CARBON LIMITS

GHGSAT

High Opportunity, Low Cost: Optimizing Landfill Operations for Methane Mitigation



The Global Methane Initiative estimates that municipal solid waste is the source of approximately 40 Mt of methane emissions each year.[i] In a review of thousands of methane super-emitting points detected via satellite in 2021 and 2022 within a subset of countries, over 800 points were determined to be originating from 89 landfills and dumpsites. These sites exhibited an average annual emissions rate of 1,300 kg CH_4/hour (39,000 kg CO_2eq/hour) based on satellite detections alone. This value is perhaps conservative considering it only accounts for super-emitting points and not for diffuse emissions emanating from the landfill surface, which are also a significant source of emissions. Over 30% of these emissions originated from 28 sites which appeared to have gas collection (GC) systems installed.[ii] These sites had an even higher average annual emissions rate, at approximately 1,700 kg CH_4/hour (51,000 kg CO_2eq/hour). While there are more than 10,000 landfill and dump sites globally, this small subset of 89 landfill and dump sites collectively emits the equivalent of over 2.7 million passenger vehicles every year. In theory, the financial and operational efforts spent at these landfill sites with installed GC systems prevent super-emitter events, but this is not the case. This paper briefly discusses the cost of mitigating super-emitter sites with or without GC systems.

This analysis – supported by the McCall MacBain Foundation – relied on satellite detections of methane plumes and was thus limited both by what the satellites had targeted (only specific areas or facilities were covered) and what they were able to detect (due to geographical or technological limitations). There are also limitations inherent in the assumptions made on landfill characteristics using satellite imagery. Details on the methodology are presented in a separate document.[iii]

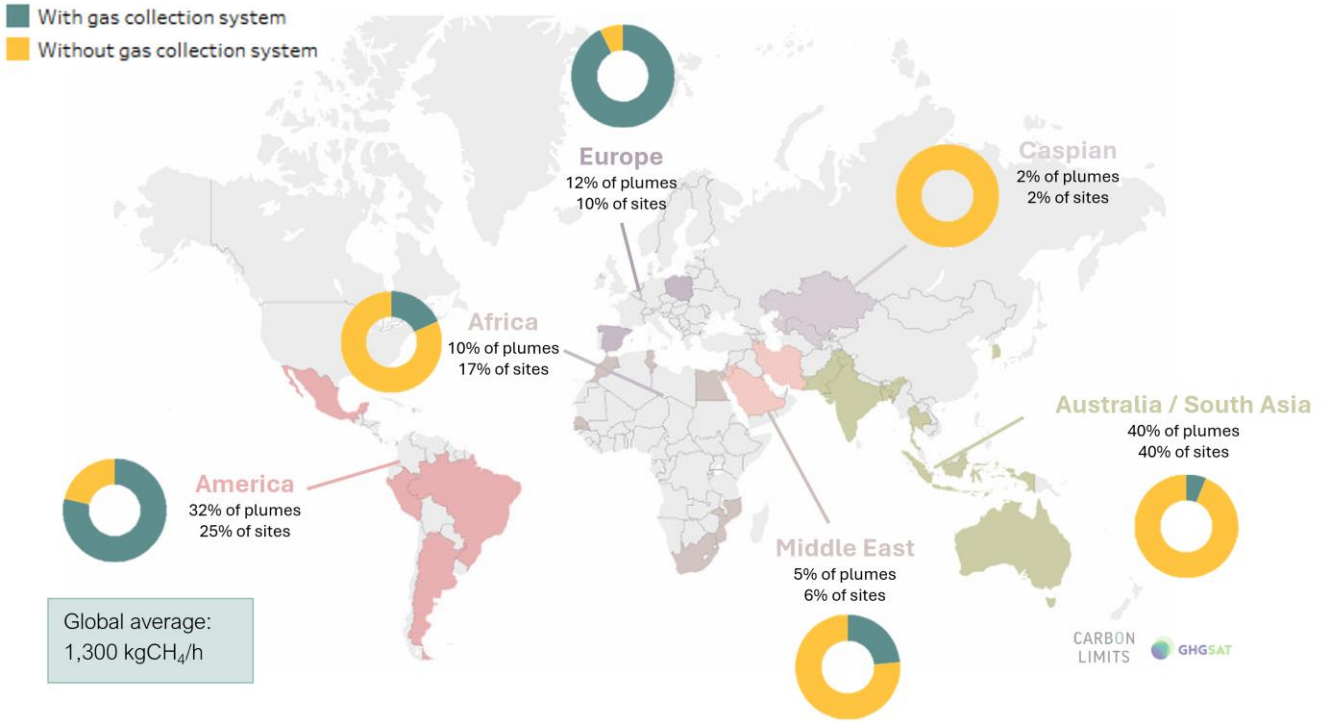

Figure 1 Summary of landfill sites observed via satellite detections. Countries are colored based on their associated region. Countries in light grey were not covered by the study.

For this analysis, satellite data from GHGSat was analyzed for super-emitting landfill facilities in 26 countries across six continents in both developing and developed countries (Figure 1). Considering the limitations of satellite detections, it is safe to assume that the landfill sites observed in this analysis represent only a small fraction of the sector's global methane emissions, yet their wide distribution emphasizes the global reach of this issue.

Landfill methane is generated by organic waste decomposing under anaerobic conditions. This process generates both diffuse emissions and emission hotspots across the landfill surface. Emission rates may be affected by environmental factors such as pressure and temperature, but this is not currently very well defined and is the topic of ongoing research.[iv,v] A common emission reduction technique is to install GC systems in closed landfill piles, which collect gas from within the pile and route it to a facility to either produce electricity for onsite or offsite use or be flared. The US EPA assumes that a GC system is 65% efficient on landfills with temporary cover and 90% efficient on landfills with a geomembrane final cover.[vi] However, a landfill with an installed GC system still has the potential to cause a super-emitting event if the system is not properly operated and monitored. A GC system that does not perform as intended will fail to prevent atmospheric emissions and can, instead, create a pathway for gases to easily escape. Such is likely the case for 28 of the sites observed in this satellite data analysis, where there were significant emissions despite apparent investments in onsite gas collection infrastructure.

There is a possibility that GC systems observed in this analysis were not functioning effectively, as evidenced by these excessive emissions. According to interviews performed with several landfill experts, this can happen due to various reasons:

- GC systems often require consistent and precise maintenance,
- Monitoring plans are typically not stringent enough to maintain optimal system performance
- Some systems may not have been optimally designed in the first place.
- GC systems are susceptible to physical damage from heavy landfill machinery or wildlife.
- Leaks, malfunctioning flares, or unlit flares can reduce the system efficiency.
- GC systems cannot be installed at active landfill sites, allowing anaerobic conditions to quickly develop in the absence of adequate surface cover.[vii]

No matter the root cause for a malfunctioning system, ultimately, the investments made to mitigate methane emissions at these sites may have not fully prevented them from continuing to emit large amounts of methane.

A significant obstacle to implementing certain landfill emissions mitigation solutions (i.e. improved consumption habits and waste management practices, such as organics diversion, composting, and anaerobic digestion) is that they require a significant adjustment to existing waste generation, collection, and management practices. In contrast, GC systems that are properly operated and monitored offer a more immediate option for effective landfill methane management. Investing in improved, more accurate, and more frequent operation and monitoring (O&M) of GC systems is essential to achieving emissions reductions, as it can lead to increased system efficiency and earlier detection, identification, and repair of leaks or other issues.

To understand the level of investment that would be required to implement well-managed GC systems at the observed super-emitting landfill sites, the US EPA Landfill Gas Energy Cost tool[viii] was used to estimate capital expenditure (CAPEX) and operational costs (OPEX).[ix] The GC system requirements were estimated using both the

surface area and the annual emission rate of each individual landfill. Labor costs were corrected by region. Figure 2 summarizes this analysis, depicting the number of landfills and average emission rates per region, as well as the estimated abatement costs for sites with and without gas collection systems.

Of the 89 super-emitting landfill sites observed in this analysis, 61 did not have observable existing GC infrastructure. Installing new GC infrastructure at these sites would require approximately $280M (USD) in CAPEX and $200M in OPEX over five years.[x] This would have the potential to abate ~88 Mt CO_2eq (3 Mt CH_4) at an estimated average abatement cost of around $6/t$CO_2$eq. This could achieve emission reductions at a cost much lower than current estimates of the carbon price needed to reach net zero emissions by 2050 and keep global warming within 1.5°C. As an example, the Network for Greening the Financial System projects a carbon price close to $200/t$CO_2$eq (USD in 2010).[xi]

A total of 28 observed super-emitting landfill sites were determined to already have GC infrastructure. Again, the EPA Landfill Gas Energy Cost tool was used, but only to estimate O&M costs. As no site-specific operational data was obtained as part of this study, the O&M cost estimates did not account for existing maintenance costs. This indicates that O&M costs for landfills which are already well-managed may be lower than expected, and vice versa for unmanaged dumpsites. Details of the calculations can be found in the appendix to the Methodology report.

An investment of approximately $160M would be necessary to reduce emissions at these sites by implementing improved O&M practices over five years. This investment has the potential to mitigate roughly two Mt CH_4 (60 Mt CO_2eq) at an average abatement cost of less than $3/t$CO_2$eq.[x,xii] This is equivalent to the annual methane emissions from the coal sector in North America, which would require 2.78 times the investment ($7.05/t$CO_2$eq) to mitigate.[xiii] It is important to highlight that this analysis did not cover all global landfill emissions; it only covered the largest emissions at a limited number of sites and further assumed that with proper O&M, the sites will abate 100% of super-emitting events. This may not be the case particularly since GC systems will not capture emissions from the active face of the landfills. Similarly, additional costs could also be incurred if extra work is necessary to identify root causes of GC issues, address those issues, and perform follow-up monitoring to ensure these issues are successfully addressed.

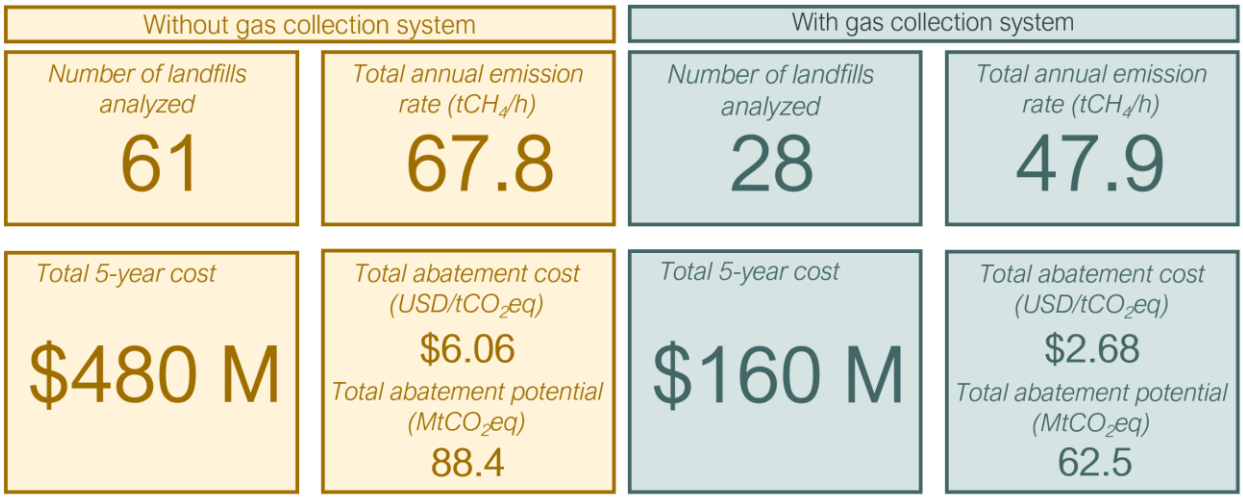

Figure 2 Summary of number of sites, emissions rates, and costs for sites with and without gas collection systems

Voluntary carbon crediting activities based on landfill GC systems might generate high-value credits, which in turn can provide a robust source of project funding. In a review by Calyx Global, a leading independent rating company for voluntary carbon offsets, landfill GC projects exhibited a high GHG integrity rating compared to other carbon crediting project types.[xiv] This is the result of various project attributes including a straightforward emissions measurement process and low associated risks (i.e. of leakage, overlapping claims, and non-permanence). Overall, both the voluntary carbon market and the compliance market (e.g., under Article 6 of the Paris Agreement) offer a promising pathway for reliable financing of landfill gas methane management.

Of course, the issue of addressing landfill methane emissions is more complex than investing in a single solution. Instead, a variety of mitigative solutions, such as improved consumption habits and waste management practices, should be used to address the problem. There is no one-size-fits-all approach to landfill methane mitigation. Sites should be individually and holistically evaluated to determine the most efficient way to achieve emission reductions. Strong, effective financial and regulatory policies and incentives will be a key driving force in implementing these solutions. Nevertheless, to ensure that the capital investments made to install landfill GC systems are worthwhile, it is crucial that there is adequate investment in the proper operation and maintenance of these systems. This could facilitate significant emission reductions at a low abatement cost.[xv]

[i] Global Methane Initiative. (n.d.). *Global Methane Emissions and Mitigation Opportunities* [Fact sheet]. Global Methane Initiative https://www.globalmethane.org/documents/gmi-mitigation-factsheet.pdf

[ii] Presence of gas collection system at sites was assessed using Google Earth aerial imagery to identify recognizable gas collection infrastructure. Additional details are provided in the methodology report.

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

[iv] Delgado, M., López, A., Esteban, A.L., & Lobo, A. (2022). Some findings on the spatial and temporal distribution of methane emissions in landfills. *Journal of Cleaner Production, 362.* https://doi.org/10.1016/j.jclepro.2022.132334

[v] Kissas, K., Ibrom, A., Kjeldsen, P., & Scheutz, C. (2022). Methane emission dynamics from a Danish landfill: The effect of changes in barometric pressure. *Waste Management, 138, 234-242.* https://doi.org/10.1016/j.wasman.2021.11.043

[vi] United States Environmental Protection Agency. (2011, June). *Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Municipal Solid Waste Landfills.* USEPA. https://www.epa.gov/sites/default/files/2015-12/documents/landfills.pdf

[vii] United States Environmental Protection Agency. (2024, April 25). *Basic Information about Landfill Gas.* USEPA. https://www.epa.gov/lmop/basic-information-about-landfill-gas#:~:text=When%20MSW%20is%20first%20deposited,the%20waste%20and%20generate%20methane.

[viii] United States Environmental Protection Agency. (2024, February). *LFGcost – Web – Landfill Gas Energy Cost Model.* USEPA. https://www.epa.gov/lmop/lfgcost-web-landfill-gas-energy-cost-model#:~:text=The%20LFGcost%2DWeb%20model%20is,and%20for%20typical%20landfill%20situations.

[ix] The estimated uncertainty of abatement costs is -30% / +50% based on comparisons between the EPA LFG Cost Tool with publicly available cost data for select landfills. Please see the methodology for more details.

[x] This value is a feasibility-level (±30-50%) estimate based on the US Environmental Protection Agency's Landfill Gas Energy Cost model. The calculation assumes monthly system monitoring events and well maintenance. It does not include costs to identify root causes of emissions or more intensive abatement activities. Due to the US-based cost model, the costs (particularly operational) are subject to vary based on local rates. See methodology report for additional information.

[xi] Network for Greening the Financial System. (2021, June). *NGFS Climate Scenarios for central banks and supervisors.* NGFS. https://www.ngfs.net/sites/default/files/media/2021/08/27/ngfs_climate_scenarios_phase2_june2021.pdf

[xii] NPV calculated over a 5-year period, assuming a 5% discount rate, and that emission profiles remain consistent.

[xiii] International Energy Agency. (2023, March 13). *Methane Tracker*. IEA. https://www.iea.org/data-and-statistics/data-tools/methane-tracker

[xiv] Calyx Global. (2024, March 26). *Wasted Potential: What we've learned after rating 100+ landfill gas projects.* Calyx Global. https://calyxglobal.com/blog-post?q=124

[xv] International Energy Agency. (2020, June 18). *GHG abatement costs for selected measures of the Sustainable Recovery Plan.* IEA. https://www.iea.org/data-and-statistics/charts/ghg-abatement-costs-for-selected-measures-of-the-sustainable-recovery-plan