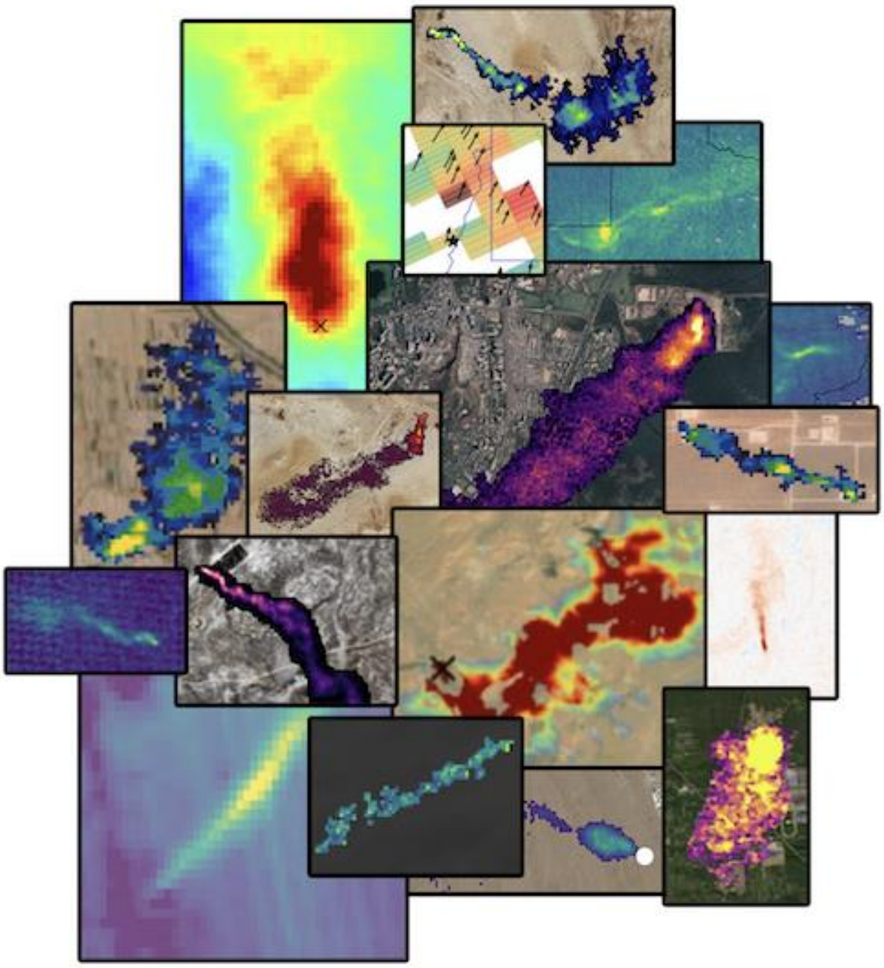
User Requirements Document v3.0

WP110 - Deliverable D1.1



ESA Contract No. 4000143908/24/I-LR

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Change log

Version	Date	Status	Authors	Reason for change
0.1	11/07/2024	Version for review by User Group	see title page	New document
0.2	29/7/2024	Version for review by project lead SRON		Included feedback from User Group (Hugo Denier van der Gon, Sander Houweling)
1.0	04/09/2024	Version submitted to ESA		Included feedback SRON

1.1	26/10/2024	Version submitted to ESA		Include feedback from ESA RID_v1.0
1.2	09/06/2025	Version for review by User Group		Yearly update
2.0	01/10/2025	Version submitted to ESA		Included feedback from User Group
2.1	21/10/2025	Version submitted to ESA		Include feedback from ESA dated 16 October 2025
3.0	21/05/2026	Version submitted to SRON		Yearly update

List of Acronyms

- CAL/VAL – Calibration and Validation
- CAMS – Copernicus Atmosphere Monitoring Service
- CEOS – Committee on Earth Observation Satellites
- CLDP – Commercial Law Development Program
- CO2MVS – Copernicus CO_2 Monitoring and Verification Support
- EC – European Commission
- ECMWF – European Centre for Medium-Range Weather Forecasts
- ESA – European Space Agency
- IG3IS – Integrated Global Greenhouse Gas Information System
- IGO – Intergovernmental Organizations
- IEA – International Energy Agency
- IMEO – International Methane Emissions Observatory
- LDAR – Leak Detection and Repair
- MARS – Methane Alert and Response System
- MEDUSA – Methane Emissions Detection Using Satellites Assessment
- MRV – Measurement, Reporting, and Verification
- NDC – Nationally Determined Contributions
- NGO – Non-Governmental Organization
- NIST – National Institute of Standards and Technology
- POD – Probability of Detection
- RMI – Rocky Mountain Institute
- SPECT – Satellite Point Source Emissions Completeness Tool
- SWIR – Short-Wave Infrared
- TNO – Dutch Organisation for Applied Scientific Research
- TROPOMI – Tropospheric Monitoring Instrument
- UKSA – United Kingdom Space Agency
- UNEP – United Nations Environment Programme
- UNFCCC – United Nations Framework Convention on Climate Change
- WMO – World Meteorological Organization

Table of Contents

1. Executive summary

The MEDUSA, Methane Emissions Detection Using Satellites Assessment, project is focusing on intercomparing and validating the detection of methane plume hot spots and their emissions quantifications across the various existing satellites.
To assist different users in utilizing this rapidly expanding and powerful satellite data, this document lists the main use cases of methane hotspot data, along with the requirements of the various users associated with each use case. These requirements are not qualitative evaluations of current capabilities, but practical specifications that indicate what information, processing steps, or metadata should be included in the satellite data products to enable their smooth integration into users' workflows and decision-making processes.

The requirements presented in this document are grounded in a broader landscape of existing work. Prior to engaging with users, a structured literature review was conducted covering: formal multi-stakeholder efforts to define common standards for satellite methane data; technical guidance on data quality, detection capabilities and validation practices; operational frameworks linking satellite alerts to mitigation actions by operators and governments; relevant policy and regulatory developments; financial sector perspectives on data credibility; and recent scientific advances in satellite-based detection and quantification. This review informed the design of the user engagement process and provided context for interpreting the requirements collected.

The users included in this project are ECMWF/CAMS, The European Commission (EC), IEA, IG3IS/WMO, IMEO-MARS, and TNO. Through individual annual sessions conducted with the users over three years, it was determined that the users' applications can currently be described by the following four different use cases:

- The detection & attribution of super-emitters (here defined as localized sources emitting above 100 kg/hr) enabling mitigation actions
- The quantification of emissions from the detected super-emitters
- Derive yearly emissions from super-emitter data at the country-level
- Incorporate super-emitter data into (facility-level) emission inventories

It should be noted that use-cases 3 and 4 do not describe total methane emissions. Rather, they focus on emissions from super-emitters (events) and are intended to complement existing inventories that account for non-super-emitting sources.

The following table below summarizes the link between the users and the use-cases.

Users / Use-cases	IMEO-MARS	IEA	ECMWF-CAMS	TNO	IG3IS	EC
1. Super-emitter detection	x	(x)	x	(x)	x	x
2. Super-emitter quantification	x	(x)	x	(x)	x	x

3. Aggregation analysis of super emitters	x	x	(x)	x	x	
4. Inventory at the facility-level	x		(x)	x	x	

(x)Lower priority

Requirements were defined for each use case across four main categories: Intercomparison, Validation, Interoperability, and Harmonization. Across all four use cases, the number of requirements identified is broadly comparable, reflecting a consistently thorough engagement across the full scope of the document. Among the four requirement categories, the interoperability one attracted the most attention from users, driven primarily by the need for standardized metadata and common data formats to enable the integration of satellite products into existing workflows. Intercomparison and Validation requirements, the second most discussed category, concentrate on metrics that characterize the capabilities of the observing system, such as detection thresholds and spatial resolution, as well as on the methods and references used to validate satellite data products. Harmonization requirements were the least developed, reflecting the earlier maturity of cross-dataset blending efforts relative to the other dimensions.

2. Introduction

The MEDUSA, *Methane Emissions Detection Using Satellites Assessment*, project is focusing on intercomparing and validating the detection of methane plume hot spots and their emissions quantifications across the various existing satellites.

The users included in this project are:

- ECMWF/CAMS represented by Richard Engelen, is responsible for developing the Monitoring and Verification Support (CO2MVS) capacity for anthropogenic CO2 and CH4 emissions, as part of its overall portfolio. CO2MVS will assist the European Commission (EC) in conducting the global stocktake by utilizing ground-based measurements, Earth observation data, and advanced modeling techniques. It will also support the EC and EU member states in implementing the EU Methane Strategy and the Global Methane Pledge by enabling the detection and monitoring of global super-emitters. Additionally, CAMS will contribute to international coordination efforts for monitoring greenhouse gas concentrations and fluxes, such as the Global Greenhouse Gas Watch led by the World Meteorological Organization and the UNEP International Methane Emissions Observatory. CAMS now has a methane hotspot tracker operational and plans to integrate data from additional satellite constellations (from the Copernicus Contributing Missions) to enhance its monitoring capabilities (CAMS, 2025, https://apps.atmosphere.copernicus.eu/methane-explorer). As such, CAMS is engaged in all four use cases. However, its top priority regarding methane plumes and hotspots is the global detection and quantification of emissions from methane super-emitters to support its ongoing initiative. On the other hand, CAMS has a growing interest in use-cases 3 and 4, although CAMS is currently more advanced in CO2 monitoring with regards to these topics (personal communication, CAMS representative at ECMWF).
- During the first year of the project, the European Commission (EC) represented by Brendan Devlin, Henry Winckle, and Leona Kolberg from its Directorate-general for Energy, was interviewed regarding the potential use of satellite-based methane plume hot spot data as one of the tools/datasets to support the new EU Regulation on methane emissions reduction in the energy sector. This data is expected to be an important component of the EC's methane transparency database, providing real-time, publicly accessible information on methane emissions. The EC also intends to use this information for the Regulation's rapid reaction mechanism, enabling swift notification and responses to significant methane emissions events within and outside the

European Union. This dual approach aims to enhance transparency, ensure regulatory compliance, and facilitate timely mitigation across the EU's energy supply chain. The EC would also use this data in support of engagement with third countries, encouraging them to also directly use the data and integrate it into or use it to create domestic monitoring, all in support of meeting the 30% by 2030 Global Methane Pledge target and thereby broader climate goals.

- IEA represented by Tomás Bredariol and Courtney Turich is focused on obtaining yearly estimates of total super-emitter emissions at country level. This data will be used to analyze trends in methane emissions, allowing the IEA to assess the effectiveness of mitigation efforts and identify emerging patterns. By tracking super-emitter emissions over time, the IEA aims to support policy development, promote best practices, and guide international efforts to reduce methane emissions in the energy sector. The IEA recently launched a new initiative focused on the accountability of companies, specifically comparing reported versus measured emissions, where they use a mix of satellite data and other sources (IEA, 2024). This would fall under use cases 1 and 2, keeping in mind this is of secondary priority for IEA.
- IG3IS/WMO, represented by Sander Houweling, pursues several objectives at different scales. First, it aims to inform Oil & Gas facilities about the detection of emission events. Second, it supports the Measurement, Reporting and Verification (MRV) of these facilities. Third, it addresses the reporting of national emissions to support countries in enhancing their national greenhouse gas inventories and evaluating their Nationally Determined Contributions (NDCs) under the Paris Agreement. While IG3IS/WMO does not directly integrate super-emitter data into national inventories, it plays a key role in formulating good practice guidelines. These guidelines help countries understand how to utilize atmospheric data, including satellite datasets, to improve methane emission reporting and ensure transparency. By doing so, IG3IS/WMO aims to empower countries to assess their emissions with scientifically sound methods, ensuring independent and traceable data flows. A key area of interest for IG3IS/WMO lies in the intersection of use-cases 3 and 4, specifically targeting urban-scale emissions where there is a strong potential in leveraging super-emitter data to refine high-resolution inventories in urban environments.
- UNEP's MARS represented by Itziar Irakulis Loitxate, Manuel Montesino San Martin and Cynthia Randles (formerly with IMEO), Yasjka Meijer from CEOS joined the telecon with MARS in 2024. MARS is the Methane Alert Response System managed by UNEP's International Methane Emissions Observatory (IMEO), which is developed to support companies and governments to reduce

their methane emissions in support of the Global Methane Pledge. MARS is leveraging satellite-based super-emitter detections and source attribution to notify operators and government stakeholders across different sectors, including oil and gas, coal and waste, among others, of ongoing methane emissions and encourage prompt mitigation actions. By providing operators with near real-time data on large events, UNEP's MARS aims to drive rapid responses and reduce methane leaks across sectors. MARS has recently expanded the notification process to the coal and waste sector although with lower notification latency due to the higher complexity to rapidly mitigate the emissions from these sectors. After some time, the data is also provided on the public IMEO's Eye on Methane data platform for transparency. As such, use cases 1 and 2 are the prime focus for MARS. More broadly, IMEO has a wider interest in satellite-based methane data including use-case 3 and 4: its data integration team is working on producing methane inventories by reconciling all available data on emitting sources, and is developing a methane emissions index for importers.

- TNO represented by Hugo Denier van der Gon and Emma Schoenmakers, is interested in using super-emitter data to improve their gridded emission inventories at the national and facility level. TNO's primary focus therefore lies in use cases 3 and 4 — the aggregation of super-emitter data at the country level and its incorporation into facility-level inventories — with the aim of improving the accuracy of methane emissions reporting and refining country-level total emission estimates on an annual basis. This data will also help distinguish between point source and diffuse emissions more accurately. This approach will provide more detailed and reliable data for tracking methane emissions, supporting both national and international climate goals through better-informed bottom-up emission inventories. During this work, TNO recognised that detecting and quantifying super-emitter events (use cases 1 and 2) is also essential for inventory development. When downscaling national emissions, some point sources may not be represented in the proxy data and therefore missed when attributing a share of the national emissions, especially outside Europe where bottom-up data are sparse. Super-emitter detections help fill these gaps, improving the accuracy of spatially disaggregated inventories. They can also capture large accidental releases, which are not included in standard inventory or reporting schemes, making their quantification a valuable addition to TNO products such as those developed under CAMS.

To ensure the accuracy and relevance of the information presented, the former paragraph has been updated based on insights gathered during informational interviews with key stakeholders.

This document draws upon existing literature and feedback gathered from individual sessions with each member of the User Group during May and June 2024, 2025 and 2026 to list the main use cases of methane hotspot data (e.g. supporting mitigation activities and improving reporting under the UNFCCC Paris Agreement), along with the requirements of the various users associated with each use case. As this field is new and rapidly evolving with emerging use cases, this document has been updated annually, with this edition serving as the final planned update.

The User Group will also assess the extent to which the MEDUSA project meets these requirements at the project's midpoint and conclusion as part of WP610.

3. Review of existing documentation

3.1 User community and the scope of this review

Methane has become an important focus for various communities that are deeply invested in detecting and mitigating its emissions. The monitoring of methane from space offers valuable information for a wide array of end users, each with specific goals, responsibilities, and decision-making needs. The following communities have shown particular interest in this technology for measuring methane plumes and emission hot spots:

- **Legislative bodies and policymakers** are interested in using satellite data to inform policy decisions, enforce regulations, and track progress towards emission reduction goals
- **Regulatory compliance bodies** use satellite-based methane detection to monitor compliance with emission regulations and verify reported emissions data
- **Researchers** aim to utilize these satellite-based Data to improve the detection and quantification of methane plumes.
- **NGOs, IGOs and think tanks** interpret satellite data to provide actionable insights for various end users, bridging the gap between complex data and practical applications
- **Operators** use methane data for leak detection and repair, emissions reduction efforts and to comply with environmental regulations

- **Investors and financial institutions** are looking for satellite-derived methane emissions data to assess climate-related risks and inform investment decisions.
- **Intermediaries** such as IMEO MARS and CAMS that provide actionable information to, for example policymakers, or to governments and companies.

Each of these user communities has requirements for methane detection from space, driven by their specific roles. The literature reviewed below has been organized thematically to reflect the different dimensions of these requirements: from structured efforts to formally define standards and user needs, to technical guidance on data quality, to operational frameworks for satellite alert response, operator workflows, regulatory compliance, and financial applications. Together, these documents map a comprehensive landscape of user requirements that satellite-based methane data must satisfy.

3.2 Structured efforts to define user requirements and common standards

The most deliberate attempts to formally document user requirements for satellite-based methane data have come from structured, multi-stakeholder events: workshops convened by technical bodies and international organisations to bring together data producers, users, and policymakers. What distinguishes this first category is their collective nature, these are not positions advanced by a single institution, but consensus-building processes designed to aggregate the views of diverse communities. Though not all have produced formal recommendations, they represent the most direct efforts to systematically define what satellite methane data users require.

CEOS/IMEO Workshop (June 2023)

CEOS/IMEOorganized a workshop (June'23, Harvard) followed by separate telecons addressing themes such as Observability, Data Integration, Use Cases, Roadmap, and Cal/Val/Testing. The objective was to craft a concise 'charter' for each working group, comprising the problem statement, methods for addressing it, and short- and long-term goals, needs, or deliverables. This charter did not come to light yet.

NIST Workshop and Summary Report (January 2024)

The NIST workshop in January 2024, associated with the forthcoming EPA super-emitter program, aimed to establish a consensus on definitions, draft standards, and best practices for point source detection, geolocation, and attribution. It also aimed to explore frameworks for data intercomparison, enhance transparency, and discuss protocols for reconciling discrepancies among data producers, particularly in response to public inquiries. Following the workshop, NIST released a summary report (Eldering A., 2024) that captured the key presentations and discussions from the event. The document served mainly as a record of the current state of efforts and preliminary planning for future work, rather than offering formal recommendations or conclusions. Since then, a change in the U.S. administration has shifted federal priorities, and further progress by NIST on this topic have slowed.

NPL Workshop (February 2024)
The NPL workshop, supported by the UKSA, in 26-28 February 2024, centered on "Towards an Internationally Recognized Standard in Methane Monitoring from Space." This event notably discussed the standardization of methodologies for super-emitter detection and quantification. While the workshop itself did not result in a dedicated report describing requirements, its discussions and outcomes contributed to a broader CEOS publication on common practices in satellite-based methane monitoring. This report is discussed in the following section.

3.3 Technical practices, data quality, and detection capabilities

Beyond formal workshops, a body of reports and scientific publications provides detailed guidance on technical practices, data quality requirements, and the capabilities and limitations of satellite-based detection, all of which directly inform what users can and cannot reliably expect from satellite methane data.

CEOS GHG Task Team on Emissions Reporting (CEOS, 2023)

A major contribution to defining these needs comes from CEOS and its GHG Task Team on Emissions Reporting (CEOS, 2023). A workshop aimed at developing a common framework for reporting estimates, uncertainties, and ancillary data related to satellite-based methane detection was organized. By prioritizing transparency, standardization, and rigorous evaluation methods, the CEOS initiative seeks to improve the usability and reliability of methane detection data from satellites, supporting both scientific research and policy-making efforts.

CEOS/WGClimate Common Practices for Quantifying Methane Emissions (2024)

Furthering this work, CEOS has also published guidance through the CEOS/WGClimate Common Practices for Quantifying Methane Emissions from Plumes Detected by Remote Sensing (CEOS/WGClimate, 2024). This report outlines a consistent set of practices for estimating methane emissions from localized plume detections and aims to harmonize approaches used across the remote sensing community. It highlights the importance of clear documentation, quality control, and methodological transparency, offering both data producers and users a reference for evaluating the reliability and comparability of emission estimates derived from satellite observations.

Rocky Mountain Institute - SPECT Tool (2023)

The Rocky Mountain Institute has advanced the technical evaluation of methane monitoring through their analysis of satellite detection capabilities (RMI, 2023). Their report introduces "completeness" as a standardized metric for comparing satellite platforms and presents the Satellite Point source Emissions Completeness Tool (SPECT). This contribution provides stakeholders across industry, policy, and public spheres with a practical framework for evaluating and implementing satellite-based methane detection technologies, making it directly relevant to any user community seeking to understand which satellite products are fit for their specific purpose.

KAPSARC - Using Satellite Technology to Measure Greenhouse Gas Emissions in Saudi Arabia (2023)

This report (KAPSARC, 2023) emphasizes the uncertainties inherent in satellite-derived GHG estimates, advocating for improved quantification methods and more rigorous integration of satellite data into national emissions inventories. For user requirements documentation, this contribution is important because it sets expectations about what satellite data can and cannot reliably provide, and defines the uncertainty information that users, from policymakers to compliance bodies, must be able to access and interpret.

Ember Climate & CATF - The geography factor: How environmental conditions shape methane monitoring from space (2025)

Ember focused on the operational challenges affecting satellite methane data quality, including cloud cover, low-light conditions, and complex terrain (Ember & CATF, 2025). Their analysis underscores the need for users across all communities to critically assess data coverage and availability when interpreting satellite observations, and to account for the conditions under which detections may be missed or unreliable. Together with RMI and KAPSARC, this work defines the technical boundaries within which user requirements must be framed.

3.4 Satellite alert and response frameworks for operators and governments

A core body of literature addresses the operational dimension of satellite-based methane monitoring: how the data flows from detection to action, and what requirements this places on both the data itself and the institutional frameworks that use it. This section covers the maturation of IMEO's Methane Alert and Response System (MARS) as the primary global alert infrastructure, the guidance developed to help governments act on satellite notifications, and the operator-facing frameworks that translate alerts into on-the-ground investigation and mitigation. While the government and operator contexts differ, they share a common dependency on satellite data that is timely, spatially precise, and capable of supporting follow-up verification, making their requirements complementary rather than separate.

An Eye on Methane series (UNEP-IMEO, 2023, 2024, 2025)

The "An Eye on Methane" reports illustrate the evolving needs of stakeholders as satellite methane detection systems mature. The 2023 edition (UNEP-IMEO, 2023) emphasized the importance of understanding the capabilities, limitations, and validation needs of satellite-based observations, particularly in the context of integrating diverse datasets for consistent and transparent emissions reporting. It laid the groundwork for aligning satellite-derived data with the expectations of both regulatory frameworks and operational decision-making.

Building on this foundation, the 2024 report (UNEP-IMEO, 2024) highlights major advancements in the International Methane Emissions Observatory's Methane Alert and Response System. The system now delivers integrated, validated satellite data directly to governments and companies, significantly enhancing the speed, precision, and operational relevance of methane detection.

The 2025 edition further documents MARS's growing scale (UNEP-IMEO, 2025): the system has now issued over 3,500 alerts to operators and governments across 33 countries, using satellite data combined with artificial intelligence. It also marks MARS's expansion beyond oil and gas to coal mines and waste sites, sectors where ground-level measurement remains scarce, identifying data gaps that future satellite capabilities must address. This evolution, from clarifying technical concepts to enabling real-time multi-sector response, reflects the growing demand for actionable, high-quality satellite data that supports immediate mitigation while maintaining scientific credibility.

IEA / UNEP-IMEO - Responding to Satellite Notifications from MARS (2026)

The IEA/UNEP-IMEO guidance document (IEA, 2026) directly addresses the user requirements of governments seeking to act on MARS notifications. It was developed in response to a persistent challenge: despite the availability of satellite alerts, global response rates to MARS notifications remain low, demonstrating that data alone is insufficient without institutional frameworks to act upon it. The document proposes a five-step sequential process. It also defines indicative timelines differentiated by urgency level, itself derived from emission rate and recurrence, both parameters that satellite products must be able to provide reliably. For user requirements documentation, this report makes explicit the data attributes, timeliness, classification, detection repeatability, and spatial precision, that government users require from satellite systems in order to fulfill an oversight or regulatory function.

OGCI - Satellite Methane Detection Response Playbook (2025)

The playbook (OGCI, 2025) addresses the detection-to-action gap from the operator's perspective, providing a structured six-step framework for responding to satellite methane notifications. It positions satellite alerts not as endpoints but as triggers for systematic on-the-ground investigation. For user requirements documentation, this playbook translates operational realities into concrete data needs: operators require satellite products that deliver sufficient spatial precision for site-level attribution, timely delivery to support prioritized dispatch, and repeat revisit capability to validate that mitigation has been effective. These functional needs constitute operator-derived requirements that any satellite-based methane monitoring system must satisfy.

OGCI - Root Cause Analysis of the Satellite Monitoring Campaign (2026)

The OGCI Satellite Monitoring Campaign (SMC) and Root Cause Analysis (RCA) report (OGCI, 2026) trace the path from methane detection to operational analysis. Between 2022 and 2023, the SMC used over 530 high-resolution satellite observations across oil and gas sites in Iraq, Kazakhstan, Algeria, and Egypt to identify major emission sources. The RCA then used accumulated satellite data to identify systemic drivers of emissions, shifting focus from isolated events to long-term inventory improvement. For user requirements, the report highlights the need for advanced satellite capabilities, including multi-temporal coverage, high detection sensitivity, and integration with operational metadata such as equipment type, site configuration, and production volumes.

3.5 Policy and regulatory frameworks

The policy and regulatory literature documents how governments and international bodies are translating satellite methane detection capabilities into formal requirements and, increasingly, into compliance obligations that directly shape the standards satellite data products must meet. This section also includes the CCAC LOW-Methane Data Strategy, which, while sector-specific, establishes a data framework with direct implications for how satellite observations should be structured to meet the evidentiary needs of mitigation finance and regulatory monitoring in the waste sector.

CLDP Handbook for Policymakers on Methane Abatement in the Oil and Gas Sector (2023)The CLDP handbook for policymakers on methane abatement in the oil and gas sector (CLDP, 2023) provides valuable contextual insights into how governments and regulatory bodies are beginning to incorporate detection capabilities into regulation. It helps translate scientific knowledge and technological advancements, including those derived from satellite-based methane detection, into effective policy instruments.

Canada Gazette, Part I, Volume 157, Number 50: Regulations Amending the

Regulations Respecting Reduction in the Release of Methane and Certain Volatile

Organic Compounds (Upstream Oil and Gas Sector) (2023)

Canada's proposed methane regulations, which now suggests rapid action for emission events exceeding 100 kg/h and reflect a broader move toward performance-based standards. Although current probability of detection benchmarks (e.g., 90% PoD for ≥1 kg/h) are not yet fully compatible with the capabilities of satellite systems, such policy developments indicate a growing expectation for precise, quantitative, and verifiable monitoring technologies. It is important to note that the amendment to the regulation on methane reduction is still in progress and has not yet been finalized or published in Part II of the Gazette.

EEMDL – Independent Verification Protocol (Interim Final, 2026)

The EEMDL Independent Verification Protocol (EEMDL, 2026) marks the most significant regulatory milestone of the 2025–2026 period. It establishes a standardized framework for third-party verification of methane emissions under the EU Methane Regulation (EUMR), which requires that all fossil fuel imports into the EU be accompanied by independently verified emissions data. While the protocol does not mandate satellite data specifically, it creates the evidentiary standard that measurement-based inventories, increasingly informed by satellite detection, must meet, effectively transforming satellite-derived data from a voluntary monitoring tool into a potential compliance input for producers and exporters supplying the European market. For user requirements documentation, this is the most regulatory-facing document in the set: it defines what attributes verified emissions data must have, traceability, methodological transparency, reproducibility, and third-party auditability, setting a floor for the quality and documentation standards that satellite-based data products must achieve to be used in compliance workflows.

CCAC – LOW-Methane Data Strategy (2025)

The CCAC LOW-Methane Data Strategy (CCAC, 2025) broadens the regulatory and policy landscape to the organic waste sector, which accounts for approximately 10% of global anthropogenic methane emissions. Its inclusion in the policy and regulatory section reflects its function as a structured governance framework for data collection and emissions accountability, one that identifies data gaps in the waste sector as a primary barrier to both mitigation action and public investment. For satellite-based methane data requirements, the strategy establishes a demand for observational capabilities that can support baseline quantification and progress tracking in a sector where ground-level measurement remains scarce, and where satellite data could play a critical gap-filling role.

3.6 Financial sector perspectives

The financial and investment community represents a distinct class of users whose requirements for satellite-based methane data differ from those of operators or regulators. Rather than needing data to manage operations or enforce compliance, financial actors require data that is credible, consistent, and comparable enough to underpin risk assessments, disclosure requirements, and investment decisions. The following contribution documents this perspective.

JPMorgan Chase – Methane Emissions Management in Oil & Gas (2023)

J.P. Morgan Chase has provided its perspective on leveraging technology for continuous improvement in methane emissions management within the Oil & Gas sector (JPMorgan Chase & Co, 2023). This note offers insights into the requirements and expectations from the financial sector, which plays a crucial role in funding and influencing industry practices. This perspective from a major financial institution adds weight to the importance of developing and implementing effective methane monitoring and abatement strategies, potentially influencing both industry practices and policy decisions.

3.7 The scientific community and the improvement of the monitoring capacities

The scientific literature also reflects a growing interest and describes the recent revolutionary advancements in satellite-based methane detection and emission quantification techniques. An extensive overview can be found in the Review State-of-the-art (D1.2). Major game changers in this field - pushed amongst others by scientific developments - have been 1. the capabilities of TROPOMI on Sentinel-5 Precursor for the first time given us a (daily) global view on methane super emitters (e.g. Lauvaux et al., 2022; Schuit et al., 2023); 2. the launch of satellites dedicated to measuring methane at facility-scale resolution (Varon et al., 2019); 3. the realisation that high spatial resolution Earth imagers not designed to measure methane but with SWIR channels can detect the largest emitters under favorable conditions (Varon et al., 2021; Cusworth et al., 2021; Guanter et al., 2022; Jacob et al., 2022); and 4. the use of tip-and-cue combining global flux mapper observations (e.g. from TROPOMI) with the facility scale high resolution satellites providing a very powerful tool to detect super emitters and identify their exact source (e.g. Maasakkers et al., 2022; Irakulis-Loitxate et al., 2022). These developments combined have led to a complex, diverse, and interconnected observing system that provides very valuable information on methane emissions but can be difficult to assess and understand for users. Recent studies have also focused on validation of various satellite systems for methane sensing at facility scale level. The validation efforts highlighted by Sherwin et al. in 2023 and 2024, and Reuland et al. In2025 (under review) aim to assess the accuracy and reliability of different satellite platforms in detecting and quantifying methane emissions from point sources. Complementing these efforts, He et al. (2026, under review at PNAS) present a coordinated validation approach for high-detection-threshold systems by synchronizing satellite observations with planned operator activities on the ground, enabling a direct and controlled assessment of methane retrieval accuracy across platforms. These advancements in remote sensing techniques and their validation are crucial in responding to the early qualitative requirements of end-users. However, the scientific community emphasizes the ongoing need for further refinement of these techniques and continued intercomparison studies to ensure accurate and reliable methane emissions data from space-based sensors. This is the focus of ESA's MEDUSA project.

4. Use-cases

This section presents the user requirements for satellite-based methane super-emitter monitoring, structured around four use cases identified through stakeholder engagement. These use cases span from the detection and attribution of individual emission events to their aggregation at national and facility scales in support of greenhouse gas inventories. For each use case, requirements are organized across four dimensions: intercomparison, validation, interoperability, and harmonization. Key terms used throughout this section are defined in Section 4.1.

4.1 Context and Terminology

Super-emitter: Here defined as a large, urban to facility-scale methane emission source quantified with a flow rate above 100 kg/h. In the oil and gas sector, such events can occur due to equipment malfunctions, pipeline leaks, or improper venting and flaring practices. In the coal industry, methane super emitters are typically associated with ventilation systems in underground mines or coal seam degasification processes. The waste sector sees similar emissions produced from the anaerobic decomposition of organic waste that escape from capture systems or open landfills. The term "super-emitters" has been used with different meanings, originally referring to facilities that both emit a lot and relatively more than similar facilities. Currently, the term is widely used in the satellite community to identify sources that have been found emitting large quantities of methane, even if those emissions are short in duration or are consistent with expected emissions and similar to other facilities.

Threshold requirement: The limit beyond which the data is of no use to a given application.

Breakthrough requirement: The level at which significant improvement in the given application would be achieved.

Goal requirement: The level beyond which further improvement would be of no value for the given application.

Intercomparison: Facilitates performance evaluation and comparison among different satellites/sensors or providers through common evaluation metrics.

Validation: Ensures the reliability and scientific rigor of the approach through independent comparison with “truth” value.

Interoperability: The combined use of super-emitter data from different satellite instruments or different data providers. Standardize data formats and metadata conventions when sharing super-emitter data to enable consistent interpretation by users.

Harmonization: Facilitates the integration and blending of datasets originating from various satellite instruments or providers, accomplished by calibrating and validating them against common reference standards.

4.2 Use case-1 Super-emitter detection & attribution leading to mitigation actions

Use-Case - Description

Access super-emitter detections with source attribution to make this data actionable for targeted mitigation actions (LDAR).

Use-Case - Illustration

Access a recent super-emitter detection over a O&G well in Algeria and notify the operator so that they can repair the leak.

Intercomparison Requirements

Detection and reliability indicator of detection (High/Medium/Low)

Allows comparison of detection reliability across different satellites or sensors

Detection threshold of the satellite used under reference conditions

Allows fair comparison of sensitivity, allowing to evaluate whether a non-detection is consistent with a detection by another instrument

Probability of detection curve

Allows fair comparison of sensitivity, allowing to evaluate whether a non-detection is consistent with a detection by another instrument

Spatial resolution of the satellite used (e.g., 20m x 20m)

Allows comparison of the ability to pinpoint emissions sources accurately

Revisit time

Allows comparison of the ability to capture intermittent emissions and to track super-emitter evolution over time

Validation Requirements

Validated instrument and approach with controlled releases or demonstrated consistency with validated instruments (related to detection threshold only)

Ensures the reliability of detected plumes

Quality control process (to filter out false positives)

Ensures overall accuracy and reduces the likelihood of misreporting emissions events

(Peer reviewed) documented methodology for methane detection with versioning

Ensures transparency and reproducibility

Interoperability Requirements

Mask of the plume

Ensures consistent visualization and analysis across different satellites or data providers

Source location, and Uncertainty about the source location (in meters)

If possible: coordinates of the most likely facility nearest to the upwind edge of the plume using public imagery. It is noted that users (such as IMEO-MARS) ultimately need operator information, but this is proprietary data and as such considered out of scope for MEDUSA.

Ensures robust integration of data from different satellites or data providers

Shared Metadata (see end section 5)

Additional Metadata:

- Version of the methodology used (for detection and attribution)
- Visual of the detection with a legend, same unit of concentration
- Most recent high-quality acquisition without any detection (if available)

Harmonization Requirements

None

4.3 Use case-2 Super-emitter quantification

Use-Case - Description

Access quantified super-emitter detections with flow rates for leak detection and repair (LDAR) and methane reporting/verification (MRV) applications.

Use-Case - Illustration

Quantify super-emitter detections over a specific oil and gas site for three months to monitor emissions after a repair intervention.

Intercomparison Requirements

Uncertainty breakdown (wind, product, background)

Enables a more nuanced comparison of quantification accuracy across different satellites or providers

Validation Requirements

Validated instrument and approach with controlled releases or demonstrated consistency with validated instruments

Ensures the reliability of observed resulted emission quantifications

(Peer reviewed) documented methodology for methane quantification and uncertainty

Ensures transparency and reproducibility

Interoperability Requirements

Flow rate (in tons/hour)

Allows a consistent interpretation of the magnitude of an emission

Flow rate uncertainty (in tons/hour)

Allows more trustworthy integration of data from multiple sources for comprehensive analysis

Shared Metadata

Additional Metadata:

- Version of the methodology used (for detection, attribution and emission quantification)
- Visual of the detection with a legend, same unit of concentration (column average mixing ratio)

Harmonization Requirements

None

4.4 Use case-3 Aggregation analysis of super-emitters

The requirements in emission integration come on top of earlier defined requirements on detection and quantification.

Use-Case - Description

Access year-over-year comparisons of total methane super-emitter emissions globally and for specific regions/countries with a distinction of persistent and short-term (potentially accidental) emissions if possible.

Use-Case - Illustration

Estimate total detected US super-emitter emissions per sector using TROPOMI detections for the year 2023.

Intercomparison Requirements

Detection threshold of the satellite used under reference conditions

Allows fair comparison of sensitivity, allowing to evaluate whether a non-detection is consistent with a detection by another instrument

Explanatory note on interpreting the estimates and their limitations

Allows to understand potential biases in aggregated results

Revisit time

Allows to assess the completeness and reliability of aggregated results

Validation Requirements

(Peer reviewed) documented methodology for the quantification approach

Ensures transparency and reproducibility

(Peer reviewed) documented methodology for the summation/upscaling approach accounting for observation coverage and leak duration

Ensures transparency and reproducibility

Identification of the datasets used and their accessibility status (public, restricted, private)

Enables reproducibility and independent validation by third parties

Interoperability Requirements

Shared Metadata

Number of useful observations over the region

Allows users understand the coverage and frequency of monitoring, evaluate potential gaps and the robustness of the analysis

Number of detections over the region

Allows users to understand the scale of the problem

Average flow-rate per detection

Allows users estimate the potential impact of mitigation efforts

Distribution of flow-rates

Allows users to access more detailed information on the distribution of emissions on top of the average value

Total super-emitters emissions for the region (in Mt)

Allows to interpret the magnitude of the emissions

Uncertainty on the total emissions (in Mt)

Allows a consistent interpretation of the magnitude of the emissions

Harmonization Requirements

Yearly updates using consistent methodology or indicating the impact of changes (e.g., more instruments in orbit)

Ensures consistent and comparable results between years

4.5 Use case-4 Emission inventory at the facility-level

The requirements in emission integration come on top of earlier defined requirements on detection and quantification.

Use-Case - Description

Access yearly estimates of total methane emissions at the facility-level based on super-emitter detection and observability metrics

Use-Case - Illustration

Estimate total methane emissions over a year of a specific compressor station based on several measurements

Intercomparison Requirements

Probability of detection (PoD) curve

Allows to assess the completeness and reliability of aggregated results

Revisit time

Allows to assess the completeness and reliability of aggregated results

Validation Requirements

Validated instrument and approach with controlled releases or demonstrated consistency with validated instruments

Ensures the reliability of observed emission quantifications

(Peer reviewed) documented methodology for methane quantification and uncertainty with versioning

Ensures transparency and reproducibility

(Peer reviewed) documented methodology for the statistical model used to derive total methane emissions from discrete measurements with versioning

Ensures transparency and reproducibility

Identification of the datasets used and their accessibility status (public, restricted, private)

Enables reproducibility and independent validation by third parties

Interoperability Requirements

Shared Metadata

Number of useful observations over the facility

Allows users to understand the coverage and frequency of monitoring, evaluate potential gaps and the robustness of the analysis

Number of detections over the facility

Allows users to understand the scale of the problem, evaluate potential gaps and the robustness of the analysis

The ratio of number of detections over the facility and number of useful observations over the facility provides the Emission frequency.

This allows users to understand the intermittency of emissions observed by satellites to assess yearly estimates.

Flow rate (in tons/hour)

Allows a consistent interpretation of the magnitude of the emissions

Flow rate uncertainty (in tons/hour)

Allows a scientifically robust estimation

Total emissions for the asset (in Mt)

Allows users to understand the scale of the problem

Uncertainty on the total emissions (in Mt)

Allows a consistent interpretation of the magnitude of the emissions

Location of the detection and uncertainty about the location

Ensures comparison of data from different satellites or data providers

If possible/If sufficient data: Might be interesting to have more frequent than yearly data (ex: quarterly) when there are significant seasonal variations

Harmonization Requirements

Yearly updates using consistent methodology or indicating the impact of changes (e.g., new statistical model)

Ensures consistent and comparable results between years

Shared Metadata

Satellite used (ex: Sentinel-2)

Ensures traceability of the detection and comparison of like with like across different providers or data sources

Product used (ex: L1/L2/etc.) and version (ex: v0.1.1)

Ensures traceability of the detection and comparison of like with like across different providers or data sources

Time of acquisition

Ensures robust temporal analysis and integration

Degree of confidence in the detection: Low/High*

Ensures consistent interpretation of reliability across different systems

Wind Data: Speed and Direction

Ensures a good understanding of the plume dynamics

Source of wind data (ex: ECMWF ERA5)

Ensures traceability of the wind data and robust integration

**High indicates strong confidence in the detection, while Low suggests uncertainty, possibly due to environmental factors or sensor limitations. Further investigation may be needed for low-confidence detections.*

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