPA (previously GSA) | GSA GNSS Technology Report (Issue 3) | 09/2022 |
| 25 | EARSC | EOcafe: Earth Observation & the Raw Materials Sector | 02/2022 |

| | | | |
|---|---|---|---|
| 26 | Citizens Information | Environmental assessments for projects and plans | 26/22/2020 |
| 27 | IRENA | REmap – Renewable Energy Roadmaps | 2022 |
| 28 | GSA Lot4 SC1, D1 V2.0 | Market research and quantification of the timing and synchronisation | 19/01/2014 |
| 29 | GSA Lot4 SC1, D2.2 V2.0 | Existing and Potential GNSS TS applications and products | 30/10/2014 |
| 30 | GNSS Security and Ro- bustness | GNSS Security and Robustness, Shankar Achanta (Schweitzer Engineering Laboratories, Inc) | 09/2015 |
| 31 | Homeland Security Researching GPS Disruptions, Solutions | Inside GNSS News, Homeland Security Researching GPS Disruptions, Solutions, Latest News, Dee Ann Divis | 10/06/2014 |
| 32 | Critical Infrastructure Vulnerabilities to GPS Disruptions | Critical Infrastructure Vulnerabilities to GPS Disruptions Sarah Mahmood, Program Manager, Resilient Systems Division Homeland Security Advanced Research Projects Agency Science & Technology Directorate | 04/06/2014 |
| 33 | GPS disruptions effort to assess risks to critical infrastructure and coordinate agency actions should be enhanced | "GPS disruptions effort to assess risks to critical infrastructure and coordinate agency actions should be enhanced", GAO-14-15 | 11/2013 |
| 34 | Consultation with Mr Jiri Luhan | Consultation report with Mr Jiri Luhan | 02/2012 |
| 35 | GSA-MKD-TS-UREQ- 233690 | Report on Time & Synchronisation User Needs and Requirements | 11/2017 |
| 36 | RICS Guidelines | RICS Guidelines for the use of GNSS in land surveying and mapping | 11/2010 |
| 37 | Galileo CS GNSS High Accuracy and Authentication | InsideGNSS - Galileo's Commercial Service: Testing GNSS High Accuracy and Authentication | 02/2015 |
| 38 | Florida Fish and Wildlife Conservation Commission | Solar Farm Best Management Practices for Wildlife | 2022 |
| 39 | Surveyor's General Guidelines | New South Wales Government - GNSS for Cadastral Surveys | 06/2014 |
| 40 | UCP 2017 | Surveying Session at the UCP MoM (Ref. doc. GSA-MKD- MS-MOM-236055-Professional-Mapping-and-Surveying) | 12/2017 |
| 41 | N/A | GSA Market Development Internal Analysis | 2020 |
| 42 | Consultation with Mr Gilles Boime | Consultation report with Mr Gilles Boime (Spectracom) | 02/2012 |
| 43 | GSA-MKD-T-S- MOM-246199 | User Consultation Platform 2018 – Minutes of Meeting of the Timing and Synchronisation Panel | 03/12/2018 |
| 44 | GSA-MKD-CI-MOM- A09266 | User Consultation Platform 2020 – Minutes of Meeting of the Infrastructure Panel | 02/12/2020 |

## EUSPA Mission Statement

The mission of the European Union Agency for the Space Programme (EUSPA) is defined by the EU Space Programme Regulation. EUSPA's mission is to be the user-oriented operational Agency of the EU Space Programme, contributing to sustainable growth, security and safety of the European Union.

Its goal is to:

- Provide long-term, state-of-the-art safe and secure Galileo and EGNOS positioning, navigation and timing services and cost-effective satellite communications services for GOVSATCOM, whilst ensuring service continuity and robustness;
- Communicate, promote, and develop the market for data, information and services offered by Galileo, EGNOS, Copernicus and GOVSATCOM;
- Provide space-based tools and services to enhance the safety of the Union and its Member States. In particular, to support PRS usage across the EU;
- Implement and monitor the security of the EU Space Programme and to assist in and be the reference for the use of the secured services, enhancing the security of the Union and its Member States;
- Contribute to fostering a competitive European industry for Galileo, EGNOS, and GOVSATCOM, reinforcing the autonomy, including technological autonomy, of the Union and its Member States;
- Contribute to maximising the socio-economic benefits of the EU Space Programme by fostering the development of a competitive and innovative downstream industry for Galileo, EGNOS, and Copernicus, leveraging also Horizon Europe, other EU funding mechanisms and innovative procurement mechanisms;
- Contribute to fostering the development of a wider European space ecosystem, with a particular focus on innovation, entrepreneurship and start-ups, and reinforcing know-how in Member States and Union regions.
- As of July 2023, EUSPA will take the responsibility for the Programme's Space Surveillance Tracking Front Desk operations service.

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