CARBON LIMITS

GHGSAT

Perspectives on Methane Super-Emitters: Determining Emission Sources using Satellite Detections



According to the 2023 IEA Methane Tracker, "satellites detected around three Mt [megatons] of methane from very large leaks from oil and gas operations in 2022". Recent work has focused on identifying and quantifying methane super-emitters (e.g., large, unintentional leaks or intentional vents) from the oil and gas sector.[i,ii] However, even though methane hot spots seen from space have become regular topics in international news articles, a systematic analysis of the sources that cause them and the total costs related to their abatement are still missing.

In this review – supported by the McCall MacBain Foundation – of thousands of methane super-emitting points based on **GHGSat satellite detections** from 2021 and 2022[iii], **over 1 $MtCH_4/y$ were analysed and attributed** to oil and gas emission sources across 27 countries in 5 regions. This white paper does not present a complete inventory of methane super-emitters in this sector but provides an in-depth analysis of the emission sources, which relies on source attribution, annualized emission rates, cause analysis, and mitigation options. The analysis is limited both by what the satellites have targeted (only specific areas or facilities are covered) and what they are able to detect (due to geographical or technological limitations). Details on the methodology are presented in a separate document.[iv]

The role of satellite data to detect methane super-emitters

To determine methane super-emitting sources, GHGSat detections of the oil and gas sector over 2021 and 2022 was compared with satellite imagery and oil and gas infrastructure databases[v] in a desktop analysis to determine the most likely source of emissions. Both plume observations and observations without detections were used to determine an average annual emission rate at the emission source level. Analyzed emission sources had between one and 85 detections, with persistencies between 0.6% and 93.3%. See the methodology paper for more information.[iv]

Globally, **1,014 $ktCH_4/y$** were observed and analysed, corresponding to over **6.7 million passenger vehicles** used on roads every year. However, improved modern satellite capabilities and increased coverage has demonstrated that this number represents **a lower bound on the actual extent of super-emitters**. This is exemplified by the 2.3x increase in emission rates that GHGSat observed from 2022 to 2023 after launching six new satellites.[vi] Four more satellites are expected to be added to GHGSat's constellation in coming years, which will likely lead to further additional observations.

Which methane super-emitting sources are the most common in the oil and gas sector?

Super-emitting sources in the oil and gas sector occur due to a variety of reasons. Figure 1 presents the contribution of methane emissions from flares, pipelines/gathering lines, equipment leaks or vents, storage tanks, and emissions at the wellhead.

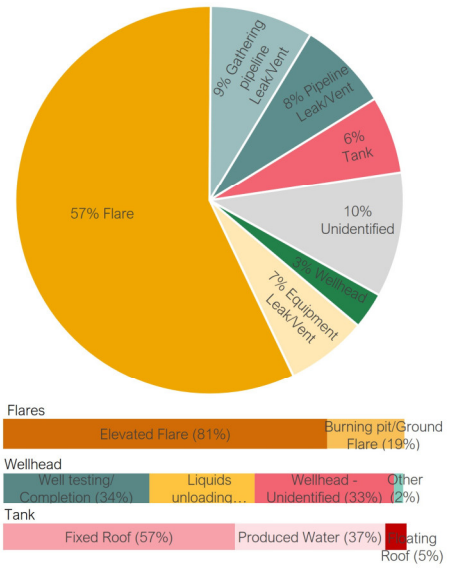

Figure 1 Relative annual emission rates of super-emitting emission sources in the oil and gas sector.

The following sections address four main emission sources in more detail, including cause analysis and the potential for mitigation.

1. Flares

Globally, 285 flares were identified and analysed and represented just over half (57%) of annual emissions from all super-emitting events. Many of the flares had an average annual emission rate <1 kt/year, yet twelve had annual average emission rates >5 ktCH$_4$/yr, and two had rates of >100 kt/year (12 tCH$_4$/hour) (Figure 2).

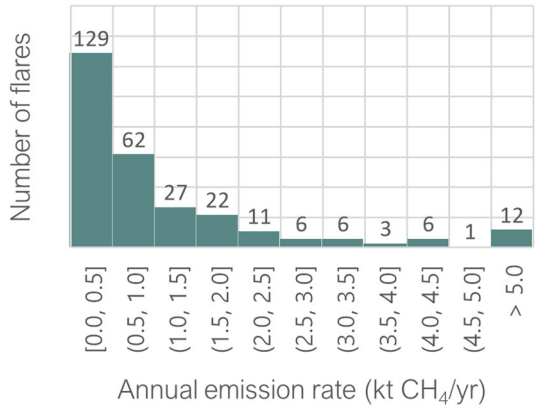

Figure 2 Histogram of annual emission rates of flares

Elevated flares represented 52% of flares, while 48% were burn pits or ground flares. To determine root causes of emissions, Visible Infrared Imaging Radiometer Suite (VIIRS) flaring data[vii] for the years 2021 and 2022 were used to corroborate potential behaviours of these flares, which include the following:

- Burn pits or ground flares with observed flaring[viii]
- Burn pits or ground flares with no observed flaring
- Elevated flares with observed flaring[ix]
- Elevated flares without flaring observations[x]

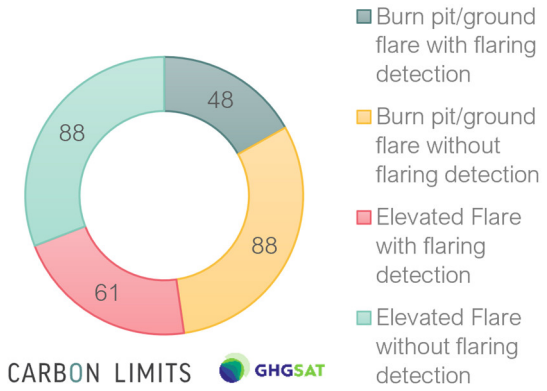

Figure 3 Number of burning/dump pits and elevated flares as sources of super-emitters, with and without flaring detections.

Of the 285 flares, 17% were burning or dump pits with observed flaring, while 31% did not have observed flaring. Similarly, 21% were elevated flares with observed flaring (lit, but malfunctioning flares with periods of high inefficiency or unlit periods), and 31% were elevated flares without flaring observations (unlit flares) (Figure 3).

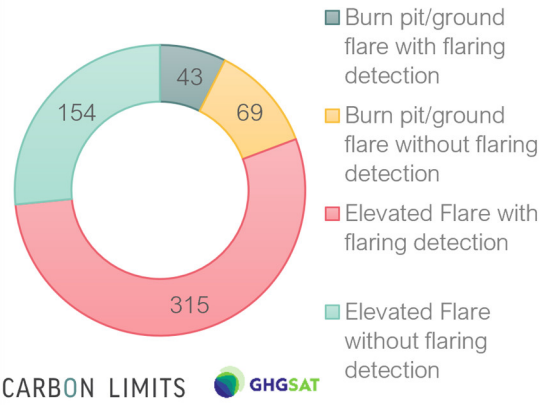

Figure 4 Annual emission rates (in ktCH$_4$/y) from elevated flares and burning or dump pits with and without observed flaring observations

Burning or dump pits with observed flaring were responsible for 43 ktCH$_4$/y (7%), and 69 ktCH$_4$/y (12%) came from burning or dump pits without flaring detections. Elevated flares with observed flaring were responsible for 315 ktCH$_4$/y (54%), and unlit

flares were responsible for 154 $ktCH_4/y$ (27%) (Figure 4).

To reduce emissions from flares, flares must be a) lit, to avoid unlit periods, and b) operating correctly when they are lit, at a high combustion efficiency such that a super-emitting event will not occur.[xi] However, the best solution is to reduce flare volumes, either by operational changes, effective regulation, or alternative gas utilization pathways. There are mature and emerging flare utilization technologies for small-medium scale flares that can be considered as economical abatement options.[xii]

The World Bank's Zero Routine Flaring by 2030[xiii] initiative is an important step towards reducing flare volumes, both through the elimination of flaring at existing oil fields and requiring gas utilization pathways in place of flaring at new oil fields.

2. Gathering and Transportation Pipelines

Upstream gathering and production site gas transportation pipelines accounted for 17% of total emissions from analysed super-emitting sources. These pipelines are responsible for transporting natural gas from well sites to processing facilities and beyond to distribution networks. Due to their large geographical coverage, they are often in remote areas and represent a unique challenge to maintain and monitor. Regular maintenance and inspection may be infrequent, such that emissions are less likely to be detected and fixed. Causes of emissions may be leaks due to structural integrity failures or damage from external factors, or the result of unrecognized emissions from planned maintenance or venting. Pipeline and Hazardous Materials Safety Administration (PHMSA) incident report data indicate that "malfunction of control/relief equipment," including control valves, relief valves, pressure regulators, and emergency shutdown device system failures, was the cause of 30% of incidents and 21% of unintentional gas emissions from gas transmission pipelines between 2010 and 2021.[xiv]

Regular monitoring and timely repairs, especially in remote areas, are crucial to minimizing methane emissions and ensuring the safe and efficient operation of pipeline infrastructure. Implementing stringent monitoring ensures the structural integrity of pipelines, thereby reducing the likelihood of major leak events.

3. Storage Tanks

Emissions from storage tanks accounted for 6% of the total emissions from super-emitting sources in the oil and gas sector. These tanks are used to store crude oil, natural gas liquids or condensates, other petroleum products or produced water across the oil and gas value chain. Despite representing a smaller proportion of the overall emissions identified in this survey, storage tanks had a high probability of emitting methane (Table 1) due to various operational and structural factors. Emissions were observed from both fixed and floating roof tanks.

Storage tanks often feature large surface areas with multiple potential points for methane release, including vents, thief hatches, seals, and connections. Emissions from these tanks can occur due to pressure changes, temperature fluctuations, or operational activities such as filling and emptying cycles. The intermittent nature of these emissions poses a challenge for detection and quantification, as they may not be constant and can vary significantly based on operational conditions and maintenance practices.

To effectively mitigate emissions from storage tanks, implementing emission control technologies, such as vapor recovery units (VRUs), or designing greenfield storage tanks with floating roofs or stabilization towers, can significantly reduce methane emissions by capturing and recycling methane that would otherwise be emitted to the atmosphere or reducing vapour release in the first place.

A subset of storage tank emission sources is produced water pits, which resemble containment ponds for the disposal of waste liquids, including off-spec crude oil and other components. Improved, two- or three-phase separation and stabilization, or vapour recovery prior to disposal could significantly mitigate methane emissions. These practices require proper maintenance and repair.

4. Unidentified Sources

A non-negligible number of sources were still not identifiable via desktop analysis. This highlights the importance of operator input, since effective mitigation requires on-the-ground knowledge. It is important to be able to identify emission sources, but the information must be in the hands of those with the ability to do something about it, including the capability to combine satellite measurements with other technologies to further detect, locate and ultimately mitigate. An example of successful direct engagement with operators and rapidly achieved mitigation action is the OGCI-led Satellite Monitoring Campaign[xv] (in cooperation with GHGSat and Carbon Limits).

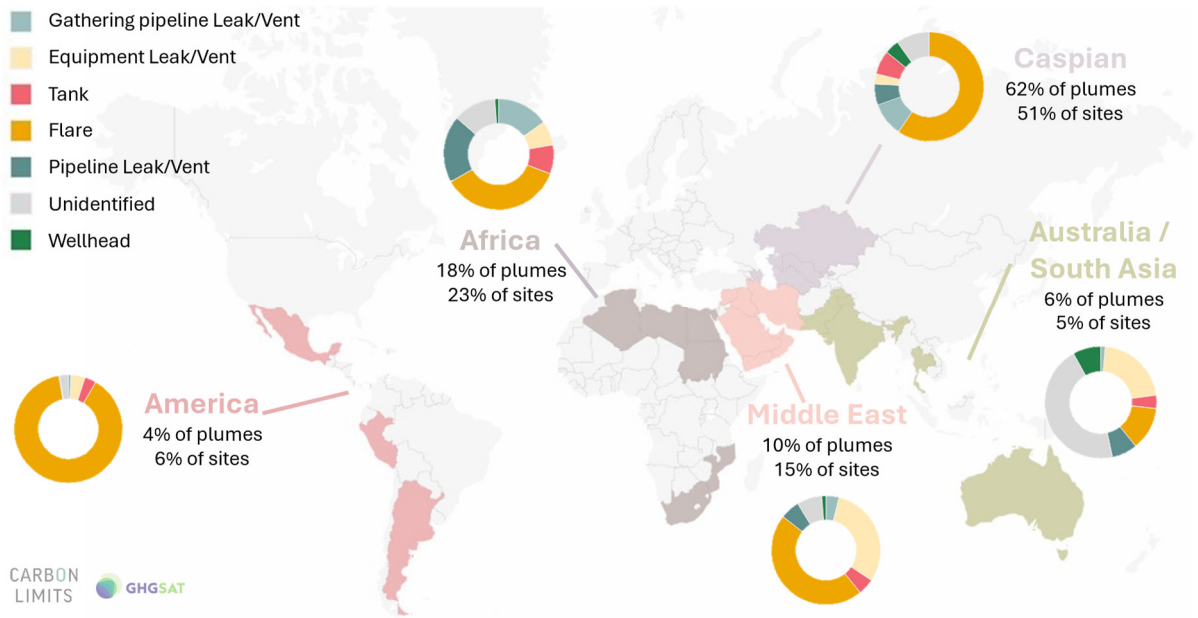

Figure 5. Global map of super-emitters by region. Countries are coloured based on their associated region. Countries in light grey are not covered by the study.

Geography of methane super-emitters in the oil and gas sector

Methane super-emitters were observed and analysed in 27 countries across 5 regions (other regions were not included in the analysis). It is important to note that emission profiles varied from region to region (Figure 5). For example, flares were the main

emission source in most regions but not in Australia and South Asia, where equipment leaks and vents were more common but also where nearly half of the emissions could not be identified. However, the point is not to provide a comparison between regions (since the analysis only included targeted sites), but rather to highlight **the diversity of regions and the global issue of methane super-emitters**. The difference across regions illustrates that applying a blanket approach to addressing super-emitters may not be the solution. Emission reduction strategies should be designed and implemented on a case-by-case basis.

It is important for regulators to understand emission sources to develop effective regulation. Timely access to high quality, source-resolved emissions data can also be used to identify emission sources that may need to be more strictly regulated or to track existing regulatory compliance. For example, the new European Methane Regulation plans to set-up "a super-emitting event rapid alert mechanism" based on satellite data,[xvi] while UNEP's International Methane Emissions Observatory launched the Methane Alert and Response System (MARS) program in 2023, which provides a global satellite detection and notification system for super-emitters globally.

What does the persistency tell us about the sources?

The persistency represents the probability of an emission source emitting methane. Table 1 presents the average persistency of all emission sources within an emission source category.

Table 1 Persistency of Emission Sources

	Average emission rate per source ($kgCH_4/hr$)	Average persistency per source (2.75, 97.5th percentiles)
Flare	233	10.1% (0.79%, 48.8%)
Tank	149	13.0% (1.59%, 49.9%)
Pipeline Leak/Vent	74.2	7.27% (0.59%, 34.1%)
Equipment Leak/Vent	70.0	8.63% (0.69%, 41.3%)
Gathering pipeline Leak/Vent	68.1	6.53% (0.72%, 27.8%)
Wellhead	47.9	5.00% (0.78%, 16.3%)
Unidentified	66.4	4.45% (0.59%, 16.0%)

Tanks had the highest probability of emitting (13.0%), but at a relatively smaller rate than flares, which on average emitted 10.1% of the time. This means that super-emitting events from flares are usually less frequent than from tanks, but when they do occur, they emit significantly higher emissions. Emissions from gathering pipelines (6.53%), pipelines (7.27%) and wellheads (5.00%) were even less frequent, which suggests emissions from these sources are highly episodic, rather than occurring continuously.

Of course, there are limitations to these assumptions, including, but not limited to, the frequency of satellite observations of individual sites and emissions that were occurring but were below the detection threshold of the satellite. Please refer to the methodology paper for further details.

This white paper demonstrates that with high quality satellite data, it is possible to analyse emission sources of super-emitters around the world. It also provides potential mitigation solutions to address them. A subsequent white paper can be found that estimates the costs to address these emissions.[xvii]

[i] Irakulis-Loitxate I., Guanter L., Maasakkers J.D., Daniel Zavala-Araiza D., & Aben L. (2022). Environmental Science & Technology 56:4, p. 2143-2152. https://doi.org/10.1021/acs.est.1c04873

[iii] Cusworth, Daniel H., et al. "Strong Methane Point Sources Contribute a Disproportionate Fraction of Total Emissions across Multiple Basins in the United States." Proceedings of the National Academy of Sciences, vol. 119, no. 38, 2022, https://doi.org/10.1073/pnas.2202338119

[iii] GHGSat. Greenhouse Gas Emissions Monitoring Service - GHGSat. https://www.ghgsat.com/en/.

[iviv] Carbon Limits (2024). *Translating Satellite Data into Abatement: A Technical Explanation for Satellite Insights on Global Methane Super Emitters*.

[v] Omara, M., Gautam, R., O'Brien, M., Himmelberger, A., Franco, A., Meisenhelder, K., Hauser, G., Lyon, D., Chulakadaba, A., Miller, C., Franklin, J., Wofsy, S., & Hamburg, S.: Developing a spatially explicit global oil and gas infrastructure database for characterizing methane emission sources at high resolution, Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2022-452, 2023.

[vi] GHGSat. 2023 Methane Emissions Report. https://www.ghgsat.com/upload/pages/GHGSat-2023-Annual-Emissions-Report_FINAL.pdf

[vii] Elvidge, C.D.; Zhizhin, M.; Baugh, K.; Hsu, F.-C. & Ghosh, T. (2016). Methods for Global Survey of Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data. Energies 2016, 9, 14. https://doi.org/10.3390/en9010014

[viii] Burn or dump pits include waste liquid or gaseous hydrocarbons which are routed to a containment area for disposal, which may or may not include an ignition source. The disposal process can cause significant release of methane-rich gases.

[ix] Unlit flares: Basic infrastructure is there but they are not operating as designed or are intentionally unlit. Often remote sites where personnel may not constantly be active, liquids unloading events where gas routes to stack that may not be lit during these operations, or unlit flare that is not closely

[x] Malfunctioning flares: the infrastructure is there but they are not operating as designed with periods of highly inefficient flaring or unlit periods. Investment in improved equipment and monitoring and awareness of site personnel are key areas to improve flaring.

[xi] Tools like the Methane Flaring Toolkit provide in-depth, useful information on assessing, measuring and monitoring flares.

[xii] For example, a Carbon Limits study for the World Bank on small scale flare utilization technologies.

[xiii] World Bank. Zero Routine Flaring by 2030. https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030

[xiv] Pipeline Safety: Gas Pipeline Leak Detection and Repair. Department of Transportation. 2023. https://www.federalregister.gov/documents/2023/05/18/2023-09918/pipeline-safety-gas-pipeline-leak-detection-and-repair

[xv] OGCI. Satellite Monitoring Campaign (SMC). https://www.ogci.com/methane-emissions/satellite-monitoring-campaign

[xvi] European Commission. New EU Methane Regulation to reduce harmful emissions from fossil fuels in Europe and abroad. https://energy.ec.europa.eu/news/new-eu-methane-regulation-reduce-harmful-emissions-fossil-fuels-europe-and-abroad-2024-05-27_en

[xvii] Carbon Limits (2024). Low Cost, High Impact: Satellite Insights on Global Methane Super-Emitters.