OIL AND GAS CLIMATE INITIATIVE

WHITE PAPER

Results of OGCI Satellite Monitoring Campaign 2022-2023 over Kazakhstan, Algeria and Egypt

MARCH 2024

OIL AND GAS
CLIMATE INITIATIVE

About The Oil and Gas Climate Initiative

The Oil and Gas Climate Initiative is a CEO-led organization bringing together 12 of the world's largest oil and gas companies to lead the industry's response to climate change. It aims to accelerate action towards a net zero emissions future consistent with the Paris Agreement.

OGCI members are Aramco, bp, Chevron, CNPC, Eni, Equinor, ExxonMobil, Occidental, Petrobras, Repsol, Shell and TotalEnergies. Together, OGCI member companies represent almost a third of global oil and gas production.

OGCI members set up Climate Investment to create a US$1 billion-plus fund that invests in companies, technologies and projects that accelerate decarbonization in energy, industry, built environments and transportation.

OUR MEMBER COMPANIES

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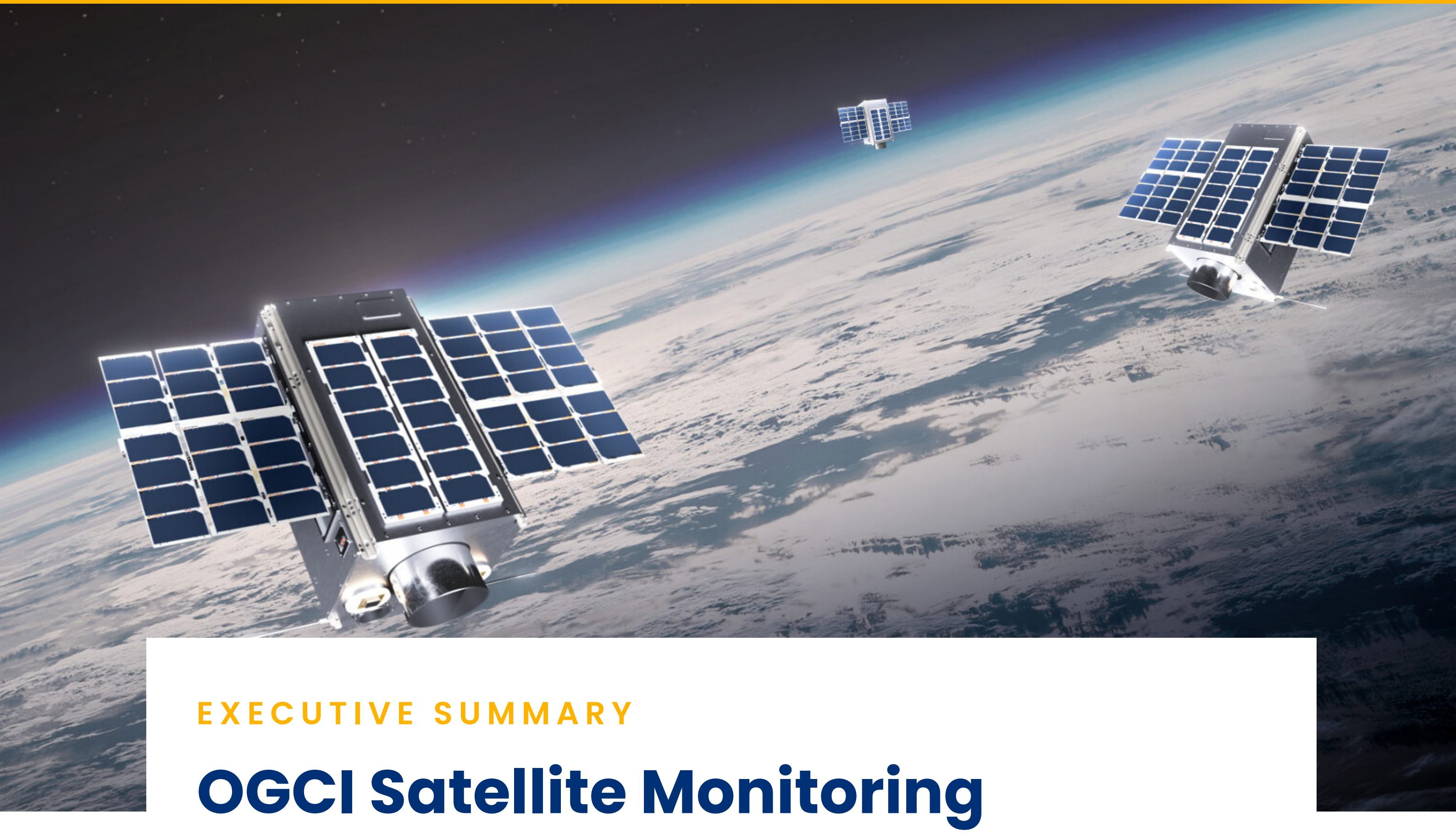


EXECUTIVE SUMMARY

OGCI Satellite Monitoring Campaign 2022–2023

A significant and rapid reduction in methane emissions is critical to achieve the goals of the Paris Agreement and has been a top priority for the Oil and Gas Climate Initiative (OGCI) since the group was founded in 2014.

Methane emissions from venting, fugitives and flaring comprise around 2 gigatonnes of carbon dioxide equivalent a year (CO_2e) – almost half the oil and gas industry's total Scope 1 and 2 emissions, according to the International Energy Agency.

In 2022-2023, OGCI extended its flagship Satellite Monitoring Campaign (SMC) to Algeria, Kazakhstan and Egypt to support more countries taking practical action to reduce methane emissions from oil and gas operations.

A successful pilot of the SMC in Iraq in 2021 had already demonstrated the capability of satellite technology to detect and quantify methane emissions and provide information to local operators to help them reduce emissions. Detection and measurement of methane emissions is a critically important first step to reducing methane emissions.

For this latest phase of the campaign, greenhouse gas monitoring company GHGSat performed over 530 high-resolution observations during one year over a total of 18 pre-selected sites (six per country), using its own satellites and public satellite data. [1]

FOOTNOTES

[1] Please note GHGSat is also an early investee of Climate Investment.

Sites were selected on criteria that included the number and size of previous and historic methane emissions, suitability for satellite monitoring, and the feasibility of engagement. The areas included oil- and gas- producing assets operated by OGCI members and non-members.
The campaign demonstrated that there are opportunities associated with using satellite data and engaging with local operators to support mitigation of methane emissions.

Importantly, it provided reliable data to local operators to further identify and characterize previously unknown persistent methane emissions sources.

It also highlighted the important role that OGCI can play in collaborating with local operators, including national oil companies and joint-venture partners, to accelerate the oil and gas industry's activities to eliminate methane emissions.

Quick win

The campaign has already enabled substantial – and quick – greenhouse gas mitigation at some locations, and has identified additional opportunities to further reduce methane emissions by continuing to engage with the operators and conduct asset specific analysis over the next 12 months, based on satellite data collected throughout this campaign.

This information and process will aid in better understanding the source of the emissions to more effectively tailor next steps and support local operators.

As of October 2023, two operators in Algeria and Kazakhstan confirmed they were able to mitigate three persistent methane emissions sources which had been confirmed with the local operators.

The three sources had a combined average emissions rate of 3,200 kg CH_4/h. This is equivalent to the hourly carbon emissions from almost 4,000 gasoline-fueled passenger vehicles.

OGCI is continuing to engage with four operators to help identify mitigation solutions for the remaining persistent emissions sources. Six emissions sources were confirmed with one operator over two monitored assets. The operator is in the process of exploring the best mitigation options.

Key findings

- **The campaign provided valuable data to operators** to further identify and characterize previously unknown persistent methane emissions sources. Operators provided on the ground confirmation for 15 persistent large sources previously detected through satellite monitoring. This additional data enables operators to locate the emissions sources and take faster methane emissions mitigation action on the assets being monitored.

- **The campaign further demonstrated that OGCI can play an important role supporting local operators, including national oil companies and joint-venture partners, to eliminate methane emissions.** Their vast networks and experience developing reporting and mitigation programs make them best placed to help partners and NOCs accelerate the oil and gas industry's activities to eliminate methane emissions.

- **Effectiveness of engagement strategies depends on geography, asset and operator.** Asset-level inventories combined with satellite and on-site measurements and monitoring technologies, such as remote sensing data and infrared cameras, are key to understanding methane emissions and the necessary mitigation actions.

- **Trust and confidentiality is critical for effective collaboration.**

Conclusion

Satellite technologies, combined with trust based on long-held relationships with local operators, can unlock large opportunities to reduce methane emissions from oil and gas operations.

OGCI member companies can support local operators by sharing established knowledge, expertise and learnings to help accelerate methane emissions reduction.

Based on this latest phase of the SMC and feedback from participants, OGCI is extending the campaign to more countries and operators. It recommends that satellite monitoring is supplemented with on-site monitoring and complementary initiatives, and knowledge and learnings are shared beyond the campaign.

Introduction

The need for fast-paced actions to cut greenhouse gas (GHG) emissions has put a spotlight on methane emissions. Since its inception in 2014, the Oil and Gas Climate Initiative (OGCI) has spearheaded several initiatives to accelerate methane emission reduction across the oil and gas sector. [2]

In 2021, OGCI set up a program with GHGSat, a leading global expert in methane emissions monitoring using satellites (and an early investee of Climate Investment), and Carbon Limits, a technical partner with in-depth knowledge of methane emissions in many countries. The program leverages high-resolution satellite monitoring technology to identify large sources of methane emissions, collects data on various emissions attributes, and shares the information with local operators to support methane emission mitigation efforts. The program was successfully piloted in Iraq in 2021-2022.

At one large site, operators were able to make improvements in routine procedures to eliminate vented natural gas. This cut continuous methane emissions to a level not detectable by satellite over the course of the following seven months. The pilot also created positive momentum among the operators in Iraq, who expressed their interest in learning more about possible sources of emissions and the mitigation solutions available. [3] Building on these positive outcomes, the campaign was extended to Algeria, Kazakhstan, and Egypt in 2022-2023.

FOOTNOTES

[2] OGCI launched the Aiming for Zero Methane Emissions Initiative, helped to develop the Methane Guiding Principles (MGP) Flaring Toolkit and supported the development of the Methane Inventory Systematic Tool (Mist) for oil and gas companies.

[3] OGCI published a white paper, in January 2023, discussing the results of Phase I in Iraq.


Source: GHGSat

Satellite Monitoring Campaign 2022–2023

Objectives of the campaign

Similar to the 2021-2022 campaign in Iraq, the 2022-2023 campaign aimed at facilitating rapid and effective action on methane emissions in the oil and gas sector in Algeria, Kazakhstan, and Egypt.

Secondary objectives included raising awareness of the methane challenge with operators in country, offering technical support and capacity building to the operators, spreading knowledge and learnings with external stakeholders, further demonstrating and assessing satellite monitoring capabilities in these countries, and characterizing methane emissions over selected oil and gas basins.

Shortlisting of countries and assets

The shortlisting of countries was governed by a number of key criteria, including (1) number and size of previous/historic methane emissions, (2) suitability for satellite monitoring, and (3) engagement feasibility.

Based on these criteria, Algeria, Egypt, and Kazakhstan were selected for monitoring in this new phase.

Table 1: Summary of oil/gas production and gas flaring volumes in three countries selected for phase II [4]

Country	Oil production (thousand barrels/ day)	Gas production (billion m^3)	Flared gas volume (million m^3)
Algeria	1,353	101	8,614
Egypt	608	68	1,969
Kazakhstan	1,811	32	1,025

A list of potential high methane emissions areas was compiled, making use of data from previous methane emissions observations from public satellites, as well as field-specific details including oil and gas production, gas/oil ratio, infrastructure age, and flaring data. Please refer to **Appendix D** 'Process & Methodology' for more details.

FOOTNOTES

[4] Based on BP Statistical Review of World Energy 2022, and the Global Gas Flaring Data published by the World Bank.

Six areas per country were shortlisted for monitoring, giving a total of 18 areas over the three shortlisted countries: those areas included oil-producing and gas-producing assets operated by both OGCI members and non-members. Each monitored area was of a significant size (12 km x 12 km) and often included several assets with potential methane emissions.

Satellite observations and detections

The selected areas were monitored for one year, starting between June and August 2022. During the one-year period, GHGSat performed over 530 high-resolution observations across the three countries: 28% of these observations (149 observations) were positive (had one of more plumes detected, with a total of 308 plume detections).

At the lower end of emissions detected, a plume with an emission rate of 75 kilograms of methane per hour (kg CH_4/h) was detected in Algeria, where satellite monitoring conditions are most favorable (due to limited cloud coverage, bodies of water, etc.) although not verified with on the ground measurement. However, GHGSat's quantification has been shown to be accurate to within a few percent. [5] The most substantial plume identified was emitting at a rate of 4,500 kg CH_4/h. These differences in rate are important; even the lower emission rate of 75 kg CH_4/h is significant, considering that a persistent emission at that rate would be equivalent to the hourly emission from the energy consumption of ~2,300 US houses [6] or hourly carbon emissions from ~90 gasoline-powered US passenger vehicles. [7] This highlights the significance of the "fat-tail" distribution, whereby operators may act on a small number of sources yet achieve significant methane emissions reduction. Limited visibility from satellite technologies below 100 kg CH_4/h confirms the need for a complementary spectrum of monitoring technologies, as outlined in **Learning 3** below.

41 detected methane plumes emitted at a rate higher than 2,000 kg CH_4/h. This is only 13% of the detected plume count, but they were responsible for 44% of the cumulative emissions detected.

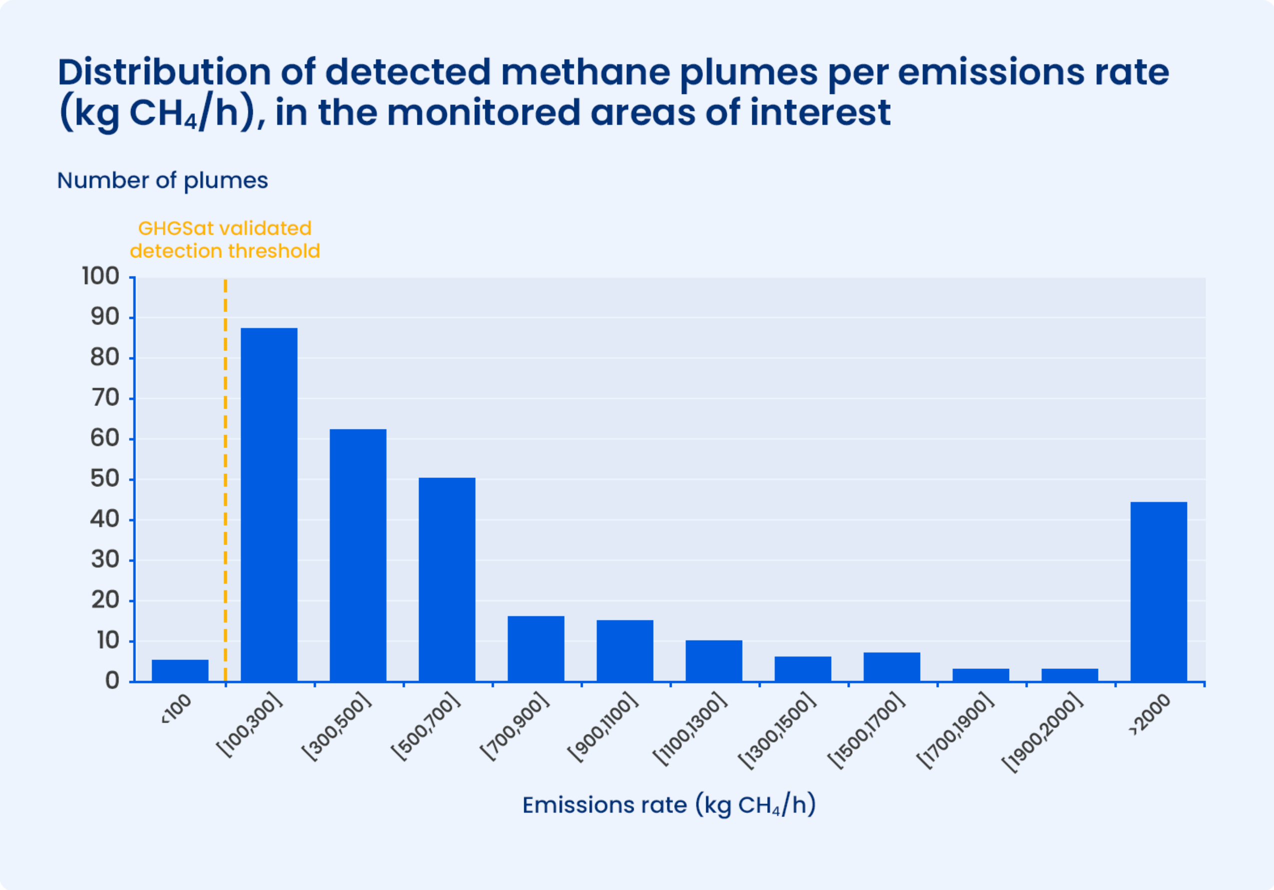
FOOTNOTES

[5] Sherwin, Evan D., et al. " Single-blind validation of space-based point-source detection and quantification of onshore methane emissions." Scientific Reports 13.1 (2023): 3836.

[6] Using United States Environment Protection Agency (EPA) GHG Equivalencies Calculator, and using GWP CH4 (100 year time horizon) = 25 [-] from the IPCC's 4th Assessment Report.

[7] Assuming the average gasoline vehicle on the road has a fuel economy of about 22.2 miles per gallon and drives at 60 miles / hour (EPA, Greenhouse Gas Emissions from a Typical Passenger Vehicle, 2023).

Figure 1: Distribution of detected methane plumes per emissions rate (kg CH_4/h), in the monitored areas of interest



Attribution, engagement and characterization of the sources of emissions

When an emission was detected, the plume was attributed by the OGCI and Carbon Limits teams to a specific oil and gas asset and operator, for further characterization. The attribution methodology relied on the analysis of plume rate, intermittency, and nearby infrastructure visible by public satellite imagery.

Carbon Limits, jointly with OGCI member companies and GHGSat, successfully engaged with 93% of the identified operators with the principal aim to (1) confirm and further characterize the sources of emissions and (2) offer technical support / capacity building to the operators to mitigate the plumes / avoid future methane emissions.

Through the engagement with operators, the OGCI and Carbon Limits teams were able to:

1. Attribute **99% of the detected emissions to nine different types of emissions sources.** Please refer to **Appendix B** to review the types of emissions sources identified.
2. Determine the **four main types of emissions sources**, accounting for two thirds of the total detected plumes and with strong regional variability, as we further discuss in the country-specific analysis: (a) incomplete combustion from burning pits, (b) gathering pipeline emissions (c) equipment venting and (d) storage tank venting.
3. Identify **26 persistent methane emissions sources, of which 15 were confirmed on the ground by the operators.** These persistent emissions sources were responsible for 73% of the total plume count and 75% of the cumulative emission rate. 83 plumes (27% of the total detected plumes) were attributed to isolated points with intermittent emissions sources. Please refer to **Appendix C** to review the count of persistent emissions sources, by type of emissions sources.

Figure 2: Distribution of methane plumes per emissions sources type in the monitored areas of interest.

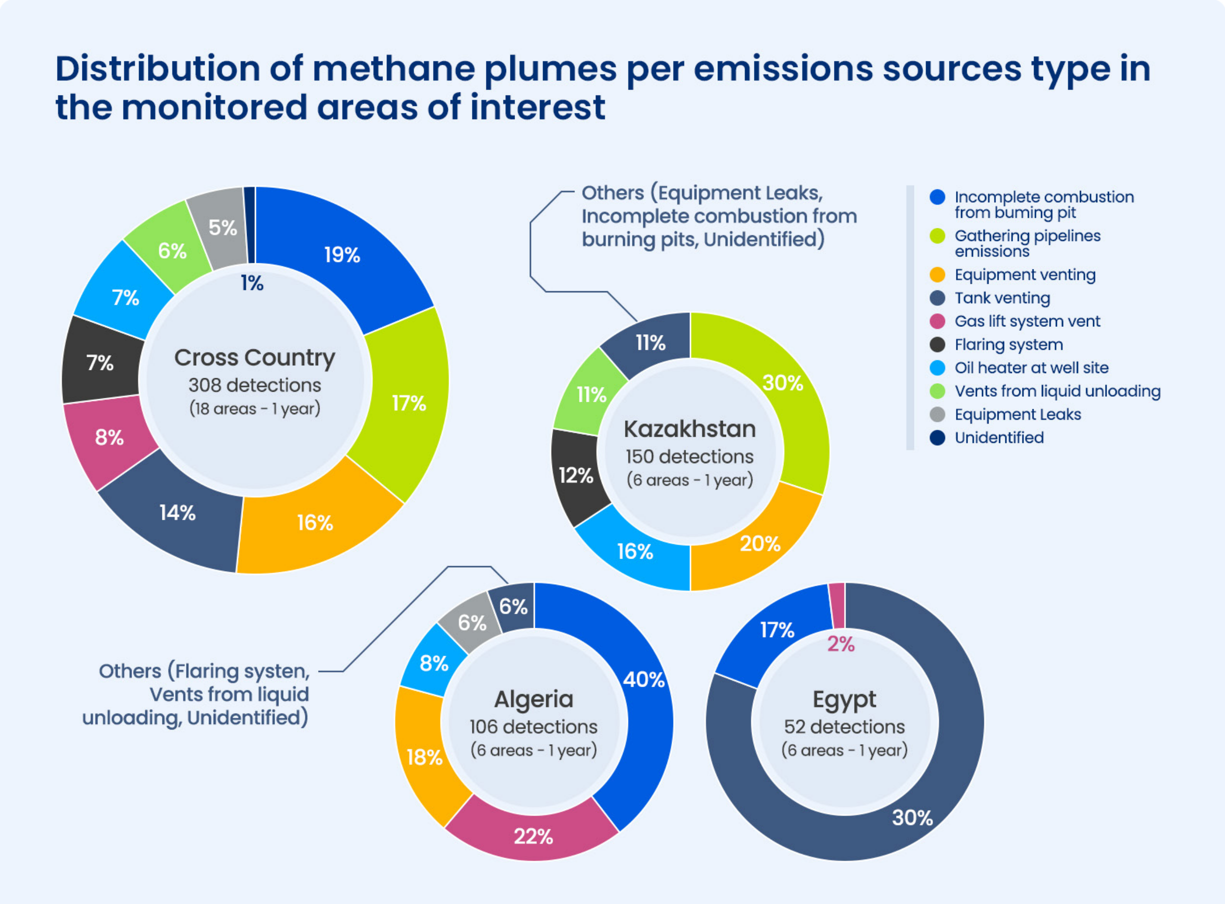
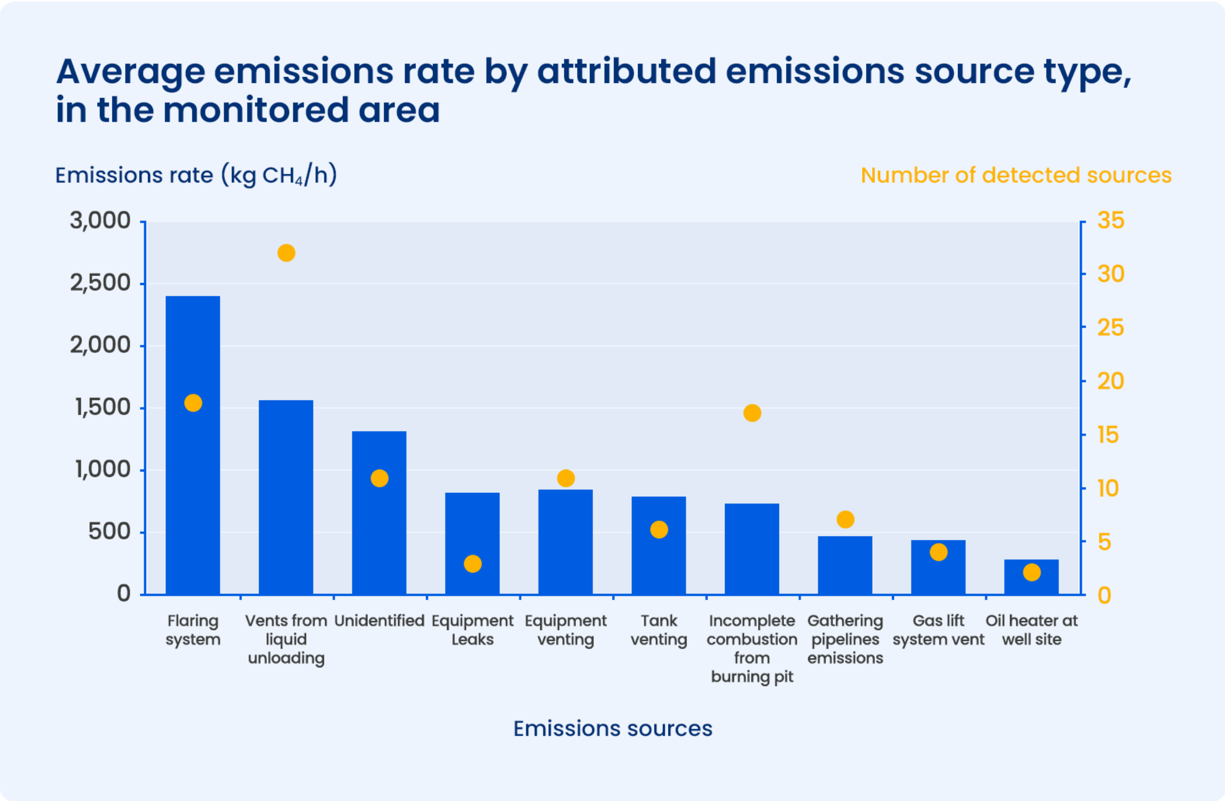


Figure 3: Average emissions rate by attributed emissions source type, in the monitored areas of interest



Realized emissions impact

Throughout the process of detection, attribution, and characterization of the methane plumes, and engagement with the operators, the campaign helped enable greenhouse gas mitigation at some locations.

At the time of writing (October 2023), two operators in Algeria and Kazakhstan confirmed they were able to mitigate three large and persistent methane emissions sources. The three sources were attributed to leaks from (1) a shut-off valve, (2) an aero-refrigerant equipment and (3) a separator, with a **combined average emissions rate of 3,200 kg CH_4/h**. This is equivalent to the hourly carbon emissions from around 3,700 gasoline-fueled passenger vehicles. [8] Following confirmation from the operators that the leaks were fixed, subsequent high resolution satellite imagery confirmed that no large emission sources above 100 kg CH_4/h were present in those locations.

In addition, engagement is continuing with four operators to help identify mitigation solutions for the remaining persistent emissions sources. Six emissions sources were confirmed with one operator over two monitored assets. These sources are split between emissions related to gas lifting systems and incomplete combustion from burning pits. The operator revealed through the engagement their awareness regarding these sources and their intention to mitigate these sources before the satellite monitoring campaign started. The operator is currently in the process of exploring the best mitigation solution to be implemented in the short term, with OGCI and Carbon Limits supporting them along the way.

The remaining emissions sources are attributed to the inefficiencies of equipment and processes in the monitored facilities, specifically emissions from oil heaters, inefficient flare systems, incomplete combustion from burning pits and tank venting. Further investigations are necessary to further characterize these emissions sources and help identify long-term mitigation actions over the relevant assets.

Box 1: Methane Mitigation timeframe

Lead time for mitigation activities is governed by the nature of the emission source. In the case of leaks or equipment malfunction for example, the emissions sources can be quickly repaired, leading to fast mitigation, i.e. within weeks.

On the other hand, other types of emissions are linked to operating practices, system design, or process inefficiencies. In these cases, mitigation requires installing additional processing modules or upgrading the current equipment. The mitigation process in these cases can extend from a few months to a few years, as we explain below.

For instance, installing a vapor recovery unit on storage tanks requires the operator to first perform on-ground measurements and provide accurate quantification of the amount and the composition of emissions from the storage tanks, required for the design of the vapor recovery system and later the procurement process.

FOOTNOTES

[8] Assuming the average gasoline vehicle on the road has a fuel economy of about 22.2 miles per gallon and drives at 60 miles / hour (EPA, Greenhouse Gas Emissions from a Typical Passenger Vehicle, 2023).

While measurement campaign planning is estimated in the order of months, the full mitigation process requires not less than one to two years.

In the case of oil heaters, the field layout is a challenge for the mitigation process. With a high number of heaters dispersed between well sites across the field, emissions reduction requires an important investment, in addition to a detailed study covering the full infrastructure in the field before implementation. This makes mitigation hard to achieve during the time of the monitoring campaign, especially if the operator chooses to replace its equipment with electric heaters.

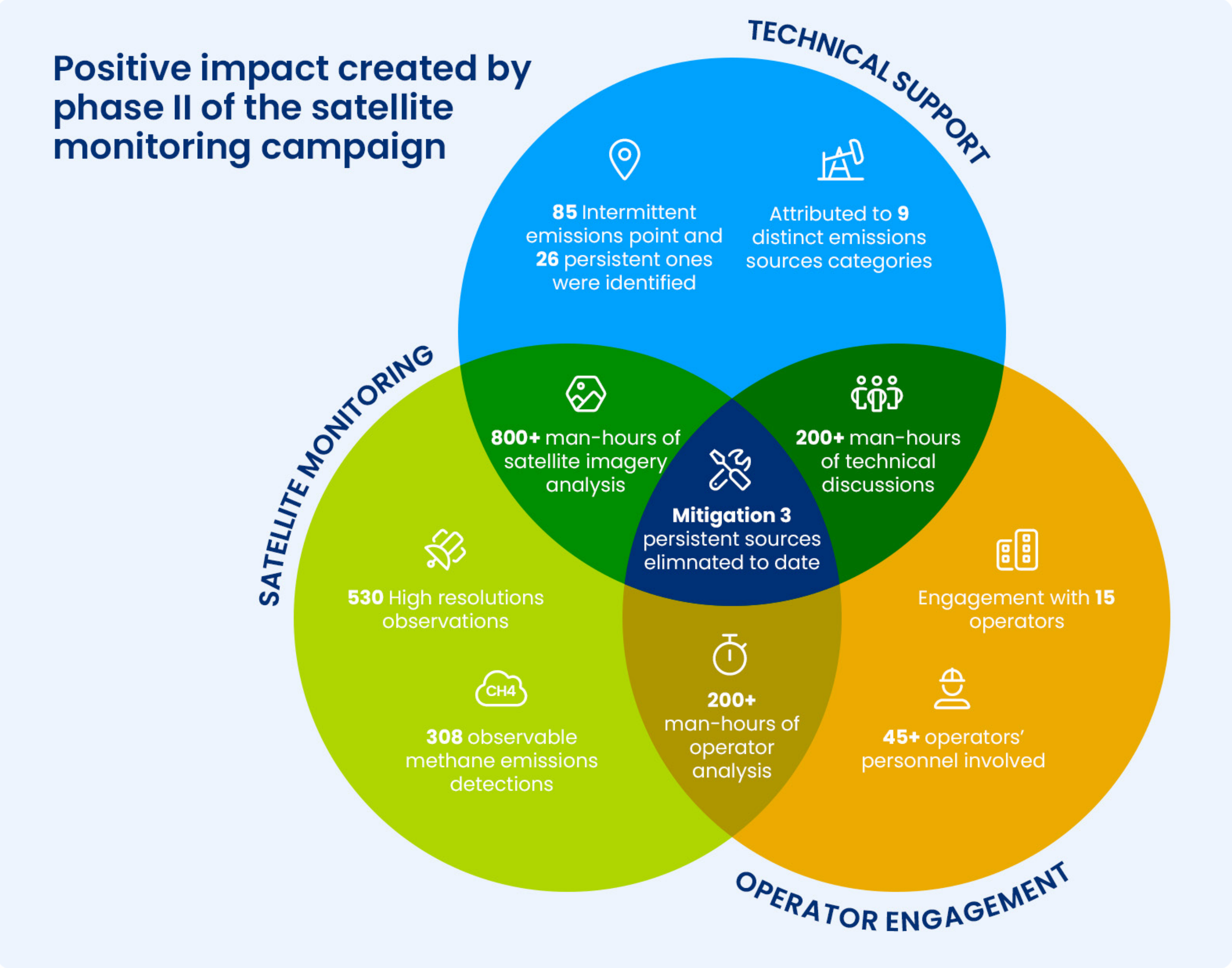
Similar processes of (i) understanding the root cause of the emissions, (ii) design of the mitigation, and (iii) procurement are also required for flare inefficiency and incomplete combustion from burning pits, which makes mitigation for the remaining emissions sources classified as medium to long-term actions.

OGCI will work in partnership with consultants and satellite data providers to develop asset specific “root analyses of methane sources”, with the aim to (1) further determine the source of emissions initially detected via satellite, and (2) detail multiple pathways towards systematic elimination of the identified source over the given asset, as additional insight and guidance to local oil and gas operators engaged. Both objectives were tackled to the extent possible under the scope of the satellite monitoring campaign.

More importantly, the campaign succeeded in building relations with the local operators. It is estimated that over 50 operators’ personnel were mobilized throughout various operator engagements, collectively investing more than 1,000 man-hours to conduct extensive follow up efforts based on the data provided including analyzing the data, discussing possible mitigation actions, running leak detection and repair (LDAR campaigns) to confirm and repair the leaks, etc.

This positive impact outlined above could not have been achieved without the intersection of the three pillars of the campaign: satellite data, engagement with the operator and technical support / capacity building.

Figure 4: Positive impact created by phase II of the satellite monitoring campaign



Box 2: Cost metric of the satellite monitoring campaign

Dividing the total satellite monitoring campaign costs over three countries (mainly associated with the purchasing of the satellite data) by the total mitigated emissions allows the authors to track the performance of satellite monitoring over given countries and assets with a new proposed cost metric:

$$Cost_{SMC\ 2022\text{-}2023} = \frac{\Sigma \text{ Costs of the satellite monitoring campaign}}{\Sigma \text{ Estimated GHG emission mitigated}} < 2 \text{ USD} / tCO_2e$$

Please note:

1. The cost above is specific to the 2022-2023 Satellite Monitoring Campaign and the assets shortlisted for monitoring in the selected countries. It should not be confused with an abatement cost, as it does not include the costs associated with the repair of emissions sources (e.g. purchasing of new equipment, man hours to replace the leaking equipment or interrupting production on the asset).
2. The metric is significantly influenced by the selection of data provider, monitored assets and sources of emissions (i.e. priority given to detection of sites with large emissions as part of the campaign).

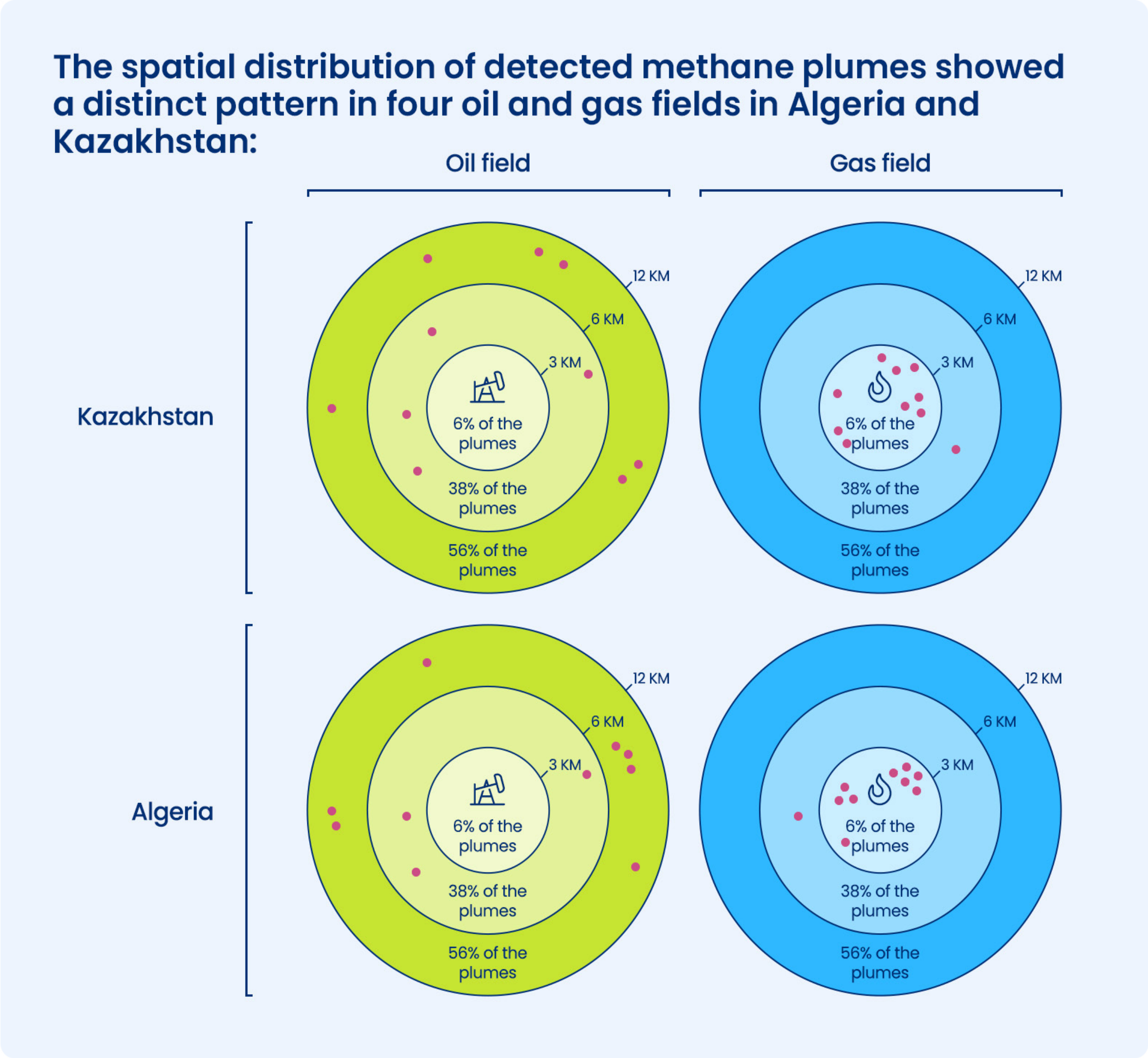
The low cost achieved in the 2022-2023 Satellite Monitoring Campaign highlight the opportunity to reduce methane emissions quickly, and is in line with past monitoring campaigns of similar nature.

Box 3: The spatial distribution of detected methane plumes showed a distinct pattern in four oil and gas fields in Algeria and Kazakhstan

1. Detected plumes from two different gas fields in Algeria and Kazakhstan where highly concentrated, with more than 80% of the detected plumes located within 3 km of the central gathering and processing facilities in both cases.
2. Conversely, a large majority of detected plumes from two oil fields in the same countries were connected to infrastructure more than 6 km distant from the central asset, near well sites, or gathering points, with another sizeable percentage of plumes being found between 3 and 6 km of the central asset. Several observations over the oil field in Kazakhstan showed 5+ simultaneous detections, distributed over the field.

These insights were consistent with the infrastructure setup of each of the fields and are valuable for the planning of on-site measurement strategies. The spatial aspect shows the importance of adapting Leak Detection and Repair (LDAR) programs, measurement approaches, and technology selection based on the type of site and emission distribution.

Figure 5: Spatial distribution of methane emissions detection in an oil field and a gas field, in the monitored areas of interest



SATELLITE MONITORING CAMPAIGN 2022-2023

Algeria findings

Summary of observed emissions in Algeria for the six assets monitored

29% of the observations are with positive detection

Incomplete combustion from burning pit is the main emissions source (40% of the detected plumes)

720 kg/h
Average emissions rate

The yearlong campaign in Algeria led to 189 high resolution satellite observations. 29% of the observations resulted in detections of observable emissions, clustered over three of the six areas monitored, with emissions ranging from 75 to 3,800 kg CH_4/h. Methane emissions in the monitored areas were attributed to seven distinct types of emissions sources (Figure 3): incomplete combustion from burning pits accounted for 40% of the total count of detected plumes, and 33% of the total emission rate.

Burning pits are used in oil and gas fields for the combustion of waste hydrocarbons, primarily in liquid phase or vapors. The root cause of methane emissions from burning pits could be due to separation process inefficiency which could lead to excessive carryover of methane, malfunctioning of the pilot or simply due to lack of ignition. Improving upstream separation or installing an advanced ignition system are an example of mitigation actions to reduce methane emissions resulting from burning pits.

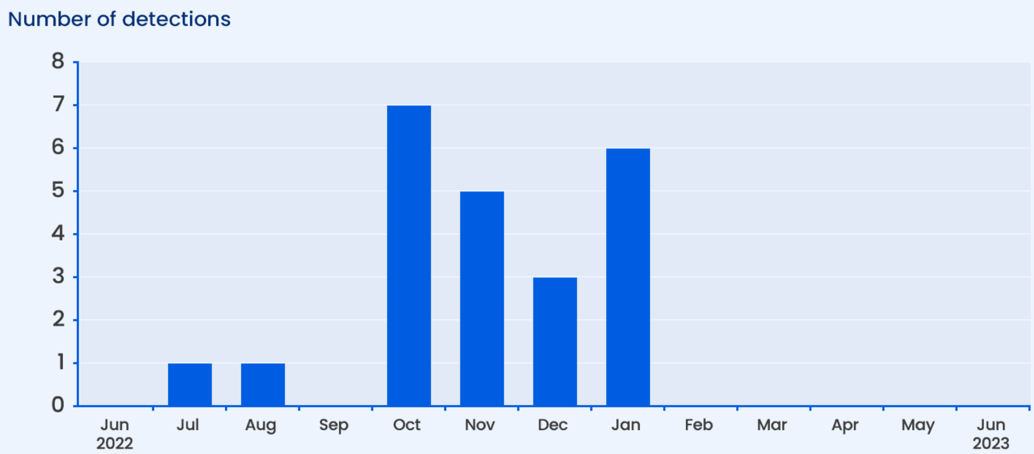
Box 4: Seasonal variability of gas lift systems methane emissions

The satellite-detected plumes revealed a unique pattern with methane emissions attributed to the gas lift system. The plumes increased from just two detections in summer (April to September 2022) to 21 detections in winter (October 2022 to February 2023).

After engagement, the operator later confirmed the gas lift pipes as the emissions source and justified the seasonal variability by the followed operational practices. When temperature drops, fluids tend to accumulate in the gas lift pipes, requiring the operator occasionally to open the dump valves to release this fluid accumulation to avoid disruption in the gas flow.

Whilst these emissions continue as of now, the operator is considering installing a heat exchanger to prevent the need for gas venting at the asset. This case illustrates how observed emissions can be used to complement the knowledge of the operational conditions to initiate and / or support proactive mitigation actions.

Methane emissions attributed to the gas lift system for one of the six assets monitored



SATELLITE MONITORING CAMPAIGN 2022-2023

Kazakhstan findings

Summary of observed emissions in Kazakhstan for the six assets monitored

34% of the observations are with positive detection

Gathering pipelines are the main emissions source (29% of the detected plumes)

910 kgCH4/h
Average emissions rate

The yearlong campaign in Kazakhstan led to 157 high-resolution satellite observations. 34% of the observations resulted in detections of observable emissions clustered over three of the six areas monitored, with emissions ranging from 100 to 4,700 kg CH_4/h. Methane emissions in the monitored areas were attributed to seven distinct types of emissions sources (Figure 3): gathering pipelines accounted for 29% of the total count of detected plumes, and 12% of the total emission rate. Emissions linked to gas pipelines can result from operational vents or leaks. Gas pipelines are found in both gas and oil fields to transport and gather both associated and non-associated gas.

Operators in Kazakhstan conducted extensive review of data provided and were able to mitigate two persistent emission sources detected through the campaign. The operators also welcomed the satellite data to improve their understanding of their methane emissions, while highlighting that the lack of specialized equipment and tools impacted their ability to build a reliable methane inventory. On one of the monitored sites, the majority of detections were attributed to oil heaters across the oil field used to improve the transportability of oil with high viscosity. By verifying the infrastructure in some of the detection locations and estimating the amount of gas directed to the oil heaters, the operator and the team managed to identify the oil heaters as the source for 12% of the detections. The operator is further exploring two possible mitigation options for the source including improving the heater efficiency and gas quality.

SATELLITE MONITORING CAMPAIGN 2022-2023

Egypt findings

Summary of observed emissions in Egypt for the six assets monitored

22% of the observations are with positive detection

Storage tank venting is the main emissions source (88% of the detected plumes)

770 kg/h
Average emissions rate

The yearlong campaign in Egypt led to 184 high resolution satellite observations. 22% of the observations resulted in detections of observable emissions, clustered over three of the six areas monitored, with emissions ranging from 140 to 2,300 kg CH_4/h. Observable emissions were highly concentrated in Egypt and attributed to three different types of emissions sources: storage tank venting, incomplete combustion from burning pits, and well site emissions (Figure 2). Storage tank venting accounted for 88% of the total count of detected plumes, and 80% of the total emission rate. The operators were able to confirm the persistent sources detected in Egypt.

On one of the monitored sites, the operators confirmed they were aware of the emissions from storage tank venting, and had previously performed an onsite measurement campaign to help identify and quantify the emissions. The operator indicated their interest in performing a detailed study to assess how to eliminate these emissions sources, including both technical and financial feasibility, and engagement with the operator is ongoing to explore next steps.

Box 5: Egypt - Storage tank venting

At one site in Egypt, 30 plumes were detected and attributed to storage tank venting. Between one and five plumes were detected per month of monitoring, with an average annual emission rate of almost 500 kg CH_4/h. [9] Satellite imagery shows large, persistent emissions from the source.

One of the mitigation options that can apply for storage tank venting is a vapor recovery unit (VRU). VRUs can help recover the vented gas and direct it to onsite use or sales. The abatement cost for a VRU is very variable and will depend on a number of factors, including the gas throughput, the discharge pressure required, the liquid content of the gas and the piping requirement. Assuming a capital expenditure ranging from USD 4–8 million, [10] installing a VRU for this site would result in an abatement cost of USD 20–90 t CH_4 [11]). If implemented, the VRU would have a payback period of about five years and recover approximately 20 million m^3/y of natural gas that would otherwise be emitted. The recovered gas is sufficient to supply the annual natural gas needs of 36,000 Egyptians. [12]

FOOTNOTES

[9] The average annual emission rate calculation methodology is explained in the annex. Note that emissions below the detection threshold were not accounted in the analysis.

[10] It is recommended that the operator perform a pre-feasibility study.

[11] High uncertainty is associated with the capital expenditure and annual operating expenditure. Calculations were performed assuming an average methane content of tank vapor of approximately 25%, and conservative estimates that 50–75% of LNG is recovered at a value of USD 4 per MMBtu, and no added value of recovered natural gas. The calculation inputs were annual operational expenditure equals 10% of capital expenditure, 5% discount rate, 5 years lifespan, and 95% VRU recovery efficiency.

[12] Assuming a per capita consumption of 555 m^3 of natural gas per year in Egypt (Statista 2022 & World Bank 2021)

SATELLITE MONITORING CAMPAIGN 2022-2023

Key learnings and recommendations for the oil and gas industry

Learning 1: Major oil and gas companies have had and still play a pivotal role in supporting national oil companies and joint ventures with limited resources to eliminate methane emissions.

Many major oil and gas companies have substantial experience in mitigating methane emissions. They are well-connected in the oil and gas sector at the global and national level, and have experience developing methane reporting and mitigation programs. As such, they are in a good position to help to accelerate the oil and gas industry's action to eliminate methane emissions and help NOCs and joint ventures shorten the time from setting ambitions to methane mitigation action.

Through both the 2021-22 and the 2022-2023 satellite monitoring campaign, OGCI member companies showcased this role. OGCI member companies helped initiate discussions and raise the interest of local operators. All joint ventures and NOCs engaged welcomed the satellite data and technical evaluation / capacity building. Engagement continues with the operators on a regular basis, to offer technical support, share experience and build capacity.

Learning 2: Engagement and mitigation need to be geography and asset operator specific.

The oil and gas industry is intrinsically diverse. Each country monitored has unique oil and gas operations, cultures, regulatory frameworks and historical practices, which evolved into today's context. Despite sharing similar climatic conditions and close geographical locations, the 12 sites monitored over Algeria and Egypt showed radically different emission profiles.

This is testament to the uniqueness of the oil and gas sector, where results cannot be extrapolated across assets or countries, and operators are instrumental in understanding and reducing emissions on each individual site. As such, asset-level inventories, combined with satellite and on-site measurements, are key steps towards gaining a better understanding of methane emissions and taking mitigation measures.

Learning 3: It is imperative to integrate monitoring technology harmoniously.

Satellite technology has proven its effectiveness and reliability in detecting large sources of emissions, with 15 persistent sources confirmed on the ground by the operators. It also demonstrated its limits, notably challenges attributing certain plumes to specific sources of emissions on sites with a complex network of oil/gas infrastructure. This highlights the need to combine satellite detection with other “near-source” or site-based technologies in some cases.

For illustration, as part of the campaign, one operator confirmed this challenge and was unable to attribute some of the satellite detections to a specific type of emission source using the supplied coordinates.

This case illustrates the need for reconciliation of remote sensing data with on-ground measurements, such as infrared cameras or other on-site methane detection approaches to complement such a satellite monitoring program.

Learning 4: Trust serves as the fundamental driver for effective collaboration.

It is crucial to establish a relationship based on trust and peer-to-peer engagement to invite openness among NOCs and joint ventures, enable deep collaboration, and prevent the misconception that campaigns such as the present Satellite Monitoring Campaign are intended to ‘name and shame’.

All joint ventures and NOCs engaged as part of the 2022-2023 satellite monitoring campaign welcomed the satellite data and technical evaluation / capacity building. The confidentiality provided throughout the campaign helped to establish a collaborative and dynamic engagement.

Learning 5: Human resources pose a constraining element.

Resources are mobilized by operators for the primary purpose of producing oil and gas safely and responsibly. Often, environmental and climate topics are within the accountability of health and safety personnel, who may struggle to prioritize action on GHG emissions, including methane emissions reduction.

Throughout the engagement with local operators, OGCI shared the principles and ambition of the ‘Aiming for Zero Methane Emissions Initiative, establishing an approach that treats methane emissions as seriously as the oil and gas industry already treats safety: aiming for zero and striving to do what is needed to get there. 90+ CEOs from major oil and gas companies, service provider, NGOs, consulting have joined the Initiative to date, driving their respective company cultures and resources allocation. A number of NOCs and joint ventures are now considering joining the Initiative.

Recommendation 1: Broaden the program to more countries and operators.

All NOCs and joint ventures engaged as part of the 2022-2023 satellite monitoring campaign welcomed the data and found it valuable in taking immediate actions to shape short and long term decarbonization strategies. There were several requests for additional data and continued monitoring.

OGCI is working towards expanding the Satellite Monitoring Campaign over additional countries to continue to support and guide other O&G operators to mitigate methane emissions and complement their decarbonization plans.

Recommendation 2: Supplement satellite monitoring efforts with on-site monitoring and complementary initiatives.

Satellite data plays an important role in methane emissions detection but in some cases is limited in its' ability to detect smaller sources (e.g. <100kg/hr). As such, satellite monitoring efforts should be complemented with LDAR, site-level monitoring and asset specific root cause analysis of methane emissions sources to achieve greater mitigation.

The campaign demonstrated that some operators lack the suitable methane detection equipment to correlate the satellite data with on-site verification. Emerging initiatives that offer on-site measurements and additional data and insights can play a pivotal role in bridging this data gap and alleviating the operational challenges faced by operators. Such initiatives also lay the groundwork for operators to embrace and plan periodic LDAR campaigns.

Recommendation 3: Broaden the program to more countries and operators.

The success of the initiative hinged on open, transparent and equal knowledge sharing between onsite experts, methane emissions experts, with technical and strategic discussions conducted at various levels of the organizations. Methane expertise and site knowledge combined in collaborative ways empowered the operator to effectively leverage satellite data towards methane mitigation. Additionally, learnings should be shared with the rest of the industry, to ensure all part of the natural gas value chains and other sectors of the economy benefit from it. It should be noted that public satellite data reviewed by GHGSat showcased additional methane super-emitters attributed to mining, waste management, and agriculture activities. Sharing the lessons learned and developing specific satellite monitoring initiatives across methane-emitting sectors can significantly contribute toward meeting international methane targets.

SATELLITE MONITORING CAMPAIGN 2022-2023

Conclusions and next steps

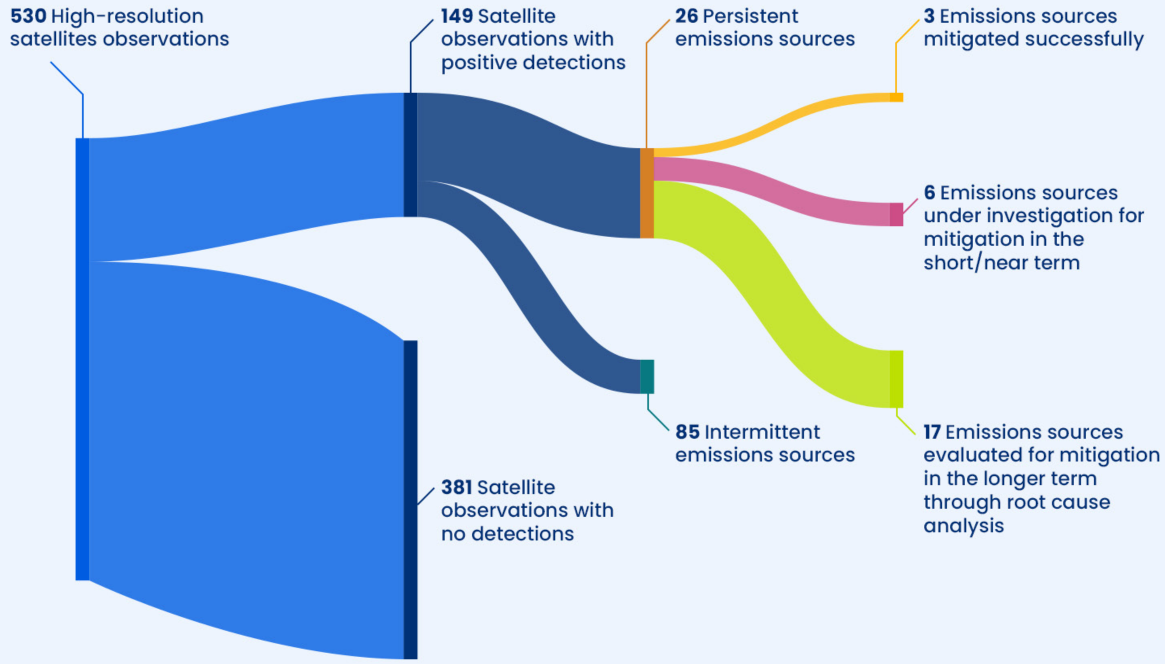
Since the 2021 pilot, the campaign has proven to be a welcome catalyst for mitigating methane emissions among NOCs and joint-venture operators. OGCI is extending the campaign over additional countries, and provide additional site level, detailed root analysis on identified methane emissions sources, to continue supporting and guiding other oil and gas operators to mitigate their methane emissions and complement their asset decarbonization plans.

Satellite technologies and long-term established relations with the operators can unlock large opportunities for collaboration to reduce methane emissions from the oil and gas sector. By focusing on operators early in their journey to mitigate methane emissions, the next phase will grant them access to the established knowledge of OGCI member companies and to a wide umbrella of options that can support their willingness to cut methane emissions.

Appendices

Appendix A: Summary of satellite observations, detections and sources in the monitored areas of interest

Summary of satellite observations, detections and sources in the monitored areas of interest



Appendix B: Glossary

Terminology	Definitions
Asset	Part of the oil and gas system, owned by an oil and / or natural gas company, comprising multiple devices that allow the company to produce, process, transport, store, and/or distribute gas.
Abatement Cost	The sum of the cost of the satellite monitoring services and the implementation cost of the mitigation option for an emissions source divided by the annual emission reduction achieved.
Annual average emissions rate	Emissions rates average of all the observations, with or without positive detections, from a specific emissions source. Please refer to **Appendix D** "Process & Methodology" for more details.
Average emissions rate	Emissions rates average of ONLY observations with positive detections, from a specific emissions source.
Detection threshold	The minimum quantity or concentration of a gas (e.g. methane) which is reliably detectable by detection equipment. This is sometimes called a minimum detection limit (MDL).
Emissions Source	A component within a process or equipment that releases methane to the atmosphere either intentionally or unintentionally, intermittently or persistently.
Gas field	A group of assets designated for the production of natural gas, as the main product.
Intermittent (emissions source)	A source is defined as intermittent in case (1) GHGSat detected one or two emissions at the same location or (2) the attributed emissions source occurrence is limited (e.g well testing).
Persistent (emissions source)	A source is defined as persistent in case it fulfills the following criteria: (1) GHGSat detected three emissions at the same location and (2) the attributed emissions source presents a repetitive emitting pattern (e.g flaring).
Plumes	A plume is a volume of gas emitted, vented, or leaked to the atmosphere.
Observable emissions	Theoretical total of Emissions with an emissions rate higher than the minimum detectable threshold of satellite technology.
Oil field	A group of assets designated for the production of oil as the main product.
Operator	Company in charge of day-to-day operations and long-term maintenance of the asset.
High-resolution observation	Satellite observation with suitable conditions for methane detections, including but not limited to meteorological conditions (e.g no clouds cover).
Super emitter	Methane emission source that represents a disproportionate amount of the total methane emissions released from all sources.
Venting	Operational release of gas into the atmosphere.

Appendix C: Types of emissions sources

Table 3: Most probable emissions sources attributed through the analysis of methane detections and engagement with the operators.

Attributed source	Scope	Applicability
Equipment Venting	Attributed to detections located near oil and gas equipment, oil and gas separator, gas processing train, gathering unit, etc.	Oil and gas fields
Equipment leaks	Attributed to detections located near oil and gas equipment, oil and gas separator, gas processing train, gathering unit, etc. Characterized by high frequency of detection in a short period of time. Leaks are confirmed through engaging with the operator.	Oil and gas fields
Flaring system	Attributed to detections located near elevated flare infrastructure, typically used for waste gas combustion.	Oil and gas fields
Gas lift system vent	Attributed to detections located near associated gas pipes near oil well sites used for gas lift. The use of a gas lift system is confirmed by the operator, or otherwise considered as gathering pipelines.	Oil fields
Gathering pipelines	Attributed to pipelines across the oil and gas fields, to collect and transport produced gas mainly in areas far from the central asset, near well sites, and gathering units.	Oil and gas fields
Incomplete combustion from a burning pit	Attributed to detections located near a burning pit or a ground flare, typically used for the combustion of waste gas or liquid hydrocarbons. In this case there is no indication of elevated flare structure, and it is hard to distinguish, based on simple satellite imagery, the existence of ground flare.	Oil and gas fields
Liquids unloading	Attributed to detections located near gas well sites only. It refers to the process of removing liquids accumulated in the well tubing.	Gas fields
Oil heater at well site	Successful engagement with the operator helped attribute detections located near oil well sites to oil heaters. Oil heaters are used to facilitate the transportation of oil with high viscosity.	Oil fields
Tank venting	Attributed to detections located within a radius of 50 meters from a tank farm.	Oil fields
Unidentified	The detections were in remote locations with no oil and gas infrastructure nearby.	Oil and gas fields

Table 4: Number of persistent emissions sources by type, detected in the monitored area

Emissions Source Type	Number of persistent emissions sources
Incomplete combustion from burning pit	7
Equipment venting	4
Gas lift system vent	3
Vents from liquid unloading	3
Equipment Leaks	2
Flaring system	2
Gathering pipelines emissions	2
Tank venting	2
Oil heater at well site	1
Total	**26**

Appendix D: Process & methodology

The key steps in the process include site selection for monitoring with high-resolution satellites, engagement with the operators and initial capacity building, and finally, technical support to investigate the source of the emissions and support for assessment of mitigation actions.

The selection of fields of interest for the Monitoring Campaign used the criteria and process below:

- A list of oil and gas fields was compiled using available information on past satellite methane observations in each country from public satellites, as well as flaring data activity from FlareIntel and the World Bank Global Flaring Data as a proxy for methane emissions.
- Field-specific details were then added to the list, using various sources, such as, Energy Information Administration (EIA), Enverus, etc, which provide information on age of infrastructure, gas/oil ratios, total oil and gas production, expansion plans, operators, etc.
- The results of the preliminary evaluation were used to select a sample of assets from both OGCI member companies and non-members for monitoring. The key selection criteria for prioritization included assets with large production volumes, higher gas/oil ratio, presence of flares and previously detected methane emissions, age of the infrastructure, etc.

The overall focus in selection of assets was on facilities that are more likely to have methane emissions, in order to be able to identify the significant emission sources and take action to achieve rapid mitigation. Thus, the sample is biased towards facilities with higher likelihood of emissions.

Upon selection of the six areas of interest per country, the operators' contact information was compiled for first engagement to test their interest in receiving actionable data on methane emissions. This proved to be a challenging process for certain assets, where the OGCI member companies, GHGSat and Carbon Limits had no previously established network.

Annual average emissions' computing method for a site:

When a facility is monitored by the GHGSat constellation over a period of time consisting of N clear observations, we are interested in estimating the annual average emission rate for the facility based on these results. We consider the case where at least one of the observations contains a positively detected and quantified plume. There are two key elements of the method:

1. The rates in the average include null events (where no plume is detected, and therefore the estimated emission rate is zero). This is important – for the common case of intermittent emitters, the results differ substantially from the simple approach of averaging all quantified non-zero rates.
2. We use Bayes' rule to correct for the effect of finite sample size. This requires a sector-specific prior persistence distribution, which is determined by empirically compiling data from the GHGSat constellation archive. This approach assumes that each emitter is governed by binomial statistics (for any given observation, there is a probability p of a detectable emission). The correction is most impactful for cases with very few observations, and makes only a minor difference for the case of large *N*.

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