Landfill methane - measurement and metrics - supplementary report

Waste and Resources research report

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Environment Agency

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Authors: Allen Grant, Beaven Richard, Broomfield Mark, Cowley Polina, Del Vento Sabino, Ingledew Dom, London Joe, Rees-White Tristan, Ricketts Hugo, Southgate James, Spencer Erin, Tsivlidou Maria, Wood Kieran

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Research contractor: Ricardo Energy & Environment, The Gemini Building, Fermi Avenue, Harwell, Didcot, OX11 0QR, United Kingdom, Tel: +44 (0)1235 75 3500

Environment Agency's technical leads: David Browell and Mark Bourn

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Executive summary

Methane (CH_4) is an important Greenhouse Gas (GHG) which has a 100-year Global Warming Potential (GWP) approximately 27 times that of carbon dioxide (CO_2). Landfills are a major source of anthropogenic methane fugitive emissions, which are estimated to account for approximately 30% of the UK's methane emissions and it is therefore important that the release of methane from landfill sites is effectively managed to help support action to limit the impact of GHG's on the climate.

The Environment Agency has been working to understand the potential for using whole site methane emission measurements in regulatory approaches. Two survey methods have been used for methane emission quantification, which can be summarised as:

- Tracer Dispersion Method (TDM) – A whole site emission quantification technique based on the principle that tracer gas released from an emission source (for this study, at a landfill) will disperse in the same manner as methane emitted from the site. The method measures both methane gas and tracer gas concentrations downwind of the source. The technique uses the ratios of the measured concentrations and the known release rate of tracer gas to calculate the release rate of methane from the landfill site.
- Unmanned Aerial Vehicle (UAV) mass balance method - This method uses a UAV (drone) to sample concentrations of the methane gas across a vertical plane downwind of the landfill site. The method requires measurements of both methane gas concentration and wind speed. A mass balance equation is applied to the measurements to calculate the flux of methane across the plane.

The first phase of the project was captured in a research report entitled *'Landfill methane: measurement and metrics* which was published in February 2026. The report on the first phase of work is referred to as the 'main report' with the second phase of work, reported in this document, referred to as the 'supplementary report'. The main report provides background context to the project and the results and conclusions from the application of both methods at four landfill sites in England.

The aim of the work recorded in this supplementary report was to provide additional measurements to ensure that all times of the year are represented in the data set and to incorporate the additional measurement data into the evidence base captured in the main report.

The second phase of field measurements comprised TDM and UAV mass balance method surveys at three of the four landfills described in the main report. Six TDM and three UAV mass balance surveys were undertaken across sites Y1, Y2, and Z. Due to site restrictions, no UAV mass balance surveys were undertaken at Site Y2. No additional surveys were undertaken at Site X in the second phase of the field work because of the consistently good site performance in landfill gas collection demonstrated in the first phase.

The results from the second phase of field measurements support the conclusions made in the main report and shed further light on the application of the two methods at three of the four landfill sites (Y1, Y2, Z) surveyed in the first phase. Each landfill had site-specific features, which presented challenges for the survey techniques. These challenges enable a better understanding of the performance of each method in providing reliable and consistent measurements of methane released from landfills.

Sites Y1 and Z are active landfill sites and Site Y2 was an active site that was closing. Site Y1 is located close to a number of closed landfill sites that are also sources of methane gas. For Site Y2, during the time of this study, alterations to the capping layer of filled landfill cells and the gas management system were carried out as the landfill site was moving into closure. Carrying out surveys during these periods provided the opportunity to understand how operational factors influence the level of methane released from the landfill. Site Z, had issues with its gas management system during a period of days when surveys were undertaken in the first phase of the work. The results from the supplementary measurements therefore helped to improve understanding of how the site performs with the gas management system functioning normally.

The results from this study support the observation made in the main report that measured fluxes by UAV mass balance are systematically lower than those measured by TDM. As part of this supplementary study, the UAV survey team have updated the approached used to estimate the uncertainty range in measurement and tested this during the field work. The results show that the application of this method for calculating uncertainty brings UAV measurements into closer agreement with those collected by TDM during the same time period. It is expected that in future the UAV mass balance surveys will be completed by commercial operators who may be permitted to fly past ‘line of sight’. This will increase the potential for the survey to capture the entire plume emitted by the site.

The evidence in this supplementary report also sheds further light on challenges in the use of the TDM method. The surveys undertaken at site Y1 illustrate that the method can be reliant on wind direction to enable measurement of the plume of the targeted source only; and that the survey team need to ensure that they account for the impact of secondary sources of methane when planning the timing of the TDM survey.

This supplementary report has continued the analysis of the factors which may influence methane flux. This has been completed by following the same methodology used in the main report where a multi factor analysis was undertaken using a dataset which combines site management data (including methane gas collection), meteorological conditions, and the survey results.

The supplementary analysis presented here builds on the main report, supporting the conclusion that variations in methane flux are principally driven by changes in site operational conditions, while also highlighting a potential role for pressure gradients in influencing emissions. These findings strengthen the case for surveys to be undertaken under normal operating conditions when being used to assess the performance of the landfill gas management system.

The evidence suggests that the following points should be considered in any potential regulatory approach for assessing the performance of landfill gas management:

- the constraints and limitations of the survey method used, and any factors to be considered in interpreting the results;
- the survey report should consider the potential influence of meteorological conditions and site activity on the survey results;
- whether the survey was carried out under normal site operational conditions and unchanging weather conditions.

In a regulatory setting, site operators and survey organisations should ideally develop over time an understanding of the limitations of each survey technique and whether the technique is therefore suitable for use at the site. Operators could be supported by survey organisation expertise and any relevant guidance produced by the EA.

This study provides further evidence that both TDM and UAV techniques could potentially be used for regulatory purposes. Surveys should be planned with a consideration of normal operational activities and for meteorological conditions that are both suitable for the survey method and unlikely to significantly influence emission rates during the survey period.

It is recommended that the EA considers the inclusion of the following information in any methane flux survey report which may be required:

- evidence to show that the survey has been undertaken in normal operating conditions, likely to include gas collection data before, during and after the survey period, and information on the gas field balancing and operation;
- details of weather conditions experienced by the site during the time of survey and for the previous five days;
- a method statement which shows that the survey has effectively measured the full plume released from the site and has not measured contributions to the plume from other sources.

There remain some areas which future research should look to explore. It is recommended that:

- further TDM and UAV mass balance surveys are carried out at a wider range of sites to explore the limitations of each survey technique and opportunities for new enhancements to the technique to develop.
- support should be given where possible to the development of a robust standard operations procedure (SOP) for each method.
- further analysis on the influence of site conditions on methane emissions should be carried out, as new survey data becomes available. This will expand the evidence base of site behaviours and could eventually lead to an understanding of common behaviour of similar type of landfills.

- methane storage within landfill cells could be investigated further, potentially by considering how the sum of methane collection and emission rates changes under conditions when this would be expected to be relatively constant.

Contents

1 Introduction

Methane (CH_4) is an important Greenhouse Gas (GHG) which has a 100-year Global Warming Potential (GWP) 27 times that of carbon dioxide (CO_2). Landfills are a major source of anthropogenic methane fugitive emissions, which are estimated to account for approximately 30% of the UK's methane emissions, and it is therefore important that the release of methane from landfill sites is effectively managed to help support action to limit the impact of GHG's on the climate. The UK has made progress on its ambition be net-zero by 2050[1], achieved by reducing greenhouse gas emissions across all sectors and the economy. As part of this progress, lower volumes of biodegradable municipal waste have been estimated to be deposited in landfills in England[1] and the overall level of methane generated within these landfills will decrease in the long-term. The Environment Agency (EA) recognises that the change in waste composition is likely to challenge existing methods used by landfill operators to capture and treat landfill gas at landfill sites.

The Environment Agency's '*Landfill methane: measurement and metrics'* project aim is to understand the potential of methane quantification survey methods in assessing how well landfill operators are capturing methane gas generated from the degradation of waste deposited within a landfill. Two survey methods were used, the Tracer Dispersion Method (TDM) and an Unmanned Aerial Vehicle (UAV) mass balance method, and these are outlined in section 2 of this report. The initial phase (phase 1) of the project has been captured in the *'Landfill methane: measurement and metrics research report'*[2]. The report on the first phase of work is referred to as the 'main report' with the second phase of work, reported in this document, referred to as the 'supplementary report'.

The main report provides background context to the project and the results and conclusions from the application of both methods at four landfill sites in England. The aim of this supplementary report is to incorporate new measurement data into the evidence base captured in the main report to further understand the potential of each method. Specific consideration as to how the measures could be used for reporting GHG emissions is being undertaken a separate ongoing project led by the Department of Environment, Food and Rural Affairs (Defra) under the Defra project Direct Measurement of Landfill Methane Emissions 2

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1 https://www.gov.uk/government/publications/net-zero-strategy

2

https://assets.publishing.service.gov.uk/media/697c6788f8f4a746d9572f68/Landfill_methane_-_measurement_and_metrics_-_report.pdf

The measurements analysed in the main report were collected through 20 Tracer Dispersion Method (TDM) surveys and 6 Unmanned Aerial Vehicle (UAV - also commonly referred to as a drone) mass balance surveys (consisting of 21 separate UAV flights), undertaken at four landfill sites in England. This first phase (Phase 1) of measurements are described in the main report. The results from Phase 1 showed:

- Methane flux calculated by each type of survey are generally comparable within uncertainty bounds.
- Comparison of measurements collected by each survey on the same day and location suggests that the UAV method is likely to underestimate methane flux.
- Each method has its own limitations that may make the survey method unsuitable for use at some landfill sites.
- The data from either survey can be paired with gas collection data to establish a gas collection efficiency value for the site's gas management system. This value can be used as an indicator of how the site is performing in managing the release of methane to the atmosphere.

The objective of this phase (Phase 2) is to continue the work documented in the main report via six TDM and three UAV mass balance surveys at three of the four sites studied in the main report. The additional measurements allow for further insights into the relationship between measurement and season as well as new data points to either confirm or reassess the conclusions drawn from the main report. Analysis of this additional data has been undertaken to further explore trends in the data collected as part of both phases. We have considered the Phase 2 measurements together with those from the first phase of the project to explore how each method could potentially be used as a regulatory tool.

2 Overview of surveys

2.1 Monitoring Plan

In the first phase of the project four landfill sites were studied (X, Y1, Y2, Z); these sites are described in section 5.2 of the main report. The monitoring plan for the second phase was designed to focus resources on the sites most likely to provide useful insights, informed by the findings from the initial phase and known operational activities at the sites.

The second phase of the project comprises six tracer dispersion method (TDM) survey windows (with one or two surveys per window) and three UAV mass balance survey windows (each consisting of two survey days), conducted between August 2025 and January 2026 across Sites Y1, Y2 and Z. Site X demonstrated consistently high performance during the first phase, with methane collection efficiencies (MCEs) of 88–99% across seven surveys, indicating consistently high performance in landfill gas collection. Site X was therefore not included in the second phase monitoring plan. As with Phase 1, UAV mass balance surveys were not feasible at Site Y2 due to tree cover, security constraints and proximity to an airport, monitoring at this site was therefore limited to TDM surveys.

The monitoring plan prioritised contemporaneous surveys at sites Y1 and Z to strengthen intercomparison between methods. The plan addressed the seasonal data gaps in Phase 1 by surveying in late summer and early autumn, and recorded any operational or infrastructure changes likely to affect methane emissions and collection performance. Table 2-1 shows the survey windows conducted under the second phase of the project.

Table 2-1 Survey windows conducted under phase two

Date(s)	Site	Method	Notes
26th Aug 2025	Site Y2	TDM	Site undergoing closure
2nd Oct 2025	Site Y2	TDM	Site undergoing closure
21-22nd Oct 2025	Site Z	UAV+TDM	Contemporaneous surveys
27-28th Nov 2025	Site Y1	UAV+TDM	Contemporaneous surveys
10th Dec 2025	Site Y2	TDM	Site undergoing closure
14-15th Jan 2026	Site Z	UAV+TDM	Contemporaneous surveys

2.2 Survey Methods

A full description of each approach is provided in the main report. Each subsection below provides a simple description of the method and details of any variation from the description provided in the main report.

2.2.1 Tracer Dispersion Method

The Tracer Dispersion Method (TDM) is a whole site emissions monitoring technique in which a tracer gas is released at a known, constant rate from the facility being measured. The concentrations of the tracer gas and target gas (methane in this case) are then measured simultaneously downwind using a mobile, high-resolution gas analyser. An estimation of the methane gas released from the landfill is made by multiplying the known controlled tracer gas rate, the ratio of measured concentrations of methane and tracer gas, and the molecular mass of the two gases. The approach used for the TDM surveys as part of this study was identical to the approach described in section 5.2 of the main report.

2.2.2 UAV mass balance

The UAV-based mass balance approach employs aerial platforms equipped with high-precision gas analysers to measure CH_4 and CO_2 concentrations. The UAV is mounted with an onboard anemometer to record wind speed and direction simultaneously with gas concentrations.

Flights are conducted downwind of the landfill, where concentration and wind measurements are integrated within a mass balance framework to derive emission fluxes. Flight plans are designed for each flight based on prevailing wind direction, with UAVs flown at multiple altitudes in a vertical “ladder” pattern to characterise the vertical structure and lateral extent of the emission plume.

Uncertainties (symmetrical positive and negative 1-standard-deviation uncertainty bounds) in the flux estimates were calculated by propagating the relative uncertainties associated with background concentration and wind speed. This follows the approaches used by Allen et al. (2018).[3]

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[3] Allen, G., Williams, P., Ricketts, H., Shah, A., Hollingsworth, P., Kabbabe, K., Helmore, J., Finlayson, A., Robinson, R., Rees, White, T., Beaven, R., Scheutz, C., and Fredenslund, A. M. (2018), ‘*Validation of landfill methane measurements from an unmanned aerial system’,*: Project SC 160006, Tech. rep., Environment Agency, UK, available from https://www.gov.uk/government/publications/validation-of-landfill-methane-measurements-from-an-unmanned-aerial-system, 2018.

The findings detailed in section 9.1 of the main report suggest that UAV-based methane flux estimates must be carefully examined to ensure that the full extent of any landfill plume is sampled (especially laterally). Operational (field) factors that may risk full capture of the plume downwind include:

- the presence of physical objects such as trees and buildings;
- access to specific areas of the landfill site;
- regulatory requirements on drone operators such as only being able to fly within line of sight.

These issues represent sampling constraints and not the fundamental accuracy of the mass balance method itself. Navigating these operational considerations can mean that some fraction of a landfill plume can be missed, especially near the surface layer (< 5 m) and at the lateral ends of the flight plan (e.g. if a UAV cannot be flown beyond the site perimeter). A careful examination of the sampled data can typically illustrate if parts of the plume may have been missed, meaning that it may be possible to understand what on-site sources may (or may not have) been missed. As methane concentrations are typically highest near the ground level in neutral or stable atmospheric conditions, the inability to sample the lowest atmospheric layer may introduce a low bias in flux estimates. Controlled-release experiments (e.g. McManemin et al., 2025[4]) have demonstrated that such underestimation is common across UAV-based mass balance methods, with environmental wind speed and atmospheric variability identified as the dominant contributing factors.

To account for the potential contribution of unsampled near-surface layers, the method described in the main report was adapted to improve estimates of the near-ground flux component (i.e. below the minimum height of the UAV flight). The changes meant that methane concentrations measured along the lowest UAV transect were linearly extrapolated downwards from the height of this transect to the ground. This extrapolated contribution was not added to the flux estimate itself, but instead incorporated solely into the positive uncertainty bound, resulting in an asymmetric uncertainty range.

This treatment preserves a flux estimate that is strictly based on measured concentrations, while transparently accounting for the expected underestimation associated with near-surface sampling limitations. By assigning the extrapolated contribution to the uncertainty term rather than directly to the flux, the approach avoids introducing model-dependent bias, maintains methodological consistency across flights with varying sampling constraints, and enhances the robustness and transparency of the mass balance

[4] McManemin, A., Juéry, C., Blandin, V., France, J. L., Burdeau, P., and Brandt, A. R (2025) '*Controlled release testing of commercially available methane emission measurement technologies at the TADI facility*', EGUsphere, 2025, 1–21, 2025.

framework. The proportion of the flux uncertainty that is attributable to this extrapolation method (for the flight surveys in this report) is between 36-73% of the overall error.

3 Measurement uncertainties

3.1 TDM uncertainty discussion

The tracer dispersion method has been developed with a number of established practices intended to minimise uncertainty. For regulatory deployment, it is important that measurement and data-processing approaches are applied in a consistent and standardised manner, in order to minimise the potential for methodological bias. A Standard Operating Procedure (SOP) for deploying TDM in a regulatory context (Main Report, Appendix 6) has been developed. The SOP is based on the methodology applied in this project. This is designed to codify good practice, improve consistency and reduce uncertainty when applying the technique.

Uncertainty in measurement is reduced during the survey by careful control of the tracer release rate (cross-checked by comparing volumetric flow and mass used), running standards through the gas analyser before and after the survey to check calibration, and ensuring the full plumes are passed through during each transect. As a rule of thumb, a minimum of 10-15 transects should be made during the survey.

Following the survey, all transects are examined to ensure that they are suitable for analysis. Transects may be discarded if, for example, the methane or tracer plume is not complete, there are secondary sources of methane overlapping the target methane plume, or if there is significant noise in the gas concentration(s) data making it difficult to delineate the plumes and/or plume boundaries. In this project, the University of Southampton (UoS), worked on the principle that at least 10 valid transects are required for estimating a methane emission rate.

For all valid transects, the average methane and tracer gas background concentration is estimated. This is typically done either statistically or by eye and may be subjective dependant on the user. Likewise, the boundaries of the gas plumes are typically set by eye which again, may impart some user uncertainty to the analysis.

The results are reported with an uncertainty range that is representative of the combined error from a number of sources. This can include the accuracy and limitations of the instrumentation used, location of the tracer gas release up or downwind of the source gas, temporal fluctuations in methane release from the source, subjectivity in selecting background concentrations and plume margins.

Uncertainty in TDM measurements is typically reported as:

- A percentage (%) error, based on an error budget/balance which takes into account experimental bias (e.g. location of tracer release point away from the centroid of methane plume in up or downwind direction) and instrument accuracy (i.e. the gas analyser, flowmeters, balance used to weigh the gas bottles etc.) and tracer gas purity. This is usually considered to be ±18-20 % of the calculated emission (e.g. Fredenslund et al., 2019[5]).

- The standard deviation of all transects calculations after statistical outliers have been removed. Standard Deviation (SDev) measures the dispersion of data points within a single sample. Whilst useful for a quick check (the larger the SDev compared to the average emission rate of all transects reflects the range in measured emissions), it is of less value when comparing between surveys.
- Standard Error (SE, also standard uncertainty of the mean), calculated from the sample standard deviation divided by the square root of the sample size, measures the precision of the estimated sample mean relative to the population mean. A smaller SE indicates more precise estimates of the true methane emission average. Again, this is calculated after statistical outliers have been removed.

The test data in this report is presented with both the standard deviation and the standard error. Data shown in the survey data comparison figures, has error bars representing ±20% of the calculated flux for individual TDM transects. This is indicative only, to help understand direct temporal comparison with UAV measurements through review of smaller periods of TDM transects. Overall, the standard error of the overall survey average should be used to understand uncertainty in the measurements.

3.2 UAV uncertainty discussion

3.2.1 High level understanding of UAV uncertainty

The uncertainty range in the UAV-based mass balance method represents the combined effect of several sources of uncertainty affecting the flux estimate, including measurement error, variability in environmental conditions (particularly wind speed), and variability in background methane concentrations. These components contribute symmetrically to both the positive and negative uncertainty bounds. Methodological error due to environmental variability (which is measured directly) is directly accounted for in the flux uncertainty. However, any uncertainty due to under-sampling of the full landfill plume is not directly accounted for without further analysis of the data post-flight to ascertain if the winds measured on the day may have led to any parts of the landfill plume exceeding the lateral bounds of the UAV sampling plane (e.g. due to the sampling constraints described in Section 2.2 above). Appendix 6 of the main report (Standard Operating Procedures) provides a description of the UAV mass balance method.

[5] A.M. Fredenslund, T.C. Rees-White, R.P. Beaven, A. Delre, A. Finlayson, J. Helmore, G. Allen, C. Scheutz (2019), "*Validation and error assessment of the mobile tracer gas dispersion method for measurement of fugitive emissions from area sources*," Waste Management Volume 83, January 2019, Pages 68-78

The uncertainty range should be interpreted as the plausible interval within which the true methane flux is expected to lie, given these sources of variability.

The positive uncertainty bound additionally includes an extrapolated near-surface flux contribution to account for the potential underestimation arising from the unsampled layer between the ground and the lowest measurement altitude. This component represents a potential low bias in the central estimate rather than a symmetric uncertainty. Therefore, this is included only in the positive bound and not in the central value or the negative bound.

The University of Manchester (UoM) have undertaken controlled release experiments conducted under both neutral and convective buoyant conditions to understanding the impact of atmospheric conditions on measurements. The results show that the mass balance method performs reliably across stability regimes, provided sufficient horizontal wind is present.

Near-zero wind conditions should be avoided, particularly under convective buoyancy, where vertical turbulence may prevent complete plume interception. Our analysis shows that mean wind speed is the dominant factor influencing flux bias, with absolute bias decreasing as wind speed increases. Based on linear regression results, a minimum wind speed of 2.2 ms^{-1} is required to maintain absolute bias below 50%, consistent with thresholds reported in previous studies.[6] The UoM survey team recommend conducting surveys during periods with sustained horizontal wind speeds exceeding ~2.2 m s^{-1} to ensure adequate plume advection across the measurement plane.

The undertaking of surveys in stable conditions, where vertical mixing is suppressed, increasing the distance between the source and the measurement plane can help promote sufficient plume development and improve representativeness of the sampled cross-section.

3.2.2 Recommended approach to limiting uncertainty in UAV mass balance measurements

It is recommended that the following considerations are made to achieve flux estimates with typical uncertainties of <30% for landfills similar to those studied in this report:

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[6] Yang, S., Talbot, R. W., Frish, M. B., Golston, L. M., Aubut, N. F., Zondlo, M. McSpiritt, J. (2018). '*Natural gas fugitive leak detection using an unmanned aerial vehicle: Measurement system description and mass balance approach*'. Atmosphere, 9(10), 383.

3.2.2.1 Selection of drone

Use of a multi-rotor UAV capable of flying for 20 minutes or more at speeds of >2.5 ms^{-1} (with payload). It is possible that a UAV with a lesser duration may be suitable, so long as multiple flights can be conducted in rapid succession (e.g. less than 10 minutes between flights) to mitigate representativeness of sampling if fluxes are expected to be temporally variable. A fixed-wing UAV may also be suitable for the task, but such platforms are less precisely manoeuvrable and may fly at various speeds depending on environmental conditions; large variances in flight speed can manifest as spatial sampling bias.

3.2.2.2 Choice of sensor

In situ methane sensors with a 1 Hz precision > 20 ppb (1σ @ 1 Hz), calibrated before flight and assessed for calibration drift, are needed. Known open path remote sensing instruments (e.g. open path laser instruments) are not suitable for flux calculation within 30% uncertainty with the mass balance method.[7,8] These sensors are however very well suited to leak detection and emission hotspot characterisation. Open path remote sensing instruments may also complement in situ sensors by providing data between the lowest possible UAV flight altitude and the ground (overcoming surface sampling limitations discussed above).

3.2.2.3 Meteorological considerations

For UAV systems similar to those used in this study, surveys should only be conducted when winds (including gusts) are between 2.2 ms^{-1} and 10 ms^{-1}. This ensures horizontal ventilation of the landfill plume such that it can be sampled downwind, and operation within the flight safety limits of most rotary UAV systems. Faster wind speeds (and gusts) may be satisfactory if the UAV system is characterised as safe to fly in expected conditions. Maximum wind constraints are UAV-specific.

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[7] Yang, S., Talbot, R. W., Frish, M. B., Golston, L. M., Aubut, N. F., Zondlo, M. A., ... & McSpiritt, J. (2018). Natural gas fugitive leak detection using an unmanned aerial vehicle: Measurement system description and mass balance approach. Atmosphere, 9(10), 383. The accuracy of the method is about 50% under preferred wind conditions (with higher wind speed and steadier wind direction) and distributes around 100% under bad wind circumstances.

[8] Fosco, D., De Molfetta, M., Renzulli, P. A., Notarnicola, B., Dimauro, G., Astuto, F., & Spizzirri, U. G. (2026). Drone-based methane emission estimation at waste, livestock and energy facilities: Experimental tests in Italy and challenges of wind–concentration integration with open-path sensors. Journal of Environmental Management, 398, 128290. Averaging over the entire column systematically overestimated fluxes, reaching 130 % at the compression facility, 116 % at the landfill, and 108 % at the farm.

3.2.2.4 Selection of route

Pre-planned automated (waypoint) flying conducted at UAV groundspeeds of 2 - 4 ms^{-1} ensures unbiased sampling of the downwind plane and smooth and steady flight. Slower speeds are satisfactory in principle, but there is a trade-off between UAV groundspeed and total survey time. Faster groundspeeds are not suitable in our experience due to limitations of in situ sensor lag and smoothing time (affecting data spatial representativity) and impacts on the accuracy of measured winds (if using an onboard anemometer – see below).

The choice of route will be informed by landowner permissions and people, property and obstacles off-site (covered by CAA regulations and potential local byelaws). Flight planning and clearance may be necessary. If full lateral sampling cannot be achieved, any missing source areas of the site footprint may need to be identified and considered in the context of the operational needs of the survey. The vertical extent of UAV sampling is more difficult to ascertain pre-flight and is a trade-off between convection and local uplift, distance from sources, and sampling time available. The UoM sampling team recommends that nominal CAA flight restrictions of ~120 m above ground level are used when sampling most UK landfill plumes through all seasons when within 200 m of the downwind fenceline, with sampling typically conducted along the downwind fenceline.

3.2.2.5 Differentiating sources of methane

A mass balance survey should consist of a sampling plane aligned horizontally perpendicular to prevailing winds[9], which extends to the expected lateral extents of any plume from the site – this is typically the full width projection of a site (perpendicular to the wind) at the site fenceline. For the mass balance method, a background concentration must be measured. In our experience, this is best derived from the survey data itself (i.e. sampling outside of the plume when downwind). We do not recommend the need for a separate upwind UAV survey conducted at a different time to any downwind survey, as we find that it is often the case that the true background varies throughout a typical day on

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[9] In principle, any off-axis sampling plane angle (<90 degrees) can be accounted for by the method. Any error in quantifying the off-axis is proportional to the inverse cosine of the offset angle, so uncertainty would increase as the wind direction moves further away from perpendicular to the sampling plane. As the off-axis angle increases, the projection of the plume on the sampling plane also decreases proportional to the sine of the angle. In operational reality, the method can cope with any deviation that does not either increase the flux uncertainty to unacceptable proportions (e.g. 100%), or mean that the plume cannot be sampled on the flux plane. A useful rule of thumb is that the off-axis angle should be no more than 30 degrees which corresponds to a factor of 0.5 on plume projection and a factor 2 on any amplification of wind variability uncertainty.

timescales of around an hour. Thus, a flight-specific background better reflects the conditions at the time of the survey.

3.2.2.6 Estimating flux uncertainty

Each survey should include measurement of 2-dimensional winds (u and v vectors. For improved accuracy, this should be measured from an onboard-UAV anemometer sampling at 1 Hz or greater. An equivalent anemometer (or anemometers) mounted on a tower of 10 m height can be a meaningful substitute, but wind variance must be considered for flux uncertainty via the mass balance method.

Sampled data should be analysed post-flight to characterise suitability for analysis in terms of data quality and sampling coverage (following the above guidance). Surveys may need to be repeated if operational needs are not met.

Flux calculation (and flux uncertainty) should be calculated using a mass balance method which considers the difference in methane concentrations at locations upwind and downwind of a source.[10] These are now widely available in the academic literature and known to be in use by commercial providers in the UK, Europe and USA. Any users should monitor updates in the academic literature, which continue to seek to reduce uncertainty and provide guidance.[11]

3.2.2.7 Reporting uncertainty

Fluxes should be reported along with a corresponding statistical uncertainty calculated from the survey data itself (and not an independent validation study) as environmental and sampling conditions dictate flux uncertainty on a survey-by-survey basis and must be derived as such. Any error calculated from a validation study (often under idealised conditions) is not truly representative of the uncertainty on any particular survey.

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[10] An example by Jamie McQuilkin is available at https://gasflux.github.io/

[11] Yong, H., Allen, G., Mcquilkin, J., Ricketts, H., & Shaw, J. T. (2024).' *Lessons learned from a UAV survey and methane emissions calculation at a UK landfill'*. *Waste Management*, *180*, 47-54.

4 Survey results

This section provides the results from TDM and UAV surveys at Sites Y1, Y2 and Z. These sites are described in section 5.2 of the main report.

The section is structured by site. Each site subsection is structured as the following:

- General site conditions;
- Results and commentary on TDM surveys;
- Results and commentary on UAV mass-balance surveys;
- Comparison of overlapping measurements made by each method.

Please note that the general site conditions is a basic commentary on notable site conditions during the supplementary phase of this project and that the comparison of overlapping measurements by each method can only be undertaken for measurements collected during overlapping time periods for each site. Further, no measurements were made by the UAV mass balance approach were made at Site Y2 and therefore no direct comparison between the two methods can be made at this site.

The results from each TDM survey and UAV mass-balance survey are provided in the subsections below for each site. Each subsection includes a table displaying the survey results. These tables include blue colouring to help differentiate surveys which are reported for the first time in this supplementary report from those captured in the main report.

4.1 Defining normal site conditions

There is frequent reference to *normal operating conditions* in this supplementary report. This refers to the status of the site encountered during the survey periods. During every survey, operators were asked to advise of any departure from their routine operations. Such departures could include the operation of the gas extraction and combustion system, and/or general site activities.

For gas extraction/combustion, normal operating conditions typically correspond to the extraction of gas from all parts of the site connected to the system, and steady operation of the gas engines. All sites under consideration in this study normally operated gas engines and did not normally operate a flare. Under normal operating conditions, gas extraction rates were stable and in line with long-term trends.

For general site activities, normal operating conditions would correspond to acceptance of waste in accordance with long-term trends. Abnormal conditions could correspond to no waste being accepted, or to maintenance being carried out. One example would be the installation of a new cell cap, which could result in the short-term removal of temporary cell covers with potential for unusual release of gas from the uncovered waste mass.

In addition to operational factors, *meteorological conditions* can also affect the observed methane flux. Examples include rapid or significant changes in atmospheric pressure, recent or ongoing heavy rainfall, or frozen ground. While a site may still be operating normally during such periods, these meteorological conditions can influence emissions. These conditions need to be taken into account when investigating the factors which affect methane emissions and methane collection efficiency and may also require special consideration when considering the affected survey results in a regulatory setting. The outcome from taking into account these considerations should result in a measurement that is reflected of normal site operating conditions.

4.2 Results from site Y1

4.2.1 Site observations at site Y1

A full description of this site is documented in section 4.4 of the main report. Site Y1 showed consistent operation of the gas extraction system across both phase 1 and 2 with no offline engines or flare operation reported by the site during surveys. Measured methane collection ranged from 269 to 314 kg/h with extraction appearing to decrease across the survey period, as extraction is higher (290 - 314 kg/h) between October 2024 - January 2025 than for surveys between February-November 2025 (252 - 269 kg/h).

A number of methane sources are present near to this site which could influence the measured methane concentration as well as many geographical features such as the presence of a neighbouring forestry area and limited road network.

4.2.2 TDM surveys at site Y1

Table 4-1 – Methane measurements collected at Site Y1 per TDM survey

Survey ID	Date	Time	Number of Plume Transects	Calculated CH_4 Flux (kg/h)	Standard Deviation (kg/h)	Standard Error of the Mean [1]	Methane collected via gas collection system (kg/h)
Y1_T1	19/10/2024	15:25 – 17:45	19	100	17	3.9	302
Y1_T2	19/10/2024	21:30 – 23:06	17	94	12	3.0	304

Survey ID	Date	Time	Number of Plume Transects	Calculated CH_4 Flux (kg/h)	Standard Deviation (kg/h)	Standard Error of the Mean [1]	Methane collected via gas collection system (kg/h)
Y1_T3	10/12/2024	19:20 – 21:35	13	95	15	4.1	314
Y1_T4	09/01/2025	19:10 – 21:05	17	90	10	2.5	290
Y1_T5	27/02/2025	20:00 – 22:15	24	72	12	2.5	252
Y1_T6	27/11/2025	11:55 – 14:48	12	132*	5	1.3	262
Y1_T7	28/11/2025	08:34 – 11:13	10	107	9	2.8	269

Note a: Standard Error of the Mean indicates how far sample means are expected to lie away from the population mean (see section 3.1).

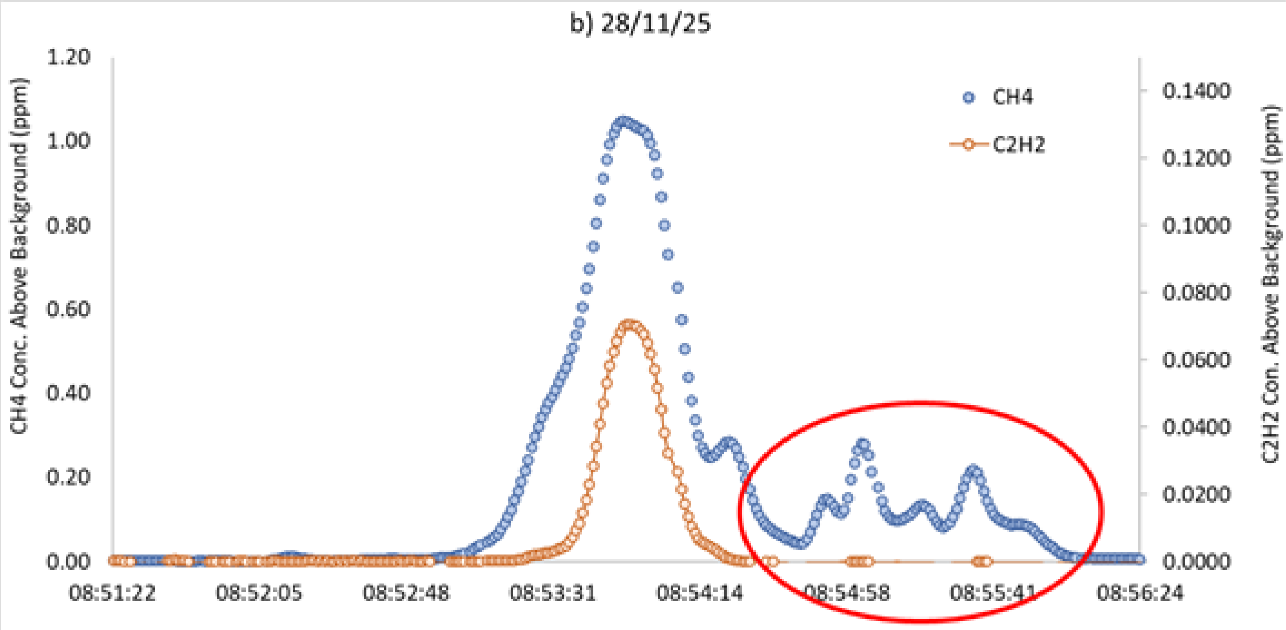
Note * This value includes ~ 25-30 kg/h estimated to have been derived from historic sites

Table 4-1 details the results of the TDM measurements made at site Y1. The results show that the TDM surveys estimate the landfill site to release a methane flux in the range of 72 -132 kg/h. The 132 kg/h value is marked with an asterisk as findings from the 28th November 2025 (the following day) suggest that this is an overestimation (see below).

Because of the wind direction, survey Y1_T6 included methane released from nearby historic sites which are known to have accepted Municipal Solid Waste (MSW). In survey Y1_T6, it was not possible to quantify the contribution of the closed sites to the overall methane measured in the survey. However, in a survey undertaken the following day (Y1_T7) where the wind direction had changed by approximately 60°, the plumes from each source (Y1 and the closed sites) were clearly separated. This is demonstrated in

Figure 4.1 (and in further detail in section A.3.3); the methane plume from Y1 is aligned with the tracer gas plume (in orange), methane from the closed landfills is further along the monitoring route shown circled in red.

Figure 4.1: Comparison of measured methane (blue dots) and measured tracer gas (orange dots) during survey Y1_T7



From this evidence, it is estimated that ~25-30 kg/h is being generated by the historic landfills suggesting that the methane flux during Y1_T6 is likely to be 97 kg/h.

The comparison of Y1_T6 and Y1_T7 highlights the challenges of conducting TDM surveys in areas where several sources of methane are present. The results suggest that conducting TDM surveys at these sites should be limited to temporal periods when wind direction allows the sites methane flux to be clearly identified.

4.2.3 UAV surveys at site Y1

Table 4-2: Methane measurements collected at Site Y1 per UAV survey

Survey ID	Date	Time	CH_4 Flux (kg/h)	Positive CH_4 uncertainty (kg/h)	Negative CH_4 uncertainty (kg/h)	Methane collected via gas collection system (kg/h)
Y1_U1	29/10/2024	13:12 – 13:22	67.3	11.9	11.9	302

Survey ID	Date	Time	CH_4 Flux (kg/h)	Positive CH_4 uncertainty (kg/h)	Negative CH_4 uncertainty (kg/h)	Methane collected via gas collection system (kg/h)
		13:36 – 13:43				
Y1_U2	29/10/2024	14:00 – 14:12	41.2	8.7	8.7	302
Y1_U3	29/10/2024	15:24 – 15:36	93.9	26.5	26.5	302
Y1_U4	29/10/2024	16:00 – 16:20	35.9	7.8	7.8	302
Y1_U5	30/10/2024	10:20 – 10:34	-			304
Y1_U6	30/10/2024	10:47 – 11:01 11:12 – 11:25	58.0	19.41	19.41	304
Y1_U7	30/10/2024	11:41 – 11:53 12:02 – 12:13	74.7	23.8	23.8	304
Y1_U8	27/11/2025	10:39 – 11:07	56.6	38.6	18.1	262
Y1_U9	27/11/2025	11:36 – 12:05	43.7	22.7	12.4	262
Y1_U10	27/11/2025	13:03 – 13:49	37.4	31.8	10.9	262

Survey ID	Date	Time	CH_4 Flux (kg/h)	Positive CH_4 uncertainty (kg/h)	Negative CH_4 uncertainty (kg/h)	Methane collected via gas collection system (kg/h)
Y1_U11	27/11/2025	14:18 – 14:56	39.6	26.0	11.3	262
Y1_U12	28/11/2025	09:27 – 09:55	49.0	31.1	13.0	267
Y1_U13	28/11/2025	10:10 – 10:35	45.7	22.2	13.7	267

Table 4-2 shows that the calculated methane flux by UAV surveys ranges between 36 – 94 kg/h across the entire study period.

The 13 surveys were conducted across 4 days which can be broken into two clear groups, those undertaken on the 29th and 30th October 2024 and those undertaken approximately one year later on the 27th and 28th November 2025.

The data shows that the range of methane flux estimated in the two groups (36 – 94 kg/h, 37 – 57 kg/h) from the UAV surveys alone suggests that the site is likely to release a minimum of 36 kg/h, or 26 kg/h with consideration of measurement uncertainty.

As discussed in section 4.1, this site is located near to other historic landfill sites which have the potential to contribute to the total methane measured when air flows from the direction of these sites. No air flows were recorded from these directions and measurements are assumed to capture methane released from the subjected landfill alone.

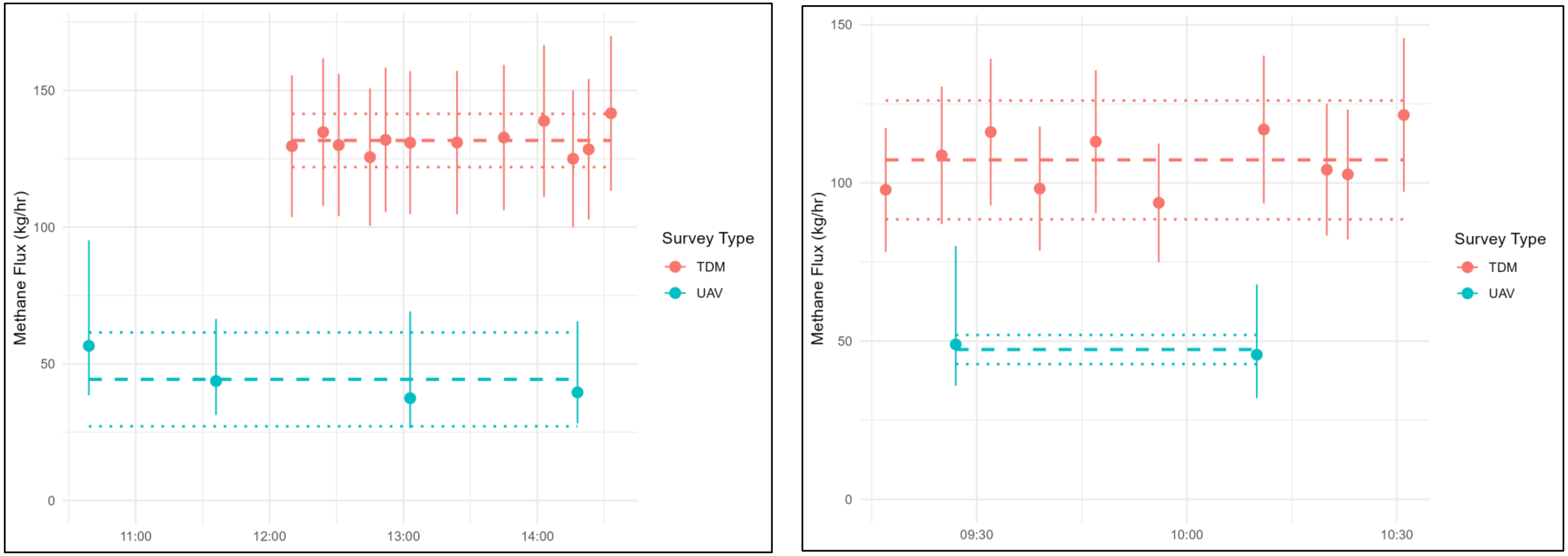
The survey measurement team have reported some challenges in collating measurements from this site, with some of the site inaccessible due to works being completed during the visit. There were known limitations for UAV measurements at this site under certain wind directions due to a treeline along part of the site boundary. During the surveys on 27th and 28th November, wind conditions constrained the UAV flight path near this treeline, preventing full coverage of the boundary and resulting in under sampling of the plume from the restored part of the site. Figure 4.2 illustrates the relationship between measurement location, landfill site and wind direction. The figure shows that at this site the UAV survey is limited to sampling the plume across a narrow section of the site with a south-westerly wind. The survey line could not be extended past the site boundary line due to the presence of obstacles at this location.

Figure 4.2: Example of a UAV flight lines with respect to wind direction at site Y1

4.2.4 Comparison of additional survey measurements at Site Y1

As undertaken in section 6.6 of the main report, a comparison of the measurements by each survey method when surveys times overlap has been undertaken. At site Y1 the surveys overlapped on the 27th and 28th November 2025.

Figure 4.3 - TDM and UAV mass balance flux measurement at Site Y1 on 27/11/25 (left) and 28/11/25 (right).



Points with error bars represent individual TDM transects or UAV mass balance flights. The dotted horizontal lines indicate the mean flux for each method and the associated uncertainty band, defined as ±2 standard deviations from the mean.

Figure 4.3 shows the results from TDM and UAV measurements collected between 10:00 and 14:30 on the 27th November 2025 and between 09:00 and 10:35 on the 28th November 2025. The following observations were made:

- Higher fluxes were measured using TDM compared to the measurements made by UAV mass balance.
- Average fluxes measured by TDM were 132 kg/h on the 27th and 107 kg/h on the 28th. The 107 kg/h average flux lies at the top of this range (within uncertainty) whilst the measured average of 132 kg/h is significantly higher than previous measurements and is likely to include methane from another source.
- Fluxes measured using UAV were between 37-57 kg/h on the 27th and between 46-49 kg/h on the 28th.
- The methods do not agree within the measured uncertainty during these surveys.

As discussed in sections 4.2.2 and 4.2.3 the difference in the estimates can be explained by the observation that the TDM method is likely to have been sampling methane released by neighbouring closed sites in its survey on the 27th November 2025. It is estimated that the additional sites are likely to account for 25-30 kg/h of the plume measured by the survey team. The UAV surveys were limited by flight constrictions which is likely to have result in the drone not being able to sample the full plume. This is a limitation which cannot be corrected through an application of a derived correction factor.

4.3 Results from site Y2

4.3.1 Site observations at site Y2

There have been significant operational changes across the survey period at site Y2 as it is undergoing closure. During the first phase of the project, methane collection at the site varied in response to the operation of the gas extraction system. During Surveys Y2_T1 and Y2_T4–6, gas extraction was relatively consistent, ranging between 397 and 447 kg/h, with the site operating either two engines or an engine and a flare. In contrast, during Surveys Y2_T2 and Y2_T3 the site was operating only a single engine with no flare, and gas extraction was significantly lower at 212 - 246 kg/h.

The cessation of waste inputs at the end of February 2025 and the temporary capping of the operational area in mid-March 2025 did not appear to have as significant an effect on methane collection as changes to the gas extraction system's operation.

From August 2025, the site underwent substantial restoration works. In August 2025, extensive capping works were underway, including the permanent capping of remaining areas and placement of restoration soils. These activities required the disconnection of many gas extraction and leachate wells. By October, capping works had been completed, but most disconnections remained while restoration soils were placed over the cap, with gas system reconnections continuing until Christmas.

The final survey took place in December 2025. Most of the gas extraction system reconnections had been completed at the time of this survey, with only a few disconnections remaining in areas still undergoing soil placement. The data from the gas management system shows that gas collection remained consistently, with two engines and no flare reported operational during surveys.

Methane collection during the second phase (August-December 2025) was lower (273-341 kg/h) than during Surveys Y2_T1 and Y2_T4-6 (397-447 kg/h), suggesting an impact from the well disconnections. Gas collection on 2nd October was the lowest of the supplementary surveys (273 kg/h), reflecting the substantial level of disconnection reported at that time.

4.3.2 TDM surveys at site Y2

Table 4-3: Methane measurements collected at Site Y2 per TDM survey

Survey ID	Date	Time	Number of Plume Transects	Calculated CH_4 Flux (kg/h)	Standard Deviation (kg/h)	Standard Error of the Mean	Methane collected via gas collection system (kg/h)
Y2_T1	05/12/2024	07:10 - 09:45	18	126	21	4.9	447
Y2_T2	17/12/2024	12:40 - 14:45	15	42	8	2.1	169
Y2_T3	14/01/2025	13:27 - 15:32	19	34	3	0.8	212
Y2_T4	04/02/2025	05:57 - 8:10	17	34	2	0.5	449
Y2_T5	18/03/2025	17:14 - 19:20	17	53	13	3.1	394

Survey ID	Date	Time	Number of Plume Transects	Calculated CH_4 Flux (kg/h)	Standard Deviation (kg/h)	Standard Error of the Mean	Methane collected via gas collection system (kg/h)
Y2_T6	21/03/2025	10:30 - 12:36	15	130	21	5.5	396
Y2_T7	**26/08/2025**	**21:06 - 23:45**	**7**	**82**	**8**	**3.0**	**320**
Y2_T8	**02/10/2025**	**17:30 - 20:15**	**15**	**94**	**23**	**6.0**	**273**
Y2_T9	**10/12/2025**	**12:02 - 15:00**	**10**	**31**	**4**	**1.2**	**341**

Table 4-3 shows that the calculated methane flux ranges between 31 – 130 kg/h across the entire study period.

As detailed in section 4.3.1, this site stopped accepting waste during the spring 2025 and the site gas management system was updated to include a number of new gas wells. It is understood that a number of gas wells that formed part of the existing gas management system was disconnected during this period to enable the new wells to be integrated. The combined gas has been stated to be operational by December 2025. The TDM data suggests that the disconnection of the gas wells is likely to have caused an increase in methane flux as observed in the highest measures seen in surveys Y2_T7 and Y2_T8. The final survey suggests that the re-connection of the gas wells alongside the full operation of the new management system is likely to have had an effect as measurements fell to its lowest during this survey. Measured methane flux may be expected to reduce further following completion of all closure works at the site.

4.4 Results from site Z

4.4.1 Site observations at site Z

There was evidence of site operations impacting methane collection and methane flux at site Z. During the first phase of the project, gas collection at the site was affected by freezing conditions in January 2025, resulting in lower methane capture rates (315 - 321 kg/h). By the March 2025 surveys, these issues had been resolved, and methane collection had increased to 430 - 439 kg/h.

Operation of the gas extraction system was generally consistent during 2025, with two engines and no flare typically in use. However, at the start of the final surveys on 15th January 2026, one engine was offline, which triggered operation of the flare. This likely explains the low methane collection observed in the first UAV mass balance survey on that day (259 kg/h), followed by much higher methane collection in the subsequent survey on the same day (472 kg/h). Aside from these two UAV mass balance surveys, it seems like normal conditions were observed in the second-phase surveys at Site Z (October 2025 to January 2026), which showed relatively stable gas collection (362–398 kg/h), although at a lower level than recorded in March 2025. The site operators have advised that there are plans to install partial permanent gas collection infrastructure in the current active areas in the future which they expect will further reduce the measured methane flux.

Additional site-specific factors also influenced survey conditions. The triangular shape of the landfill boundary (see Figure 4.5) meant that, under certain wind directions, particularly southerlies, it was difficult for UAVs to capture the full methane plume due to spatial constraints. Furthermore, muddy ground conditions during some surveys limited UAV accessibility to parts of the site boundary, further affecting the ability of the UAV to capture the entire plume.

4.4.2 TDM surveys at site Z

Table 4-4: Methane measurements collected at Site Z per TDM survey

Survey ID	Date	Time	Number of Plume Transects	Calculated CH_4 Flux (kg/h)	Standard Deviation (kg/h)	Standard Error of the Mean (kg/h)	Methane collected via gas collection system (kg/h)
Z_T1	20/01/2025	12:54 – 16:10	18	287	42	9.9	320

Survey ID	Date	Time	Number of Plume Transects	Calculated CH_4 Flux (kg/h)	Standard Deviation (kg/h)	Standard Error of the Mean (kg/h)	Methane collected via gas collection system (kg/h)
Z_T2	20/01/2025	19:22 – 21:19	23	260	43	9.6	260
Z_T3	19/03/2025	17:29 – 19:33	24	141	33	6.9	113
Z_T4	19/03/2025	22:45 – 01:16	18	94	15	3.9	94
Z_T5	21/10/2025	12:08 – 15:36	21	198	69	15.1	390
Z_T6	22/10/2025	09:34 – 11:14	11	57	4	1.3	397
Z_T7	14/01/2026	12:30 – 15:15	16	129	8	1.9	366
Z_T8	15/01/2026	11:25 – 13:00	9	210	43	14.3	387

Table 4-4 shows that the calculated methane flux by TDM surveys ranges between 57 – 287 kg/h across the entire study period. As reported in section 6.4 of the main report, there were known issues with the gas collection system that led to high measured fluxes in January 2025.

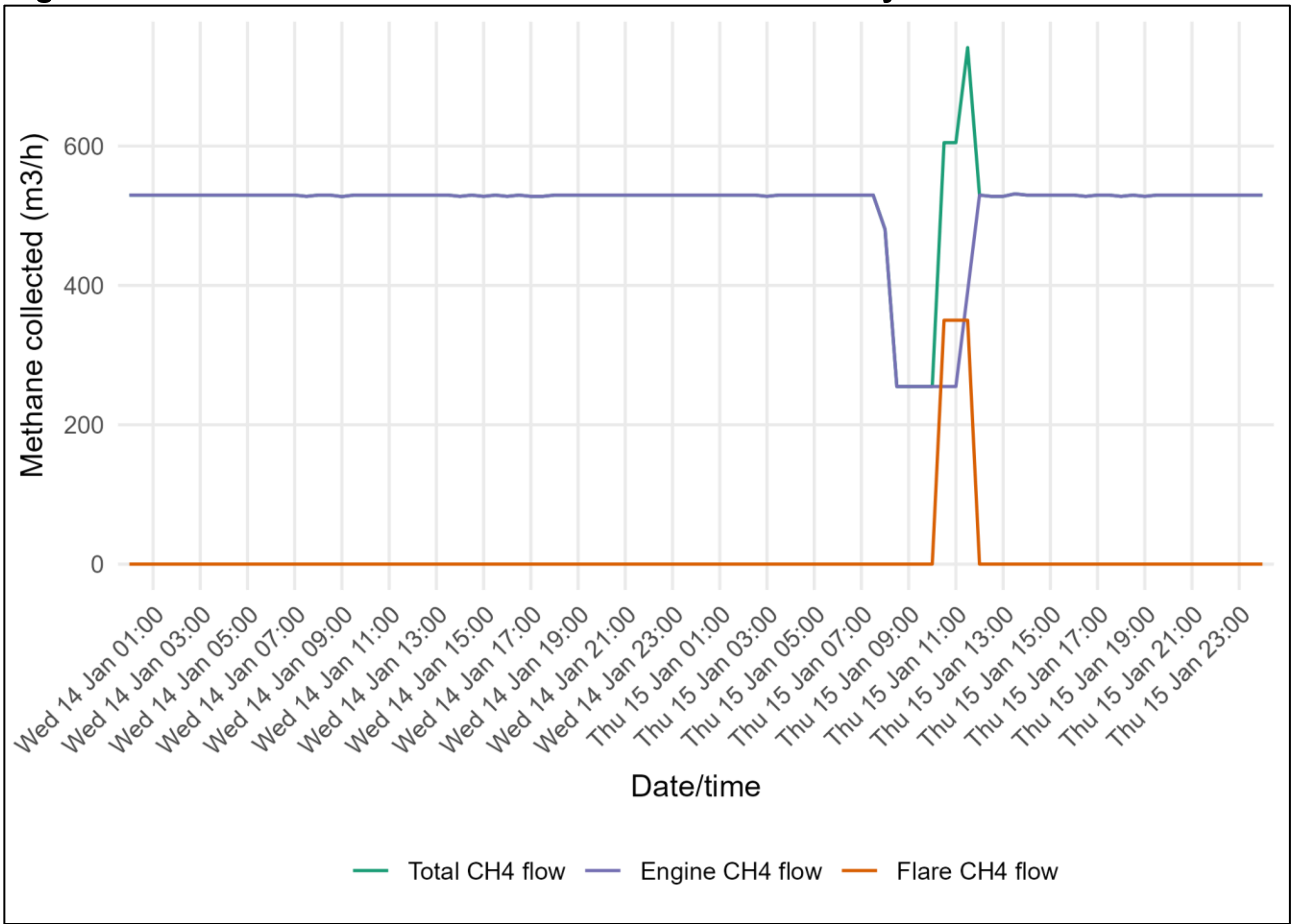
In the second phase of this project significantly different methane fluxes were measured across the four surveys. These surveys were conducted in pairs of two, each across a two-day period in October 2025 and January 2026 respectively.

For the surveys in October, the measured methane flux on the 21st was considerably higher (198 kg/h) than the measured flux on the subsequent day (57 kg/h). There were no abnormal operations reported by the site across the two days and the gas collection system showed consistent operation.

Further analysis of meteorological data (see section 4.4.4) showed there was a significant change in atmospheric pressure across the two days with a minimum pressure of approximately 979 kPa during the survey on the 21st while the survey on the 22nd was conducted during the pressure maximum of approximately 988 kPa. The literature suggest atmospheric pressure can have a strong influence on methane flux at landfill sites and could be one possible explanation for the significant difference in measured fluxes.

Similarly large difference between measure methane fluxes were observed between surveys conducted on the 14th and 15th January, with measured flux 129 kg/h on the 14th compared with 210 kg/h on the 15th. During the 14th January the operator did not report any operational issues and gas extraction data showed consistent operation of the gas extraction system. However, on the 15th January the gas collection data shows that an engine was offline from approximately 7:30 - 11:00 am with the flare coming online from 10:00 - 12:00am to manage gas extraction, which could be a reason for the higher measured methane emissions that day. Figure 4.4 shows the operation of the gas collection system across these days.

Figure 4.4: Gas collection at site Z on 14th and 15th January 2026



Another influencing factor on the methane fluxes measure across these two surveys could be the meteorological conditions. As with the previous set of surveys, there was also a significant pressure change across the two days, with lower fluxes corresponding with more closely with an atmospheric pressure maximum (1003 kPa on the 14th) and a higher flux corresponding more closely with a pressure minimum (991 kPa on 13th).

4.4.3 UAV surveys at Site Z

Table 4-5: Methane measurements collected at Site Z per UAV survey

Survey No.	Date	Time	CH_4 Flux (kg/h)	Positive CH_4 uncertainty (kg/h)	Negative CH_4 uncertainty (kg/h)	Methane collected via gas collection system (kg/h)
Z_U1	20/01/2025	13:10 – 13:21	160.9	41.6	41.6	318

Survey No.	Date	Time	CH_4 Flux (kg/h)	Positive CH_4 uncertainty (kg/h)	Negative CH_4 uncertainty (kg/h)	Methane collected via gas collection system (kg/h)
Z_U2	20/01/2025	13:42 – 13:53	168.8	48.6	48.6	318
Z_U3	20/01/2025	14:26 – 14:39 14:45 – 14:48	150.1	42.1	42.1	318
Z_U4	20/01/2025	15:09 – 15:21	189.6	49.5	49.5	318
Z_U5	21/01/2025	11:17 – 11:29 11:36 – 11:48	252.4	145.4	145.4	318
Z_U6	21/01/2025	12:45 – 12:56 13:13 – 13:18	115.7	62.0	62.0	317
Z_ U7	21/01/2025	14:14 – 14:27 14:36 – 14:46	287.5	108.3	108.3	315
Z_U8	21/10/2025	13:25 – 13:56	91.1	84.7	30.8	390
Z_U9	22/10/2025	08:47 – 08:59	36.9	41.8	11.5	398
Z_U10	22/10/2025	09:47 – 10:21	31.2	31.4	8.2	396

Survey No.	Date	Time	CH_4 Flux (kg/h)	Positive CH_4 uncertainty (kg/h)	Negative CH_4 uncertainty (kg/h)	Methane collected via gas collection system (kg/h)
Z_U11	22/10/2025	10:45 – 11:17	38.8	31.9	11.9	390
Z_U12	22/10/2025	12:30 – 12:57	41.1	29.4	13.2	388
Z_U13	14/01/2026	11:05 – 11:32	33.31	28.3	10.4	369
Z_U14	14/01/2026	12:35 – 13:03	30.74	31.2	11.1	367
Z_U15	14/01/2026	13:37 – 14:09	40.7	47.0	20.3	366
Z_U16	14/01/2026	14:57 – 15:24	79.1	32.4	32.5	366
Z_U17	15/01/2026	9:55 – 10:25	26.3	33.5	9.3	259
Z_U18	15/01/2026	11:19 – 11:49	43.9	38.9	12.7	472
Z_U19	15/01/2026	12:16 – 12:43	35.4	28.8	11.7	362
Z_U20	15/01/2026	13:29 – 14:00	73.3	44.9	28.6	363

Table 4-5 shows that the calculated methane flux by UAV surveys ranges between 26 – 288 kg/h across the entire study period.

At this site, 20 surveys were undertaken across 5 days which can considered as three observation periods:

- 1st observation window (20th – 21st January 2025), flux range (115 – 288 kg/h)
- 2nd observation window (21st – 22nd October 2025), flux range (31 – 91 kg/h)
- 3rd observation window (14th – 15th January 2026), flux range (26 – 79 kg/h)

UAV mass balance measurements collected during the first observation window show the methane flux to be significantly higher than the 2nd and 3rd observation windows with both the minimum and maximum reducing with each observation window. As noted in section A2 of the main report, issues with the gas collection system resulted in elevated flux measurements in January 2025. The lower fluxes recorded during subsequent surveys are therefore likely to reflect more stable and consistent operation of the gas management system at those times.

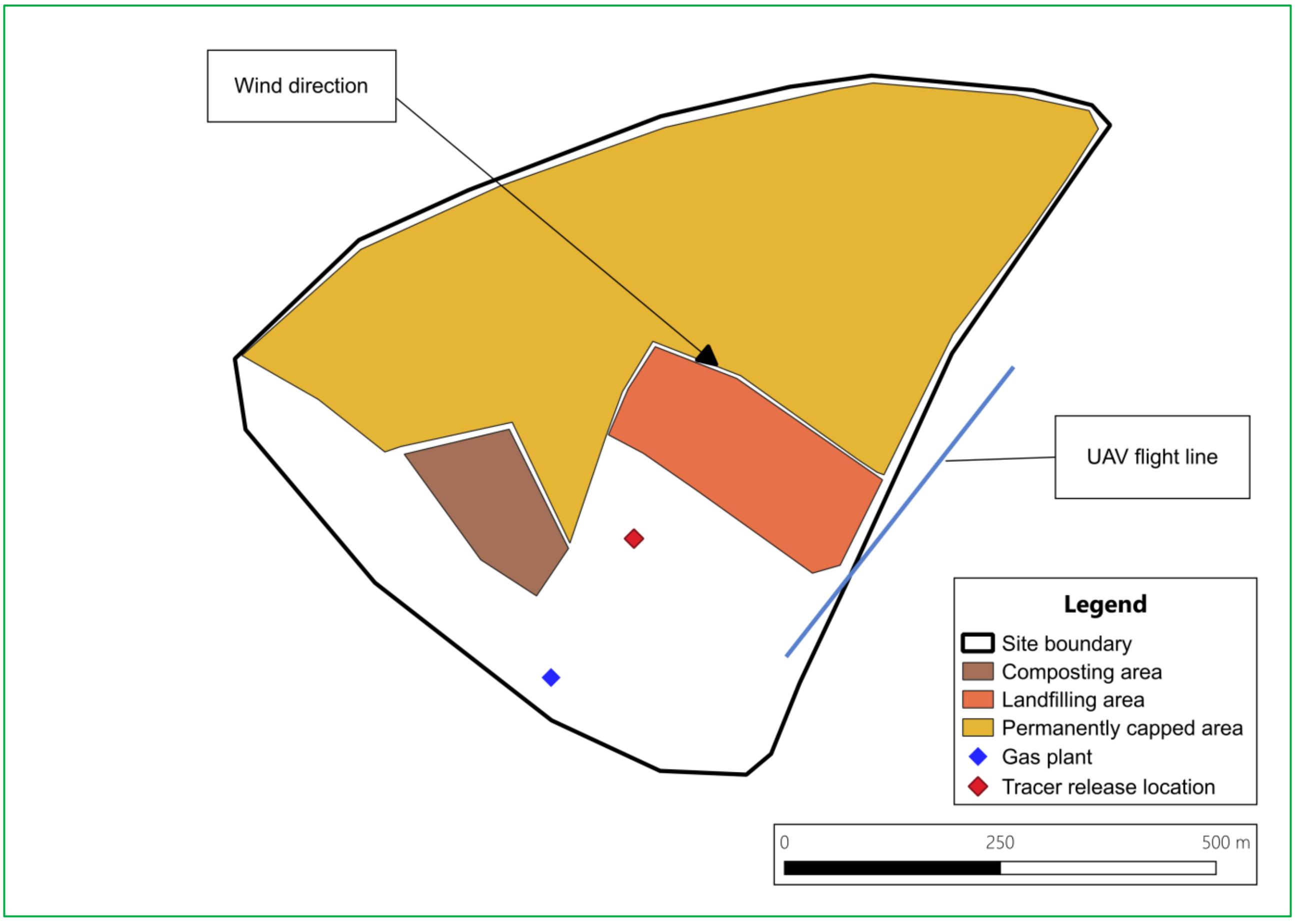
As with the TDM results (section 4.4.2), the UAV surveys conducted in October 2025 measured higher flux on the 21st (91 kg/h) than on the 22nd (31 - 41 kg/h). There was no site activities reported that could explain the difference in measured fluxes across the two days, and gas collection was consistent across the period. The difference in the measured fluxes is attributed to the significant change in atmospheric pressure across the two days with higher flux on the 21st coinciding with a pressure minimum and lower fluxes on the 22nd coinciding with a pressure maximum (as discussed in section 4.4.4).

For the UAV mass balance surveys conducted in January 2026, there is no obvious difference between fluxes measured across the two days as there is with TDM. On the 14th January methane fluxes ranged from 31-79 kg/h. Measured flux during the final survey of the day (Z_U16) was notably higher (79 kg/h) than the previous three surveys (31 – 41 kg/h), however there is not an obvious reason for this difference.

On the 15th January abnormal operation of the gas extraction system impacts gas collection during the surveys and appears to influence the measured fluxes. During the first survey on that day (Z_U17) gas extraction is significantly lower due to an engine going offline (see Figure 4.4), which corresponds with lower measured flux. Both gas extraction and methane flux increase during the next survey (Z_U18) as the flare becomes operational to maintain gas extraction at the site. By the third survey of the day (Z_U19) gas extraction has returned to normal operation with both engines operational and a methane flux of 35 kg/h is recorded. These findings show the robustness of the technique for capturing changes in the gas extraction system. The final survey on the 15th January (Z_U20) measured significantly higher flux (73 kg/h) than the previous survey on the same day (35 kg/h) despite consistent operation of the gas extraction system at the time. However, for this survey, the flight location was moved further towards the downwind site boundary to attempt to capture more of the plume from the capped area of the landfill site. This suggests that earlier UAV measurements that day were not capturing the entire landfill plume and therefore underestimating methane flux.

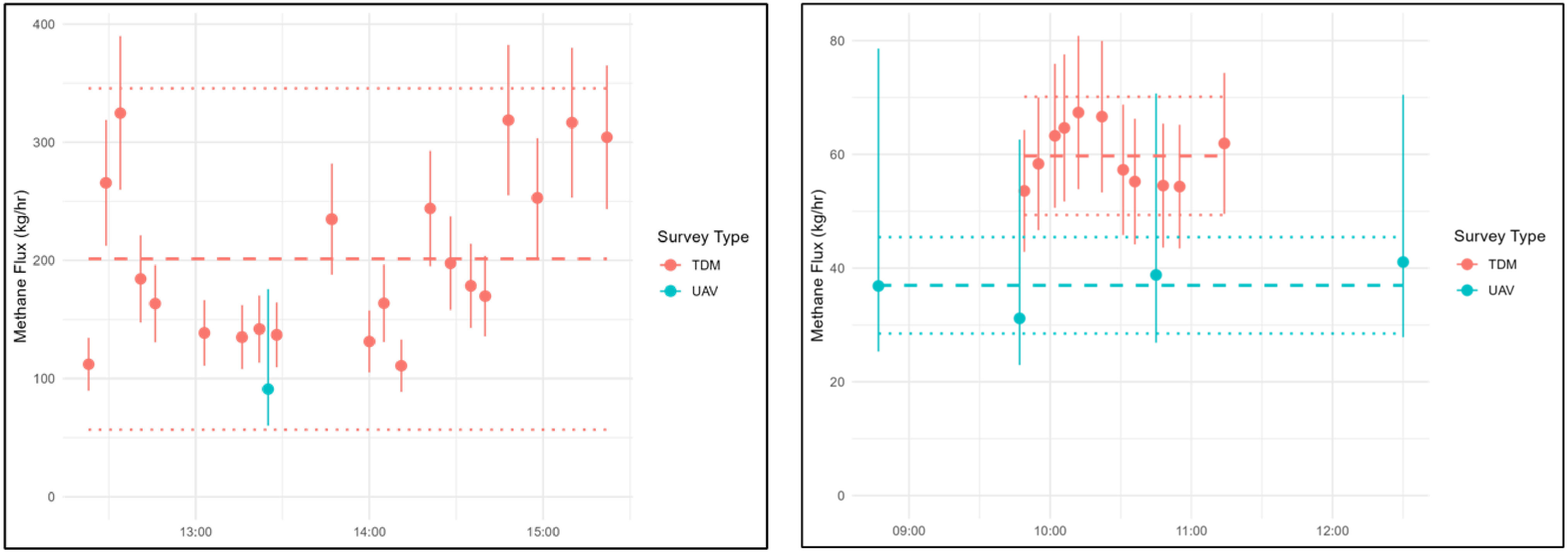
Figure 4.5 provides an illustration of a typical UAV measurement at this site. The image shows that the survey team were able to sample along the eastern edge of the site boundary and able to sample beyond the site boundary where required.

Figure 4.5: Example of a UAV flight path during Surveys completed at site Z



4.4.4 Comparison of additional surveys measurements at site Z

Figure 4.6: TDM and UAV mass balance flux measurement at Site Z on 21/10/25 (left) and on 22/10/25 (right)



Points with error bars represent individual TDM transects or UAV mass balance flights. The dotted horizontal lines indicate the mean flux for each method and the associated uncertainty band, defined as ±2 standard deviations from the mean.

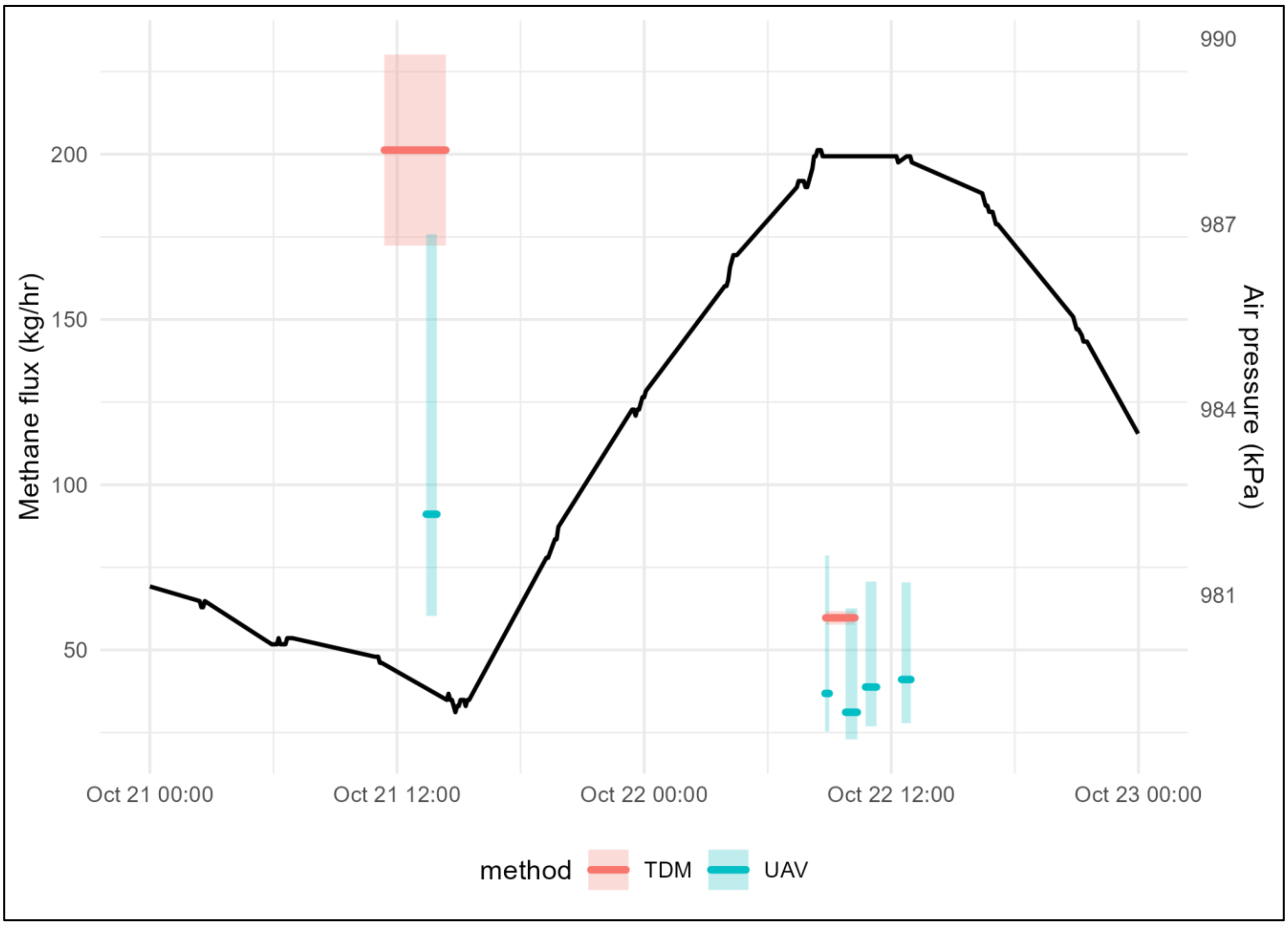
Figure 4.6 shows the results from TDM and UAV measurements collected between 12:00 and 16:00 (Z_T5, Z_U8) on the 21st October 2025 and between 08:30 and 12:30 (Z_T6, ZU9-12) on the 22nd October 2025. The following observations are made:

- There was a significant difference in the TDM measurements on consecutive days (198 and 57 kg/h on the 21st and 22nd October respectively). A difference between survey days was also observed in the UAV results, although it was less pronounced than that seen in the TDM data. However, it's possible the UAV mass balance results are influenced by undersampling of the lateral extent of the plume on these days.
- On the 21st there was substantial variation between individual TDM flux measurements, with a range between 109 and 320 kg/h, and an uncertainty of 15 kg/h. As discussed in section 4.4.2, the reasons for the level of uncertainty is unclear. The results on the 22nd were more consistent with a clear profile shown.

The results from the 22nd October show that the additional positive uncertainty associated with ground extrapolation brought the UAV mass-balance fluxes into agreement with the TDM individual transect estimates. This supports the conclusion that limited sampling close to the ground introduces a systematic under-bias in the UAV mass-balance method. Nevertheless, under-bias may also arise where the full lateral extent of the landfill plume is not adequately captured.

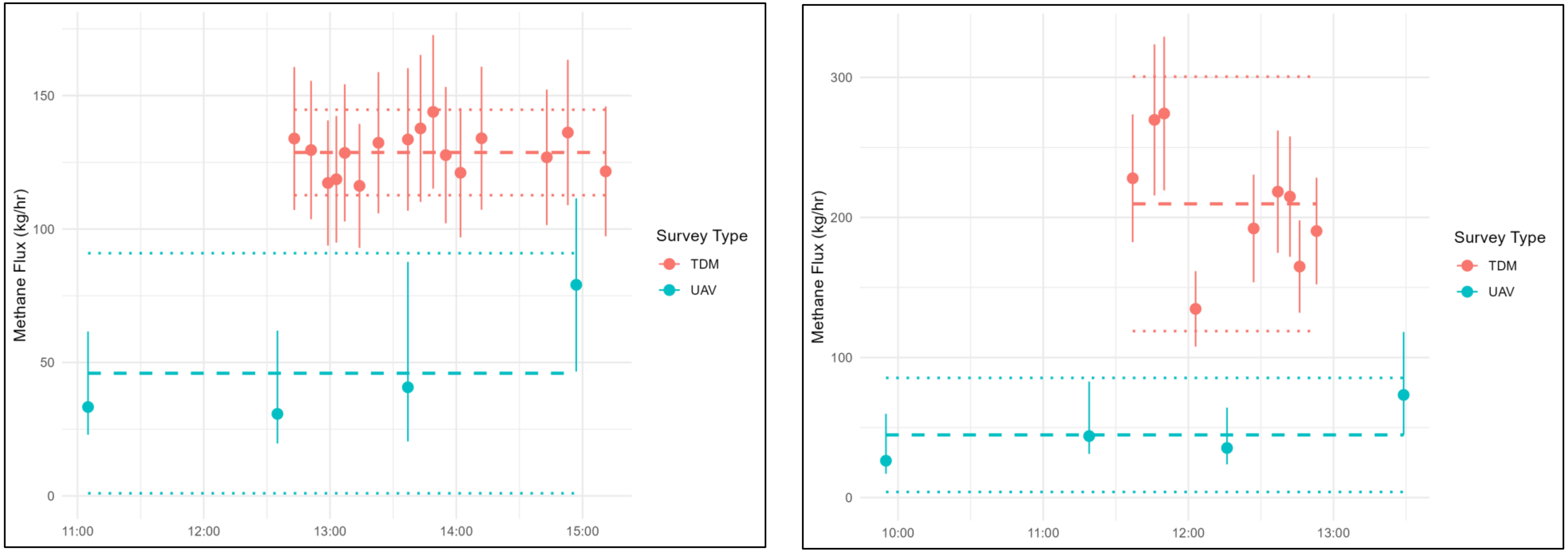
Figure 4.6 shows air pressure (blue line, left Y-axis) over the 24-hour period covering 21st and 22nd October. TDM (green) and UAV (orange) fluxes are also plotted (right Y-axis), with the uncertainty given by the shaded areas. The figures show a significant change in air pressure across the two days from 979 kPa at 15:00 on the 21st to 988 kPa by 9:00 on the 22nd. The analysis indicates that the higher fluxes observed on 21st coincide with the pressure minimum, while the lower fluxes measured on 22nd align with the pressure maximum during the period. In the absence of any operational changes that could account for the difference between the two days, variations in atmospheric pressure provide the most compelling explanation for the observed flux differences.

Figure 4.7: Air pressure and measured fluxes at site Z on 21st and 22nd October 2025



Note 1: The coloured horizontal lines on each sample represents measured flux across the time duration for each sample. The vertical colouring represents the upper and lower uncertainty bounds. The black line indicates air pressure.

Figure 4.8: TDM and UAV mass balance flux measurement at Site Z on 14/01/26 (left) and 15/01/26



Points with error bars represent individual TDM transects or UAV mass balance flights. The dotted horizontal lines indicate the mean flux for each method and the associated uncertainty band, defined as ±2 standard deviations from the mean.

Figure 4.9 shows a comparison of survey results collected at site Z on 14th and 15th January. The results show that:

- lower fluxes were measured using UAV mass balance than TDM.
- the uncertainty ranges of UAV measurements do not overlap with uncertainty ranges of TDM measurements

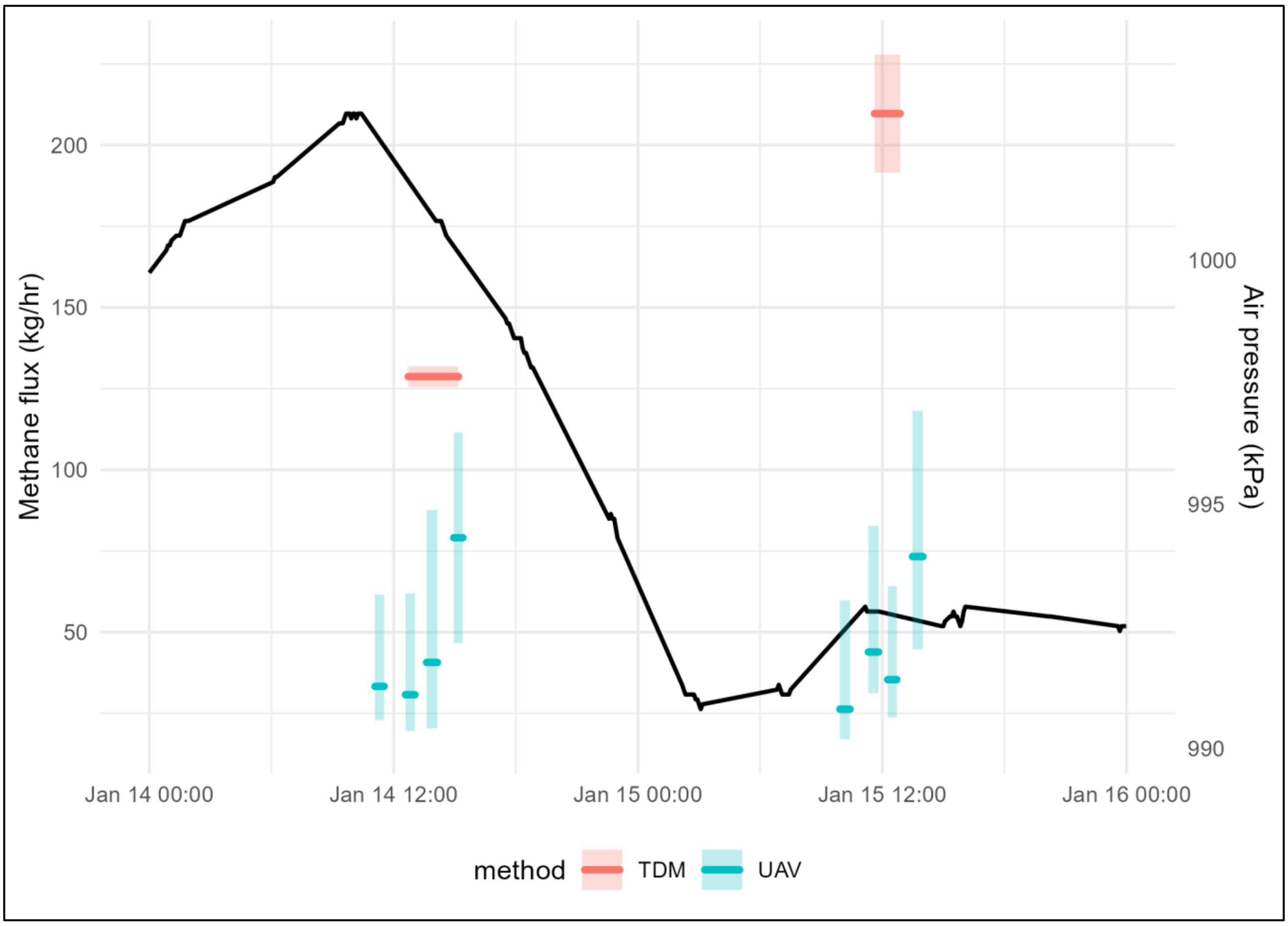
The difference between the two techniques may, in part, be explained by under sampling the full landfill emission area during the UAV survey as discussed in section 4.3.2. During the surveys on 15th January, muddy conditions at the site limited access to the site boundary for the UAV surveys, meaning that much of the capped area of the landfill could not be captured. However, during the final survey of the day the team moved the UAV flight path closer to the downwind site boundary (although still not at the boundary) and this result showed the closest agreement with the measure TDM flux. This suggests that methane from the capped area of the landfill, not captured during UAV mass balance surveys, is a significant source of the difference between the two methods.

In the TDM measurements, there was again a substantial difference in fluxes between the two survey days, although a similarly large difference was not observed in the UAV mass-balance results. As discussed in section 0the gas extraction system was operating abnormally on the morning of 15th January, with one engine offline and the flare activated. This affected gas collection, and is likely to have influenced methane fluxes in UAV surveys Z_U17 and Z_U18, with an estimated impact of around 18 kg/h. The same operational issue also provides a plausible explanation for the 80 kg/h difference between the TDM surveys on 14th January (Z_T7) and 15th January (Z_T8), although the magnitude of this difference is much greater than the variation observed in the UAV measurements. As the UAV mass balance method did not capture the full plume from the capped area of the landfill on these days, this suggests that a significant portion of methane emissions may have originated from this area and may be sensitive to the operation of the gas extraction system.

Whether the large difference in TDM-derived fluxes can be attributed solely to changes in the gas-extraction system is uncertain, as a significant pressure change also occurred during the 14th-15th January survey window. Figure 4.9 shows air pressure (blue line, left Y-axis) over the period, alongside TDM (green) and UAV (orange) fluxes with associated uncertainty (right Y-axis). Air pressure decreased substantially from around 1003 kPa at 10:00 on 14th January to approximately 991 kPa by 03:00 on 15th January. The lower TDM fluxes on 14th align more closely with the pressure maximum, while the higher TDM fluxes on 15th correspond with the more closely with the pressure minimum of the period. However, it is unclear why pressure changes would influence TDM fluxes but not the UAV mass balance estimates, unless the pressure effect is acting predominantly on capped areas of the landfill that were not fully captured by the UAV surveys.

There was no evidence collected during the surveys that suggest contribution of confounding sources to the measured TDM flux on the 15th January. However, this can be a source of elevated fluxes that affects TDM but not UAV mass balance.

Figure 4.9: Air pressure and measured fluxes at site Z on 14th and 15th January 2026

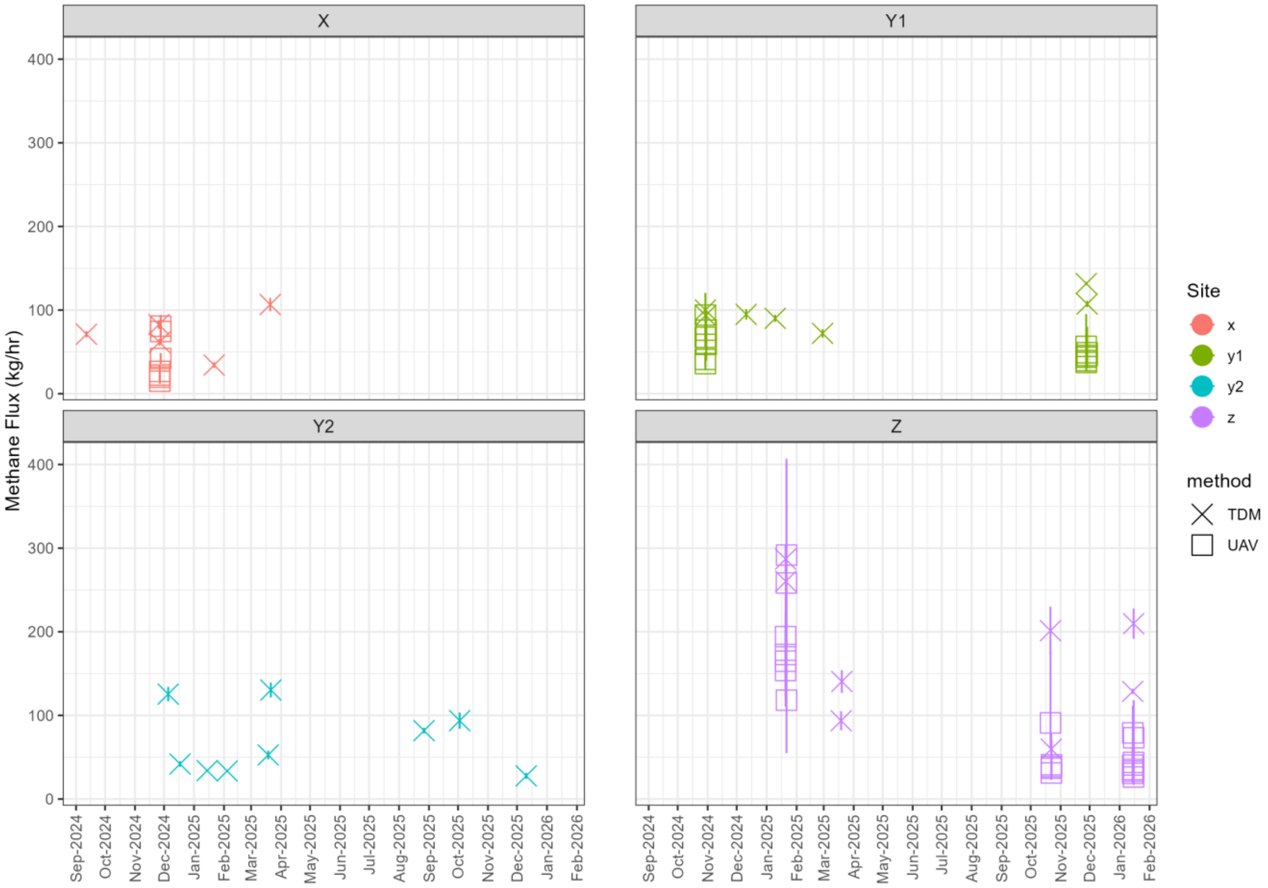


Note 2: The coloured horizontal lines on each sample represents measured flux across the time duration for each sample. The vertical colouring represents the upper and lower uncertainty bounds. The black line indicates air pressure.

4.5 Summary of comparable survey measurements

Figure 4.10 provides a summary of the results from the two survey techniques at each site.

Figure 4.10: Plotted comparison of TDM and UAV measurements



As discussed in sections 4.2.4 and 4.4.4, the TDM survey results were shown to be consistently higher than those reported by the UAV surveys. Some of this can be explained by known limitations at each site as described in sections 4.2 and 4.4.

In addition to the limitations known at each site, each method has its own disadvantages, as discussed in section 3, TDM measurements are limited to the range of the surrounding road network and is more sensitive to wind direction compared to the UAV method. Additionally, the post processing technique used will also have a bearing on how results compare.

It is generally accepted by the project team that the UAV method is likely to have under sampled due to site and operational restrictions (as discussed in section 4.2.3). The project team have applied a new technique to account for the part of the uncaptured near surface plume. The results show that the technique brings the upper uncertainty range of UAV measurements into better agreement with the TDM measurements.

4.5.1 Methane slip estimates

The following section provides estimates of combustion efficiency of gas engines and flares present on site Y1 and Z from measurements made by the UAV mass-balance surveys in this second phase of the study.

Table 4-6 and Table 4-7 provide detail of findings from the main report alongside the new surveys undertaken during the second phase. The key statistic to note is that the ratio value for the change in CH_4 and change in CO_2 (final two columns) where a value of below 20 ppb/ppm typically indicate combustion-related emissions with minimal influence from fugitive or background methane sources, whilst ratios greater than 20 ppb/ppm suggest a significant contribution from uncombusted (fugitive) methane sources (red text in Tables 4.6 and 4.7). This reflects the fundamental difference in emission composition: fugitive emissions are comprised of roughly equal proportions of CH_4 and CO_2, whereas under conditions of complete combustion, methane is completely oxidised to carbon dioxide, resulting in a markedly lower CH_4:CO_2 ratio. The calculation of the combustion efficiency is fully described in Appendix 6 of the main report. The rectangle method utilises all measurements made across a rectangular area covering the identified plume released from the gas engines and flares. In contrast, the results from the points method uses only specific measurements that exceed a set threshold within the same rectangle area.

These results are given to provide an indication of how UAV measurements could potentially support landfill site regulation. As stated in the main report, the combustion efficiency approach applied here is novel and beyond the objectives of this project, the project team will seek to publish these results in a future peer-reviewed paper.

Table 4-6: Methane slip estimates at site Y1

Site	Date	Time	Efficiency (rectangle method) (%)	Efficiency (points method) %	ΔCH4/ΔCO2 Rectangle (ppb/ppm)	ΔCH4/ ΔCO2 Points (ppb/ppm)
Site Y1	29/10/2024	14:00 – 14:12	99.3	99.4	7.4	6.4
Site Y1	29/10/2024	15:24 – 15:36	98.4	99.0	16.2	9.9
Site Y1	29/10/2024	16:00 – 16:20	96.2	97.3	**39.3**	**27.9**
Site Y1	30/10/2024	10:20 – 10:34	-	-	-	-
Site Y1	30/10/2024	10:47 – 11:01, 11:12 – 11:25	97.2	97.3	**28.7**	**28.2**

Site	Date	Time	Efficiency (rectangle method) (%)	Efficiency (points method) %	ΔCH4/ΔCO2 Rectangle (ppb/ppm)	ΔCH4/ ΔCO2 Points (ppb/ppm)
Site Y1	30/10/2024	11:41 – 11:53, 12:02 – 12:13	97.9	98.9	**21.6**	11.1
Site Y1	27/11/2025	10:39 – 11:07	92.7	93.2	78.1	72.1
Site Y1	27/11/2025	11:36 – 12:05	96.7	98.0	33.7	19.4
Site Y1	27/11/2025	13:03 – 13:49	87.9	95.1	137.1	50.5
Site Y1	27/11/2025	14:18 – 14:56	95.8	97.6	43.4	23.7
Site Y1	28/11/2025	09:27 – 09:55	95.0	97.4	51.9	26.1
Site Y1	28/11/2025	10:10 – 10:35	95.5	98.6	46.0	26.6
Site Y1	28/11/2025	10:39 – 11:07	90.0	97.3	107.8	26.9

Table 4-7: Methane slip estimates at site Z

Site	Date	Time	Efficiency (rectangle method) (%)	Efficiency (points method)	ΔCH4/ΔCO2 Rectangle (ppb/ppm)	ΔCH4/ ΔCO2 Points (ppb/ppm)
Site Z	20/01/2025	13:10 – 13:21	63.7	66.3	**570.8**	**507.2**

Site	Date	Time	Efficiency (rectangle method) (%)	Efficiency (points method)	ΔCH4/ΔCO2 Rectangle (ppb/ppm)	ΔCH4/ ΔCO2 Points (ppb/ppm)
Site Z	20/01/2025	13:42 – 13:53	65.2	63.2	**532.6**	**570.0**
Site Z	20/01/2025	14:26 – 14:39, 14:45 – 14:48	78.0	77.9	**281.9**	**284.0**
Site Z	20/01/2025	15:09 – 15:21	73.7	73.4	**357.4**	**362.0**
Site Z	21/01/2025	11:17 – 11:29, 11:36 – 11:48	66.5	64.2	**504.0**	**555.4**
Site Z	21/01/2025	12:45 – 12:56, 13:13 – 13:18	86.4	85.8	**157.8**	**165.5**
Site Z	21/01/2025	14:14 – 14:27, 14:36 – 14:46	74.5	72.8	**341.9**	**374.1**
Site Z	21/10/2025	13:25 – 13:56	89.9	88.3	115.5	131.72
Site Z	22/10/2025	08:47 – 08:59	91.7	89.4	90.4	117.5
Site Z	22/10/2025	09:47 – 10:21	92.9	91.9	75.9	87.45
Site Z	22/10/2025	10:45 – 11:17	91.7	91.5	90.4	92.2
Site Z	22/10/2025	12:30 – 12:57	87.8	86.6	138.1	154.4

Site	Date	Time	Efficiency (rectangle method) (%)	Efficiency (points method)	ΔCH4/ΔCO2 Rectangle (ppb/ppm)	ΔCH4/ ΔCO2 Points (ppb/ppm)
Site Z	14/01/2026	11:05 – 11:32	96.7	95.5	33.7	46.5
Site Z	14/01/2026	12:35 – 13:03	96.4	94.7	37.1	23.1
Site Z	14/01/2026	13:37 – 14:09	91.8	91.5	88.8	92.0
Site Z	14/01/2026	14:57 – 15:24	94.5	97.2	57.7	28.1
Site Z	15/01/2026	9:55 – 10:25	95.4	96.3	47.7	51.9
Site Z	15/01/2026	11:19 – 11:49	90.9	92.6	99.4	79.6
Site Z	15/01/2026	12:16 – 12:43	96.6	95.7	34.6	44.5
Site Z	15/01/2026	13:29 – 14:00	85.3	88.5	171.2	129.0

5 Factors affecting methane emissions

5.1 Summary of investigation of factors from the main report

An analysis of the factors affecting methane emissions was undertaken and reported in section 8 of the main report. This analysis was performed using statistical analysis to identify the key components which are likely to influence the level of release of methane from a landfill site.

This was completed through a multi-linear correlation analysis, which considered the relationship between methane flux and Methane Collection Efficiency (MCE) with other measured variables. This included:

Environmental factors:

- Air temperature at the time of the survey (°C)
- Air temperature gradient for the preceding five days (°C/day)
- Air pressure at the time of the survey (kPa)
- Air pressure gradient for the preceding 24 hours (kPa/hr)
- Rainfall during the survey (mm)
- Rainfall during the preceding 24 hours (mm)

Operational factors:

- Site X: Existence of temporary cap
- Site Y1: Tipping taking place, location of operational area moving,
- Site Y2: Flare operating; issue with engines; tipping taking place; open tipping face, site closure, temporary capping, permanent capping, installation of gas infrastructure
- Site Z: Tipping taking place; flaring taking place

The outcome of the main report analysis of Phase 1 data was that the **24-hour pressure gradient** and **air temperature** were found to be associated with both methane flux emissions and methane collection efficiency at all sites during the time of each survey. Site management variables were also associated with MCE. These findings were consistent with wider research detailed in section 3 of the main report.

5.2 Findings from the multi-linear correlation analysis

The approach used in the main report was repeated with the entire dataset to explore whether new insights could be drawn from a wider dataset. However, where surveys results were not deemed to be representative of the site methane plume they have been excluded from the analysis to avoid bias in the results. The excluded surveys and the reasoning are described in Table 5-1.

Table 5-1: Survey results excluded from multi-linear factor analysis

Site	Method	Survey	Date	Time	Reason for exclusion
Site Y2	TDM	Y2_T2	17/12/2024	12:40 - 14:45	Results imply unusually high estimated methane storage quantity during this survey, potentially due to unusual operations at the site (only a single engine in operation). This value is excluded to avoid skewing the analysis
Site Y2	TDM	Y2_T3	14/01/2025	13:27 - 15:32	Results imply unusually high estimated methane storage quantity during this survey, potentially due to unusual operations at the site (only a single engine in operation). This value is excluded to avoid skewing the analysis
Site Y1	TDM	Y1_T6	27/11/2025	11:55 - 14:48	Contribution of methane from nearby historic landfill sites
Site Y1	UAV mass balance	Y1_U10	27/11/2025	13:03 - 13:49	Suspected under sampling of the plume due to tree line
Site Y1	UAV mass balance	Y1_U11	27/11/2025	14:18 - 14:56	Suspected under sampling of the plume due to tree line
Site Y1	UAV mass balance	Y1_U12	28/11/2025	09:27 - 09:55	Suspected under sampling of the plume due to tree line
Site Y1	UAV mass balance	Y1_U13	28/11/2025	10:10 - 10:35	Suspected under sampling of the plume due to tree line
Site Z	UAV mass balance	Z_U13	14/01/2026	11:05 - 11:32	Suspected under sampling of the plume due to flight location
Site Z	UAV mass balance	Z_U14	14/01/2026	12:35 - 13:03	Suspected under sampling of the plume due to flight location
Site Z	UAV mass balance	Z_U15	14/01/2026	13:37 - 14:09	Suspected under sampling of the plume due to flight location

Site	Method	Survey	Date	Time	Reason for exclusion
Site Z	UAV mass balance	Z_U16	14/01/2026	14:57 - 15:24	Suspected under sampling of the plume due to flight location
Site Z	UAV mass balance	Z_U17	15/01/2026	9:55 - 10:25	Suspected under sampling of the plume due to flight location
Site Z	UAV mass balance	Z_U18	15/01/2026	11:19 - 11:49	Suspected under sampling of the plume due to flight location
Site Z	UAV mass balance	Z_U19	15/01/2026	12:16 - 12:43	Suspected under sampling of the plume due to flight location
Site Z	UAV mass balance	Z_U20	15/01/2026	13:29 - 14:00	Suspected under sampling of the plume due to flight location

Additionally, shorter pressure gradient times (2 to 6 hours) were investigated alongside the previous use of pressure gradient over the preceding 24 hours, in the light of information from independent studies detailed in section 8 of the main report.

The methodology used in the main report was adapted to include the potential impacts of pressure changes the site experienced in smaller windows. The analysis was repeated for each site using results from across both phases of the project with the pressure gradient parameter changing. The following pressure gradients were used in this analysis:

- 2-hour pressure gradient
- 3-hour pressure gradient
- 4-hour pressure gradient
- 5-hour pressure gradient
- 6-hour pressure gradient
- 24-hour pressure gradient

These pressure gradients were calculated using the meteorology measured onsite at sites Y1 and Z and the weather station located at a nearby airfield for site Y2. The pressure gradient is the rate of change of pressure from the time of the survey measurement and the measured pressure 2 to 6 hours and 24 hours previously.

This section provides a summary of the results from the multi-factor analysis. Full details of the approach and results are provided in Appendix A.5.

The analysis consists of an initial assessment to understand the impact of different pressure gradients on each of the landfills. This was undertaken by reviewing each of the R^2 values derived from the regression analysis undertaken for each of the different gradients. For the purposes of this analysis, we only present below the results from the TDM surveys, in order to avoid any bias introduced by the survey methods. The TDM analysis is presented over UAV mass balance because the TDM surveys were conducted at all three sites and provides a larger number of measurements at each location, resulting in a more complete dataset. In contrast, UAV mass balance measurements were only carried out at two of the three sites. Results from both methods are presented in Appendix A.5. Table 5-2 provides the correlation coefficient (R^2) values from the statistical analysis.

Table 5-2: Comparison of R^2 values from regression analysis of TDM methane flux using different pressure gradient time windows (all sites)

Site	Air Pressure Gradient 24h:	Air Pressure Gradient 6h:	Air Pressure Gradient 5h:	Air Pressure Gradient 4h:	Air Pressure Gradient 3h:	Air Pressure Gradient 2h:	Spearman rank correlation coefficient
Y1	0.380	0.450	0.440	0.409	0.452	**0.481**	-0.8
Y2	**0.869**	**0.869**	0.867	0.864	0.853	0.854	0.9
Z	0.770	0.770	0.770	0.770	**0.776**	0.771	-0.8

The R^2 value represents the strength of the multifactor regression model in predicting observed methane flux when using the specified pressure-gradient window for the pressure-gradient variable. This analysis was repeated across multiple pressure-gradient windows, ranging from 24 hours to 2 hours, to assess whether there was a correlation between pressure gradient window period and the R^2 value.

The Spearman rank correlation coefficient method was used to evaluate how the regression model's performance (as measured by R^2) varied with changes in the pressure-gradient window. The coefficient reflects the strength of association between the chosen pressure-gradient window and the resulting model fit within each regression analysis. The coefficient value can range between -1 and 1. Values towards +1 or -1 indicate a strong relationship between the chosen pressure-gradient window and the resulting model fit within each regression analysis. Weaker relationships are seen as the value tends towards 0.

Across the three sites, the relationship between the multifactor regression model and observed methane fluxes varies both in overall strength (as indicated by R^2) and in how sensitive that relationship is to the choice of pressure-gradient window. At Site Y1, the regression model shows consistently low correlation with observed fluxes across all window lengths (R^2: 0.380–0.481). Despite this, the Spearman rank correlation coefficient indicates a strong underlying relationship between shorter pressure-gradient windows and improved regression model performance at this site.

In contrast, Site Y2 exhibits the strongest overall agreement between the regression model and observed fluxes (R^2: 0.853–0.869). The Spearman coefficient again suggests a strong relationship between the choice of gradient window and regression model performance. However, unlike the other sites, longer pressure-gradient windows improve regression model correlation at Y2, the opposite of the pattern observed at Y1 and Z.

Site Z demonstrates moderate to strong consistency between the regression model and observed fluxes across all windows (R^2: 0.770–0.776). As with Site Y1, the Spearman correlation indicates that shorter windows are associated with higher model correlation.

Overall, the strongest regression correlation occurred with a 2-hour pressure-gradient window at Site Y1 and a 3-hour window at Site Z, whereas Site Y2 performed best with either the 24-hour or 6-hour windows. The results indicate that site-specific conditions determine how pressure gradients interact with methane flux, resulting in different pressure-gradient windows being more strongly correlated at different sites.

Based on this finding, a comparison of the influence of other variable factors was undertaken using the 6-hour pressure gradient window. This window was used based on the observation that a window of 6 hours had a reasonable correlation with methane flux across all sites. The multifactor correlation approach followed the methodology outlined in Section A.5 of the main report.

Table 5-3 shows the rankings per factor (each row) at each site (columns). For example, column 1 shows the indicative ranking number of each factor (1 = strongest, 9 = weakest) for site Y1. Note that some factors may share rank position and the – symbol has been used to show where no data or activity was recorded. The results are colour coded with the cell of the first position coloured in orange, second position in blue, and third position in yellow.

Table 5-3: Ranking of condition factors across all sites (TDM results only)

Factor	Site Y1	Site Y2	Site Z
Precipitation in previous hour (mm)	-	9	5
Precipitation in previous 24 hours (mm)	3	8	4
Temp (°C)	6	4	6
5-day T gradient (°C/day)	2	1	1
Flaring	-	5	7
Tipping	4	2	9
Abnormal operation	-	6	2

Factor	Site Y1	Site Y2	Site Z
Air pressure (kPa)	5	7	3
6-hour air pressure gradient (kPa/hr)	1	3	8

The results show that influences on methane flux (kg/h) varied across the sites. All sites suggest that the 5-day temperature gradient had a significant influence on fluxes. At sites Y2 and Z, the 5-day temperature gradient was shown to be the most significant factor, whilst it was the 2nd most significant factor at site Y1. It is unclear why the 5-day temperature gradient appears to have a significant influence on methane flux. Further work would be needed to investigate this finding. At sites Y1 and Z the air pressure gradient had the 1st and 3rd most significant influence on methane fluxes respectively, whilst site Z was more influenced by the instantaneous air pressure (3rd most significant factor).

At site Y2 the 2nd most significant factor was whether the site was tipping or not, which has a positive correlation with methane flux (suggesting higher fluxes when tipping). However, the site was only tipping during the first three surveys at the site, and all of these coincided with known abnormal operations at the site. Therefore, it is difficult to determine which factors are having the strongest influence in fluxes. Site Z also showed influence from operational factors as 'abnormal operation' is shown to be the 2nd most significant factor, linked principally to known issues with gas collection at the site during surveys in January 2024. This provides further evidence of the influence of operation of the gas extraction system on methane flux. Site Y1 was the only site where no significant influence from operational conditions was observed. This resulted from the relatively consistent and steady operation of the gas extraction system across all the survey periods. Importantly, this should not be interpreted as gas extraction being unimportant; instead, its influence could not be assessed due to a lack of operational variability.

Overall, the findings suggest that both site operations (e.g. abnormal operations, tipping, flaring) and meteorological factors influence methane fluxes across sites. As both sites with known changes in operation (sites Y2 and Z), had operational factors ranked highly, whilst at all sites temperature gradient appeared to be a significant factor in methane fluxes. Air pressure gradient was also significant factor at sites Y1 and Y2.

Meteorological variables are based on measurement whereas site operations were only inputted as a simple 1 or 0 to indicate that the activity was being undertaken or not. As a result, the meteorological factors are influenced by the extent of measurement of these parameters at the time of the surveys, which makes comparison of site conditions difficult.

5.3 Methane storage

The sum of the measured methane collection rate and the contemporaneous methane flux measurement can be taken to be an indicative measure of the methane generated plus or minus the change in storage. Averaging this sum from every survey across the entire survey period would give a figure that could be a reasonable estimate of the methane generation rate at that landfill (neglecting methane oxidation), provided site operation is consistent across that period. This appears to be the case for Site X, Site Y1 and Site Z.

During surveys Y2_T2 and Y2_T3 the site was operating only a single engine with no flare, and gas extraction was significantly lower at 212 - 246 kg/h. Therefore, these two periods were treated separately. Analysis of the influence of meteorological conditions on methane storage and flux could not be conducted on surveys Y2_T2 and Y2_T3 because there were relatively few measurements in these two surveys, resulting in greater uncertainty in this analysis. There are also greater uncertainties in the conceptual model for methane formation, storage and release during these periods as the model indicates an unusually high flow of methane into storage. A summary of the estimated site methane generation is shown in Table 5-4. To avoid introducing differences arising from the measurement techniques, we present here the analysis based solely on the TDM results, as TDM measurements are available for a greater number of surveys across all sites compared with the UAV mass-balance method. Estimates of the change in methane storage, by survey, for each measurement technique are provided in Appendix A.6.

Table 5-4: Methane generation by site (TDM only)

Site	Average estimated methane generation
Site X	890 ± 147 kg/h
Site Y1	388 ± 58 kg/h
Y2_1 and Y2_4-9	453 ± 162 kg/h
Y2_2 and Y2_3	229 ± 48 kg/h
Site Z	565 ± 124 kg/h

Note: Uncertainty in average methane collection rate plus methane flux is represented by 2 × Standard Deviation

Subtracting these average values from the measured values enables us to estimate the change in storage of methane in the landfill over time during the survey periods. The concept of methane storage is explained in section 7.5 of the main report.

Analysis of the correlation between methane storage and range of operational and meteorological conditions during the survey periods was evaluated using the multivariate correlation approach described in section 5.2. The aim of this was to determine which factors were significantly correlated with changes in methane storage. As with the analysis of factors affecting methane flux, surveys not considered representative were removed from the analysis. These are given in Table 5-1.

This section provides a summary of the results from the multi-factor analysis. Full details of the approach and results are provided in Appendix A.6.

An initial assessment of the influence of different pressure gradients on each landfill site was carried out by reviewing the R^2 values from the regression analyses performed for each gradient. As previously, we only present below the results from the TDM surveys, in order to avoid any bias introduced by the survey methods. Results from both methods are presented in Appendix A.6. Table 5-5 provides the correlation coefficient (R^2) values from the statistical analysis.

Table 5-5: Comparison of R^2 values from regression analysis of TDM methane storage using different pressure gradient time windows (Y1, Y2, Z)

Site	Air Pressure Gradient 24h:	Air Pressure Gradient 6h:	Air Pressure Gradient 5h:	Air Pressure Gradient 4h:	Air Pressure Gradient 3h:	Air Pressure Gradient 2h:	Spearman rank correlation coefficient
Y1	0.795	0.821	0.814	0.804	0.819	**0.832**	-0.6
Y2	**0.953**	**0.953**	0.952	0.951	0.949	0.950	0.9
Z	0.497	0.493	0.495	0.492	**0.502**	0.494	0.0

The analysis of the R^2 values shows a similar pattern to that observed for methane flux in in Table 5-2, with the pressure-gradient window that yields the highest correlation remaining consistent with the results observed for methane flux. However, at Y1, the overall correlation is much stronger for methane storage (R^2: 0.795-0.832) than for methane flux (R^2: 0.380-0.481). Conversely, for site Z, the correlation is substantially lower for methane storage (R^2: 0.492-0.502) than for methane flux (R^2: 0.770-0.776). Site Y2 shows the strongest correlation between the multiple regression and observed values for both methane flux and storage, indicating that the variables chosen in the multifactor analysis are appropriate for explaining the observed variability in both methane flux and methane storage.

Further analysis of the influence of other variable factors was undertaken using the 6-hour pressure gradient window. This window was used based on the observation that a window of 6 hours had a reasonable correlation with methane flux across all sites. Table 5-6 shows the indicative rankings per factor (each row) at each site (columns).

Table 5-6 Ranking of condition factors across all sites (TDM results only)

Factor	Site Y1	Site Y2	Site Z
Precipitation in previous hour (mm)	-	8	6
Precipitation in previous 24 hours (mm)	2	9	4
Temp (°C)	5	5	7
5-day T gradient (°C/day)	3	2	2
Flaring	-	7	5
Tipping	4	3	8
Abnormal operation	-	4	1
Air pressure (kPa)	6	1	3
6-hour air pressure gradient (kPa/hr)	1	6	9

Analysis of the factors influencing methane storage shows broadly similar patterns to those identified for methane flux in Table 6-3, albeit with some differences. As with methane flux, the five-day temperature gradient shows a strong influence across all sites, and each site shows either pressure gradient or instantaneous air pressure among the top three influencing variables. However, at Y2, instantaneous air pressure is the most significant factor affecting methane storage, whereas for methane flux, pressure gradient was more significant. Operational factors also play demonstrate significant influence on methane storage at sites Y2 and Z, with tipping activity strongly influencing storage at Y2, while abnormal operation of the gas-extraction system is the dominant factor at Z.

As with methane flux the overall findings suggest that both site operations (e.g. abnormal operations, tipping, flaring) and meteorological factors influence methane storage across sites.

6 Methane Collection Efficiency analysis

As detailed in the main report, an assessment of the use of the Methane Collection Efficiency (MCE) as a metric for site management performance was undertaken. This was completed by using the methane flux measurement recorded by each of the surveys, meter readings by the on-site gas collection system, and a methane surface oxidation factor (1.1) [12] into Equation 1 shown below.

Equation 1: Methane Collection Efficiency

$$MCE = \frac{Methane\ collected}{Methane\ collected\ +\ Methane\ surface\ oxidation - Methane\ slip + \ Site\ methane\ flux}$$

6.1 MCE analysis

This section sets out the methane collection efficiencies (MCEs) from the second round of surveys. The calculated MCE values include an allowance for surface methane oxidation estimated to be 10% of methane not collected) and methane slippage (estimated to be 2% of methane collected).

Each subsection below contains a table detailing the MCE calculated from data collected in the main report (rows which are in normal font) alongside estimates from the 2nd round of measurements (rows which are in **bold** type with a blue cell fill). Data from the main report has been included to provide a full understanding of how each site was found to perform. The presented MCEs differ from the previously presented survey fluxes as where several UAV mass balance surveys were conducted on a single day, the flux results have been aggregated to provide a single MCE value.

Note that the survey numbers for UAV have been adapted from earlier references as an average for multiple surveys undertaken on the same day has been used. To capture the range of surveys the grouped surveys have been labelled in the following format site_U_date (e.g Y1_U_29102024).

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[12] IPCC guidelines 2006 (Volume 5 Section 3.3)

6.1.1 MCE measurements at Site Y1

Table 6-1: Site Y1 Methane Collection Efficiency

Survey Type	Survey no's	Date	Start Time	End Time	Survey Methane Flux (kg/h)	Metered Methane Collected (kg/h)	Total Estimated Methane Production (kg/h)	MCE (%)	MCE Lower Bound (%)	MCE Upper Bound (%)
UAV mass balance	Y1_U_291024	29/10/2024	13:12	16:00	60	302	362	84%	71%	97%
TDM	Y1_T1	29/10/2024	15:51	17:46	100	302	407	74%	67%	81%
TDM	Y1_T2	29/10/2024	21:57	23:07	94	304	402	76%	70%	82%
UAV mass balance	Y1_U_301024	30/10/2024	10:47	11:41	68	304	372	82%	76%	88%
TDM	Y1_T3	10/12/2024	19:44	21:11	95	314	413	76%	70%	82%
TDM	Y1_T4	09/01/2025	19:44	21:13	90	290	384	76%	71%	81%
TDM	Y1_T5	27/02/2025	20:22	22:25	72	252	327	77%	71%	83%
UAV mass balance	Y1_U_2271125	27/11/2025	10:39	14:18	44**	262	306	86%**	80%**	89%**
TDM	Y1_T6	27/11/2025	12:10	14:33	132*	262	403	65%*	63%*	67%*
TDM	Y1_T7	28/11/2025	09:17	10:31	107	269	383	70%	68%	72%
UAV mass balance	Y1_U_281125	28/11/2025	09:27	10:10	47**	267	314	85%**	78%**	89%**

* This value includes ~ 25-30 kg/h of methane flux estimated to have been derived from historic sites

** Undersampling of the plume during these surveys likely results in underestimate of methane flux and overestimate of MCE

Four sets of surveys (shown in blue) were undertaken at this site as part of the second round of measurements. These were undertaken on the 27th and 28th November 2025. The calculated MCEs for site Y1 across the two days of new survey ranged between 65% - 86% with total estimated methane production ranged between 306 - 403 kg/h.

As discussed in section 4.2.3, UAV mass balance surveys conducted on the 27th and 28th were not able to capture the entire landfill plume to the wind direction and nearby treeline restricting flights along the boundary. Therefore, MCE surveys Y1_U_2271125 and Y1_U_281125 are considered to underestimate site methane flux and therefore overestimate MCE.

TDM survey Y1_T6 on the 27th is considered an overestimate of site flux (thus underestimate of MCE) as nearby historic landfill plumes were picked up due to wind direction constraints. As discussed in section 4.2.2, it is important that the survey team and site operators understand whether the sample collected is likely to be representative of methane released from the targeted landfill site.

The systemic underbias in the UAV mass balance approach identified in section 9.1 of the main report has also not been accounted for in surveys Y1_U_291024 and Y1_U_301124, so these may also represent overestimate of the MCE. Outside of the limitations of the survey conditions identified, the site reported consistent operation of the gas extraction system across all the surveys. Considering this, surveys Y1_T1, Y1_T2, Y1_T (all TDM) are likely to be representative of site performance under normal conditions, suggesting 70-77% (68-83% when considering uncertainty) MCE at this site. Our analysis indicates that the differences between TDM and UAV mass-balance fluxes are primarily driven by under-bias in the UAV method. There is no evidence in our results to suggest a systematic bias in the TDM measurements, unless confounding methane sources can be explicitly identified.

The methods showed agreement within their respective uncertainties during the surveys conducted in October 2024, indicating that under the right conditions, either approach could produce representative MCEs at this site. During these surveys, a north-westerly wind direction (Section A.4) enabled isolation of the landfill plume from confounding sources and access to the site boundary.

6.1.2 MCE measurements at Site Y2

Table 6-2: Site - Y2 Methane Collection Efficiency

Survey Type	Survey no	Date	Start Time	End Time	Survey Methane Flux (kg/h)	Metered Methane Collected (kg/h)	Total Estimated Methane Production (kg/h)	MCE (%)	MCE Lower Bound (%)	MCE Upper Bound (%)
TDM	Y2_T1	05/12/2024	07:18	08:40	126	447	577	78%	72%	84%
TDM	Y2_T2	17/12/2024	13:05	14:48	42	169	212	80%	73%	87%
TDM	Y2_T3	14/01/2025	13:53	15:37	34	212	246	86%	83%	89%
TDM	Y2_T4	04/02/2025	06:28	08:22	34	449	477	94%	93%	95%
TDM	Y2_T5	18/03/2025	17:35	19:25	53	394	444	89%	83%	95%
TDM	Y2_T6	21/03/2025	10:38	12:36	130	396	533	74%	68%	80%
TDM	Y2_T7	26/08/2025	20:21	22:24	82	320	404	79%	77%	81%
TDM	Y2_T8	02/10/2025	16:44	19:00	94	273	371	74%	72%	75%
TDM	Y2_T9	10/12/2025	12:16	14:45	28	341	365	94%	92%	95%

Three surveys (Y2_T7 – Y2_T9) were undertaken at this site as part of the second round of measurements. These were undertaken on the 26/08/25, 02/10/25 and the 28/11/25. The calculated MCE for site Y2 across these surveys ranged between 74 - 96% with total estimated methane production ranged between 365 - 404 kg/h. At this site the new surveys were undertaken over a four-month period.

There have been significant operational changes at this site as it has undergone closure during the survey period. This began with cessation of waste inputs at the end of February 2025 and temporary capping of the operational area in mid-March 2025. As outlined in Section 4.3.1, significant disconnections in the gas extraction system occurred during ongoing capping and soil-restoration works in the second phase of surveys.

It should be noted that Y2_T4 and Y2_T5 were undertaken under normal operating conditions, with both engines running and no flare. These surveys indicate that the site typically achieves an MCE of 89–94 % under normal conditions.

The lower MCEs observed in surveys Y2_T7 and Y2_T8 correspond to extensive gas-extraction system disconnections: during survey Y2_T7 these disconnections were ongoing, and by survey Y2_T8 most of the gas network remained offline following the completion of capping works. This is consistent with the reduced gas collection and higher measured fluxes during survey Y2_T8.

By December 2025 when the final survey took place at this site most reconnections of the gas extraction systems had been completed with only a few disconnections remaining in areas that still required soil restoration. By survey Y2_T9 most reconnections of the gas extraction system had been completed with only a few disconnections remaining in areas that still required soil restoration. This is reflected in the increase in gas collection and decrease in methane flux, which leads to higher MCE (94%).

The results from this site demonstrate the robustness of the TDM method, which effectively captured changes in gas-management practices as the site progressed through closure. They also highlight the importance of effective capping and gas extraction for controlling methane emissions: the lowest fluxes were recorded when the site was fully capped, and the gas-extraction system was operating efficiently. These findings further support a regulatory approach in which closed, restored sites are expected to outperform operational sites under normal conditions in terms of methane control.

Overall, the results from this site provide an insight into the influence of the operation of the gas extraction system on site performance, both during its operational period and through closure. With surveys conducted under normal operational conditions suggesting the site can achieve 89–94 % MCE.

6.1.3 MCE measurements at Site Z

Table 6-3: Site Z - Methane Collection Efficiency

Survey Type	Survey no	Date	Start Time	End Time	Survey Methane Flux (kg/h)	Metered Methane Collected (kg/h)	Total Estimated Methane Production (kg/h)	MCE (%)	MCE Lower Bound (%)	MCE Upper Bound (%)
TDM	Z_T1	20/01/2025	13:08	15:55	280	320	625	52%	42%	62%

Survey Type	Survey no	Date	Start Time	End Time	Survey Methane Flux (kg/h)	Metered Methane Collected (kg/h)	Total Estimated Methane Production (kg/h)	MCE (%)	MCE Lower Bound (%)	MCE Upper Bound (%)
UAV mass balance	Z_U_200125	20/01/2025	13:10	15:09	177	321	511	63%	58%	68%
TDM	Z_T3	20/01/2025	19:36	21:17	260	321	603	53%	45%	61%
UAV mass balance	Z_U_210125	21/01/2025	11:17	14:14	223	319	560	58%	34%	82%
TDM	Z_T5	19/03/2025	17:44	19:35	133	435	575	76%	65%	87%
TDM	Z_T6	19/03/2025	22:59	01:01	94	440	536	82%	77%	87%
TDM	Z_T7	21/10/2025	11:23	14:22	201	390	606	65%	64%	67%
UAV mass balance	Z_U_211025	21/10/2025	12:25	12:25	91	390	484	81%	63%	88%
UAV mass balance	Z_U_221025	22/10/2025	07:47	11:30	37	393	426	92%	88%	95%
TDM	Z_T10	22/10/2025	08:49	10:14	60	397	455	87%	86%	89%
UAV mass balance	Z_U_140126	14/01/2026	11:05	14:57	46	367	410	90%	85%	93%
TDM	Z_T12	14/01/2026	12:43	15:11	129	366	502	73%	71%	75%
UAV mass balance	Z_U_150126	15/01/2026	09:55	13:29	45	364	406	90%	85%	93%
TDM	Z_T14	15/01/2026	11:37	12:53	210	387	613	64%	61%	66%

Seven surveys (coloured in blue) were undertaken at this site as part of the second round of measurements. These surveys were undertaken on four days, 21/10/25, 22/10/25, 14/01/26 and 15/01/26. Both TDM and UAV measurements were collected on each day at during overlapping time periods.

Over the seven surveys, the MCE ranged between 65% – 92%. The MCE value from each technique undertaken during overlapping times was in agreement on the 22/10/25 with 92% (UAV) and 87% (TDM). On each of the other days, the TDM measurements indicated lower MCE values than the UAV data. The data from the main report shows only one other date (20/01/25, Z_T1 and Z_U_200125) where TDM and UAV derived estimates could be directly compared. On this occasion, the TDM (52%) and UAV (63%) were consistent within the uncertainty ranges TDM (42% – 62%) and UAV (58% – 68%).

As discussed in 4.4.3, site conditions and wind directions restricted the ability of the UAV to fly the entire downwind site boundary, so that some of the methane plume from the restored parts of the landfill could not be sampled. As discussed in 4.4.3, on the 15th January moving the flight path closer to the boundary of the site showed elevated fluxes compared to the previous surveys, suggesting there is substantial methane flux from the restored parts of the landfill.

Across each two-day survey window in the second phase, atmospheric pressure varied substantially, by around 10 kPa (see Figures 4.2 and 4.4). These pressure changes potentially contributed to the large differences in both flux and MCE observed between consecutive survey days, particularly for TDM. For example, TDM-derived MCE increased from 65 % on 21st October to 87 % on 22nd October and decreased from 73% on 14th January to 64 % on 15th January. The results suggest a pattern of higher fluxes (lower MCE) associated with pressure minima, and lower fluxes (higher MCE) associated with pressure maxima. However, the 15th January measurements were also affected by abnormal gas-extraction system operation in the morning, when an engine went offline and the flare was activated, which likely influenced the MCE observed on that day. Additionally, for the UAV mass balance survey (Z_U_150126), the evidence suggests under sampling of the landfill plume due to restricted access to the fenceline, and therefore lower estimated fluxes.

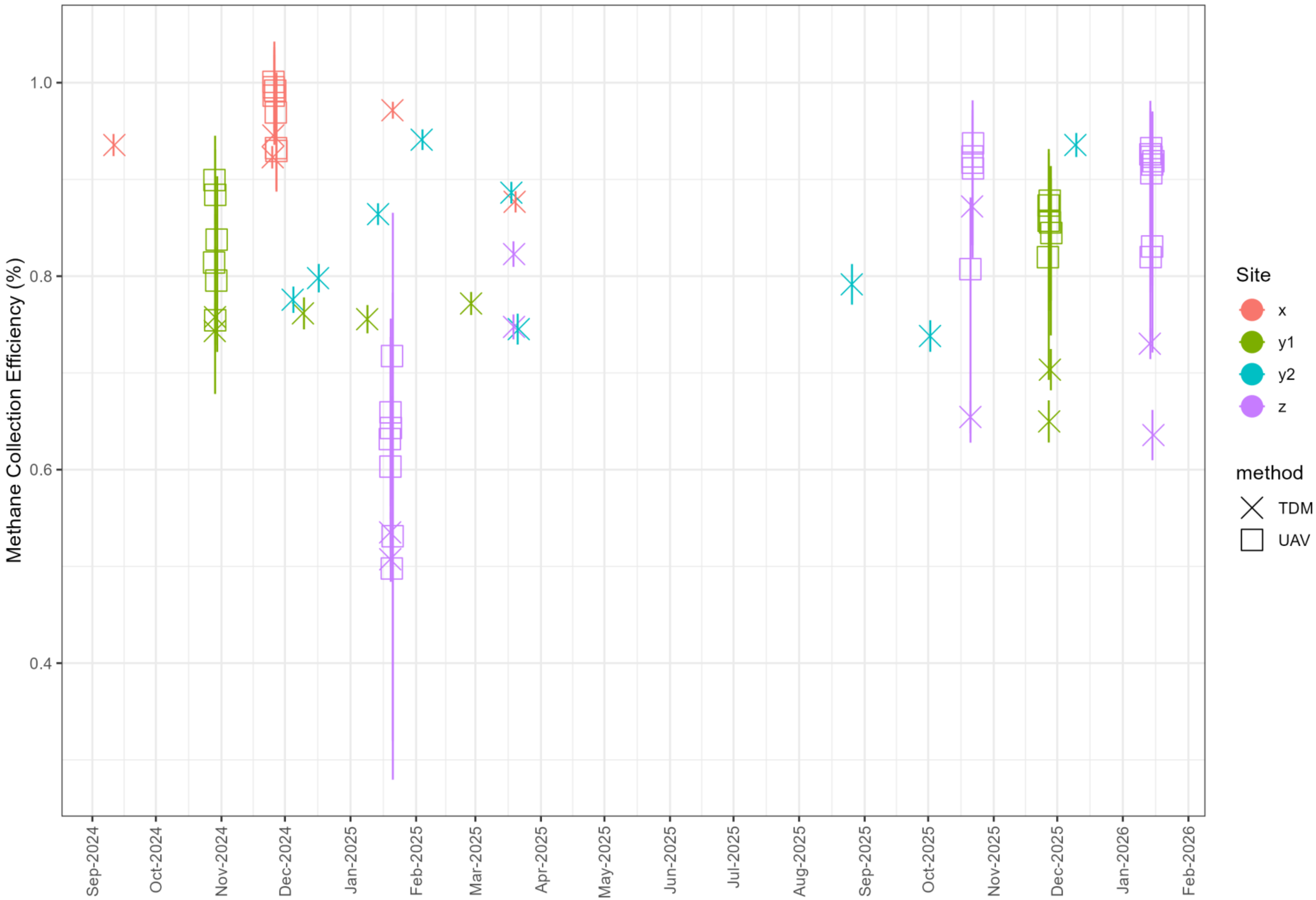
The results indicate that both techniques have the potential to yield comparable MCE values at this site, as demonstrated by the good agreement between methods during the January 2025 surveys. However, the data also show that the UAV mass-balance method is unsuitable at this site under certain conditions, when the full plume cannot be captured. Under a regulatory framework based on annual surveys, monitoring would therefore need to be undertaken only in conditions favourable for complete plume capture for the UAV mass balance method, or an alternative method should be selected. The survey techniques were only in agreement in 2 of the 5 survey periods where direct comparisons could be made. The differences in outcome relate to limitations in one or both survey methods, as discussed in Sections 0of this report.

The only MCE results deemed to be representative of the site plume and conducted under ‘normal’ conditions are Z_T5 and Z_T6. These show that under the conditions that site performs at 76-82% MCE (65-87% when considering uncertainty).

6.1.4 MCE measurements across all sites

Figure 6.1 provides a comparison of all measurements split by measurement type. The data shows, with the exception of measurements collected at Site Z in January 2025 (which reflects known issues with gas extraction at this time), that calculated MCE is broadly consistent, with most values at Y1, Y2 and Z falling between 70% – 85%. The data further shows how late 2025 and early 2026 measures at individual sites correspond with measurements made the previous year (for example Dec 2025 measurements at Y1 are shown to be broadly consistent with those made at the same site in Nov 2024).

Figure 6.1: Calculated MCEs across all surveys (Phase 1 and 2 of the project), September 2024 to January 2026



7 Approaches to regulation of sites

7.1 Identified potential regulation framework from the main report

An output of the main report was to outline potential regulatory framework which could be implemented for regulating landfills. The framework is described in full in the main report, Table 7-1 provides a summary of the steps considered and

Table 7-2 sets out the action that could potentially be taken in the event that a site exceeds an indicative benchmark of 85%.

Table 7-1: Potential regulatory steps from the main report

Step	Step name	Description
1	Conduct methane measurement survey.	Operators could be required to conduct an annual methane survey at their sites to estimate methane flux using a regulatory-approved methodology. The chosen method may be determined by site-suitability.
2	Calculate methane collection efficiency as a metric of landfill performance.	Operators could be required to submit gas collection data, both long-term and at the time of the surveys, both to estimate the Methane Collection Efficiency (MCE) and determine whether surveys are conducted under normal operating conditions.
3	Assess landfill site against benchmark for performance.	Site performance could then be assessed against a benchmark for performance which would determine the regulatory outcome. This benchmark could be determined from the annual survey results across the landfill population.

Table 7-2: Potential regulatory outcomes (Step 3)

Assessment against Methane Collection Efficiency (MCE) performance benchmark	Regulatory Outcome
Above the regulatory benchmark (even when accounting for uncertainty)	No regulatory action required
Approaching benchmark (Benchmark falls within calculated uncertainty of MCE)	No regulatory action required.
Below regulatory benchmark (even when accounting for uncertainty)	Regulatory action required. Operator would need to demonstrate interventions to improve gas management at the site, which could be monitored through subsequent surveys.

7.2 Amendments to the potential regulatory framework

The results show that methane flux (Section 0) and Methane Capture Efficiency (Section 6) measurements by TDM and UAV give systematically different results. UAV appears to give systematically lower values for methane flux, and consequently systematically higher values for MCE. Both methods have value as ways to record and track the performance of a landfill site in controlling emissions of methane to the atmosphere. It would be important to report which technique was used to measure MCE as the limitations of the survey methods are an important part of the interpretation of the results. Another approach would be to treat the 'extrapolated flux' as an explicit component of the UAV mass-balance method by reporting it separately and adding it to the standard flux estimate. For this approach to be successful it would be necessary to ensure the full lateral extent of the landfill plume is captured.

Operators should report the meteorological conditions and operational conditions before and during a survey. The key parameters to record are given in Table 9-6 of the main report. Plume-transect paths mapped geographically against the site, together with information on any nearby potential confounding sources should also be reported. This would provide evidence that the full landfill plume has been captured and that emissions from adjacent sources have not been included. This is particularly important given that incomplete plume capture, and influence of confounding sources, were identified as limitations of the methods under certain conditions in this study. It is likely these limitations can be avoided at most sites by planning surveys under favourable meteorological conditions, however the evidence would still be needed for interpretation of the results.

It would be necessary to demonstrate that a survey is representative, both in terms of capturing the full landfill plume and being undertaken under normal operating conditions (which can be defined in technical guidance). This supporting evidence would accompany the survey results and enable the EA to consider whether operational or meteorological factors may have influenced the measured methane fluxes and MCE. Based on this information, the EA could determine whether the results indicate compliance with an appropriate benchmark for MCE, compliance within measurement uncertainty, or non-compliance.

Indicative regulatory outcomes at the three sites measured during the second phase of the project are provided in Table 7-3, Table 7-4 and Table 7-5 to illustrate the potential approach. For the purposes of this exercise, an indicative regulatory benchmark of **85% MCE** has been applied. However, determining an appropriate benchmark for regulatory use may require further analysis and supporting evidence.

The regulatory outcomes presented below illustrate how each survey could be interpreted in a regulatory context if treated as an annual assessment. **They are not intended to suggest any regulatory action for the case-study sites.** It is important to note that, due to the constraints of this project, many surveys were conducted within a relatively short period. In a regulatory setting, operators would have far greater flexibility in choosing when to undertake a survey, using weather forecasts and planning around site operations. This would reduce the likelihood of surveys being carried out under atypical conditions and, consequently, decrease the need for any repeat surveys.

Table 7-3 - Example potential regulatory outcomes at Site Y1

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
UAV mass balance	8	27/11 /25	86	80	89	Approaching indicative benchmark	No, wind direction leads to potential under sampling of the plume.	Survey not considered for regulatory outcome as entire plume not captured.	Survey not considered to be representative as there is possible under sampling leading to an underestimate in the measure flux (and corresponding overestimate in the MCE).
TDM	9	27/11 /25	65	63	67	Below indicative benchmark	No, wind direction leads to confounding plume from historic landfills. An estimate of this contribution was calculated but not subtracted from the	Survey not considered for regulatory outcome as confounding sources captured in the methane plume.	Survey not considered to be representative as methane from historic landfills also measured leading to an overestimate in the flux (and corresponding underestimate in the MCE).

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
							emission result.		
TDM	10	28/11/25	70	68	72	Below indicative benchmark	Yes	Regulatory action required. Operator would need to demonstrate interventions to improve gas management at the site, which would be monitored through subsequent surveys.	Survey results consistent with other TDM surveys expected to be taken under normal conditions (e.g. 29/10/24). So suggests survey is representative of actual site performance.
UAV mass balance	11	28/11/25	85	78	89	Approaching indicative benchmark	No, suspected under sampling of plume due to wind direction and treeline obstruction.	Survey not considered for regulatory outcome as entire plume not captured.	Survey not considered to be representative as there is possible under sampling leading to an underestimate in the measure flux (and corresponding overestimate in the MCE).

Table 7-4 - Example regulatory outcomes at Site Y2

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
TDM	7	26/08 /25	79	77	81	Below indicative benchmark	No, Site is closed to waste and capping works were in progress. Many gas extraction and leachate wells disconnected.	Survey not considered for regulatory outcome as site is undergoing closure and so operating under normal conditions. Useful to assess changes in performance as parts of the gas network are disconnected.	Survey result consistent with other surveys at this site where the gas system is deemed to be operating abnormal. Result is reflective of the impact of disconnection of parts of the gas extraction system at the site on performance.
TDM	8	02/10 /25	74	72	75	Below indicative benchmark	No, Site is closed to waste. Capping works complete but disconnections in this area remain as soils are placed on top of new cap.	Survey not considered for regulatory outcome as site is undergoing closure and so not operating under normal conditions. Useful to assess changes in performance as parts of the gas network are disconnected.	Survey result consistent with other surveys at this site where the gas system is deemed to be operating abnormally. Result is reflective of the impact of disconnection of parts of the gas extraction system at the site on performance.
TDM	9	10/12 /25	94	92	95	Above 85 % indicative benchmark	No, Site is closed to waste. Most reconnections	Survey not considered for regulatory outcome as site is undergoing closure and so not	Higher performance during this survey appears to be reflective of the capping works

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
							complete in capping area but some new disconnections for soil restoration.	operating under normal conditions. Useful to assess changes in performance as parts of the gas network are disconnected.	being completed (no active area) and most the gas collection system reconnected. Demonstrates impact of capping and gas extraction.

Table 7-5 - Example regulatory outcomes at Site Z

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
TDM	7	21/10 /25	65	64	67	Below indicative benchmark	No. Significant pressure change across surveys on 21st and 22nd Oct (around 11 kPa) that could be cause of significantly different fluxes	Survey not considered for regulatory outcome.	Seems to be representative of atmospheric conditions rather than site operations. Declining pressure trend to a minimum before surveys on the 21st seems to release more gas, followed by a sharp increase to a maximum on the 22nd where methane flux is supressed.

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
							across the two survey days.		
UAV mass balance	8	21/10/25	81	63	88	Approaching indicative benchmark	No. Significant pressure change across surveys on 21st and 22nd Oct (around 11 kPa) that could be cause of significantly different fluxes across the two survey days.	Survey not considered for regulatory outcome.	Seems to be representative of atmospheric conditions rather than site operations. Declining pressure trend to a minimum before surveys on the 21st seems to release more gas, followed by a sharp increase to a maximum on the 22nd where methane flux is supressed.
UAV mass balance	9	22/10/2025	92	88	95	Above 85 % indicative benchmark	No. Significant pressure change across surveys on 21st and 22nd Oct (around 11 kPa) that could be cause of significantly different fluxes	Survey not considered for regulatory outcome.	Seems to be representative of atmospheric conditions rather than site operations. Declining pressure trend to a minimum before surveys on the 21st seems to release more gas, followed by a sharp increase to a maximum on the 22nd where methane flux is supressed.

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
							across the two survey days.		
TDM	10	22/10 /25	87	86	89	Above 85 % indicative benchmark	No. Significant pressure change across surveys on 21st and 22nd Oct (around 11 kPa) that could be cause of significantly different fluxes across the two survey days.	Survey not considered for regulatory outcome.	Seems to be representative of atmospheric conditions rather than site operations. Declining pressure trend to a minimum before surveys on the 21st seems to release more gas, followed by a sharp increase to a maximum on the 22nd where methane flux is supressed.
UAV mass balance	11	14/01 /2026	90	85	93	Above 85 % indicative benchmark	No, suspected under sampling of plume due to wind direction and restricted access to the boundary of the landfill. Additionally large changes in atmospheric	Survey not considered for regulatory outcome.	Survey not considered as representative of site performance due to potential under sampling of the plume leading to an overestimation of MCE. Significant changes in atmospheric pressure may have impacted measured fluxes during this survey. Therefore, it cannot be

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
							pressure may have influenced results.		determined whether this survey is representative of site performance under less variable atmospheric conditions.
TDM	12	14/01 /2026	73	71	75	Below indicative benchmark	No. Large changes in atmospheric pressure may have influenced results.	Survey not considered for regulatory outcome.	Significant changes in atmospheric pressure may have impacted measured fluxes during this survey. Therefore, it cannot be determined whether this survey is representative of site performance under less variable atmospheric conditions.
UAV mass balance	13	15/01 /2026	90	85	93	Above 85 % indicative benchmark	No, suspected under sampling of plume due to wind direction and restricted access to the boundary of the landfill. Additionally, there was an	Survey not considered for regulatory outcome.	Survey not considered as representative of site performance due to potential under sampling of the plume leading to an overestimation of MCE. Significant changes in atmospheric pressure may have impacted measured fluxes during this survey.

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
							engine down at the site which activated the flare during the start of the survey. Additionally large changes in atmospheric pressure may have influenced results.		Therefore, it cannot be determined whether this survey is representative of site performance under less variable atmospheric conditions.
TDM	14	15/01 /2026	64	61	-	Below indicative benchmark	No, there was an engine down at the site which activated the flare during the start of the survey. Additionally large changes in atmospheric pressure may have	Survey not considered for regulatory outcome.	Survey considered representative as lower MCE reflective of abnormal operation of the gas extraction system.

Survey Type	Survey No	Date	MCE (%)	MCE lower limit (%)	MCE upper limit (%)	Assessment of site performance	Normal survey conditions?	Regulatory outcome	Comment on survey representativeness of site performance
							influenced results.		

7.3 Considerations for regulatory deployment

The effective assessment of landfill gas management performance through measured MCEs should consider a number of key factors:

- MCE is affected by site operational conditions with MCE typically higher during normal operating conditions;
- Calculation and interpretation of MCE requires data on site gas management, operations and meteorological conditions;
- Calculation of MCE requires good data recovery from survey technique(s) used with no issues due to plumes that could not be sampled.

The first two of these factors are within the control of the landfill operator and would be expected to be satisfied under any regulatory implementation of the concept of MCE.

There may be some sites where either TDM or UAV mass balance measurements cannot be deployed due to site-specific constraints (e.g. limited adjacent road networks, restricted access to the site boundary or interference from adjacent sources outside the operator's control). Where these methods are not feasible, alternative methods for calculating MCE might be suitable, for example the DIAL method[13] or inverse modelling techniques.[14]

If no appropriate whole site methane emission measurement technique can be identified for a particular site, it may not be possible to implement a regulatory approach based on a calculated MCE at that individual landfill.

[13] Innocenti, F., Robinson, R., Gardiner, T., Finlayson, J., Connor, A., 2017. Differential absorption lidar (DIAL) measurements of landfill methane emissions. Rem. Sens. 9 (9), 953. https://doi.org/10.3390/rs9090953.

[14] https://www.gov.uk/government/publications/quantifying-methane-emissions-using-inverse-dispersion-modelling

8 Conclusions and recommendations

The analysis presented in this supplementary report supports the conclusions made in the main report. The following subsections provide the key findings from both phases of this study.

8.1 Use of UAV mass-balance surveys

The evidence in this supplementary report supports the observations made in the main report that measured fluxes by UAV mass balance are systematically lower than those measured by TDM. Based on the evidence detailed in the main report, the UAV survey team has updated the approached used to estimate the measurement uncertainty range. The results from the supplementary measurements show that the application of this method brings UAV measurements into closer agreement with those collected by TDM at sites Y1 and Z during the same time period.

This evidence strengthens the needs for uncertainty to be fully accounted for in any recommendation for including UAV as a regulatory monitoring technique. It is envisioned that some uncertainty in the UAV mass balance approach could be reduced in commercial surveys through improved operational flexibility and sensor deployment. For example, beyond visual line of sight (BVLOS) operations may allow wider transects to better capture the full lateral extent of the plume, while alternative sensing approaches may help quantify very near-surface and ground level plume regions that cannot be safely sampled directly by UAVs. It is important to distinguish between lateral and vertical sampling limitations, as they arise from different causes and must be accounted for in different ways. While near-surface dead space can be extrapolated using the methods described earlier in this report, failure to capture the lateral extent of a plume cannot be easily mitigated or accounted for. In the case of incomplete lateral sampling, any flux result would represent emissions from only part of the site upwind (projected from the wind angle at the lateral edges of the sampling plane). Therefore, while it may be possible to diagnose what parts of a site may not have been sampled due to incomplete lateral sampling, it would not be possible to extrapolate any flux estimate to areas of the site for which the downwind plume was not intercepted.

8.2 Use of TDM surveys

The additional evidence presented in this supplementary report shows consistency with the findings and conclusions set out in the main report. This supplementary report provides a good example (through measurements collected at site Y1 - see section 4.2.1) of the challenge in using the TDM approach to evaluate site performance at locations where multiple secondary sources are present.

The analysis shown in section 4.2.1 shows strong evidence that the survey team will need good knowledge of the site, the surrounding area, and the likely meteorological conditions when planning each visit. As shown in the Y1_T6 survey undertaken at site Y1, the sampling team will need to consider whether the sampling conditions are likely to capture methane emitted from the targeted landfill source alone or otherwise be able to account for the contribution to total methane measured by secondary sources. Much of the understanding of the site will need to be developed through ongoing review of the measurements when a TDM measurement is undertaken at the specific site.

8.3 Factors affecting methane flux

The evidence from this supplementary report adds to the evidence base that methane flux is strongly correlated to site operations and changes in temperature gradient and changes in pressure over the course of 6 hours.

The results shows that the extent of influence varies between sites, but all three sites surveyed by the TDM method were consistent in that the 5-day temperature gradient was either the first or second most influential factor. However, the direction of the relationship was not consistent across sites. Lower temperatures were associated with higher fluxes at sites Y1 and Z, whereas the opposite pattern was observed at site Y2. This inconsistency precludes the identification of an underlying mechanism by which temperature gradients influence emissions. The 6-hour air pressure gradient was also influential at sites Y1 and Y2 but not at site Z. The analysis at site Z shows that the abnormal operations linked to issues with cold weather impacting the functionality of the gas management system, was a key influence on methane flux. Abnormal operations were also included as a factor at site Y2, where new gas wells and connections were being completed.

This assessment was not able to fully quantify some of the factors which potentially affect methane emissions. For example, flaring operations was coded as either occurring (scored as 1) or not occurring (scored as 0) at the time of the survey measurement. The results therefore did not account for the rate of methane combustion at this time, or the flare combustion efficiency.

This study therefore provides clear evidence that there are several factors that should be considered when planning to undertake a site survey. It is critical that survey organisations have an understanding of what factors are most like to influence methane flux and that this is accounted for when planning for a survey to be undertaken so that the survey results are representative of normal conditions at the landfill site (as discussed in section 4.1). Equally it is important for those undertaking the surveys to be aware of how site activities and meteorological conditions are likely to influence the measurement collected. These observations will need to be reflected in survey design and implementation, the interpretation of measured data, and the survey report. The survey report should also detail what mitigation actions were undertaken to reduce uncertainties in the survey measurement due to the on the day conditions, enabling the results to be accepted as measurements representative of normal conditions.

8.4 Recommendations for regulatory assessment

This study provides further evidence that both TDM and UAV techniques could be used for potential regulatory approaches and should be planned with consideration of likely operational activities and meteorological conditions.

If the EA is minded to implement methane flux surveys using the techniques described in this report within the regulatory process, it is recommended that the EA considers the inclusion of the following information in any site survey report which may be required:

- evidence to show that the survey has been undertaken in normal operating conditions.
- details of weather conditions experienced by the site during the time of survey and for the previous five days;
- a method statement which shows that the survey has effectively measured the full plume released from the site only.

The findings from this supplementary report further supports the conclusion made in the main report that an understanding of the operation and management of the landfill site is important to ensure that methane survey results can be properly interpreted. The following points should be considered if surveys are carried out to assess the performance of landfill gas management:

- the constraints and limitations of the survey method used, and any factors to be considered in interpreting the results;
- have the conclusions from the survey report considered the potential influence of meteorological conditions and site activity on the survey results?
- are the results of the survey reflective of normal site conditions and operations?

If these survey techniques are applied in a regulatory setting, site operators and survey organisations should ideally develop over time, an understanding of the limitations of each survey technique and whether the technique is therefore suitable for use at the site. Operators could be supported by organisation expertise and any relevant guidance produced by the EA.

8.5 Recommendations for further work

This study provides strengthened evidence that both TDM and UAV surveys can be appropriate for regulatory use and should be applied with good understanding of the limitations of the method and in a period of stable operations and meteorological conditions.

There remains some important knowledge gaps which future research should look to bridge. It is recommended that:

- further TDM and UAV mass balance surveys are carried out at a wider range of sites. The results from this supplementary report show that each landfill used in this study has its own challenges for the application of each survey method. Carrying out measurements at a larger pool of sites is likely to lead to ongoing improvements in understanding of the suitability of each method and may inspire new solutions to mitigating uncertainty in the application of each method. There should be an emphasis on surveys using different techniques being carried out simultaneously, to further improve understanding of how the results from the two methods differ and can be reconciled.
- support should be given to the development of a robust standard operations procedure (SOP) for each method. Multiple survey operators should be consulted as part of developing these procedures. The consultations between these parties should be documented to enable transparency on how the SOP was developed and where limitations or differences in approach lie.
- further analysis on the influence of site conditions on methane emissions should be carried out as new survey data becomes available. This could be limited to surveys undertaken in specific circumstances to provide targeted evidence to add to the existing evidence base. New evidence should enable enhancements to the analysis undertaken in this report to be considered, such as more detailed quantification of the influence of site operations on methane emissions in the multi-factor analysis.
- methane storage within landfill cells could be investigated further, potentially by considering how the sum of methane collection and emission rates changes under conditions when this would be expected to be relatively constant.

Finally, any use of whole site methane emission measurements in landfill regulation would need to be supported by clear guidance on the selection of a suitable measurement method, the conditions under which to undertake surveys and how to interpret measurement data in the context of the design and operation of the landfill site.

A.1 Updated Standard operation procedure for TDM measurements

The standard operation procedure for the TDM survey method used in this study remained consistent with the procedures documented in section A6 of the main report.

A.2 Updated Standard operation procedure for UAV measurements

The Standard Operating Procedure for UAV-based methane measurements described in the main report remains applicable for the majority of the measurement workflow. This includes instrument operation, flight planning, execution of UAV transects, data screening and quality control, and the application of the mass balance approach used to derive the central methane flux estimate. No changes have been made to these elements of the procedure. Where operationally safe, UAV transects were conducted as close to the ground as practicable to minimise the extent of the unsampled near-surface layer.

The updated SOP introduces a refinement to the treatment of the vertical region below the lowest UAV transect, which is not directly sampled during flights. To account for the unsampled near-surface layer, an additional extrapolation step has been implemented. Methane concentrations measured at the lowest transect are extrapolated downwards to the ground to estimate a potential near-surface flux contribution.

This extrapolated flux component is used to assess the potential magnitude of emissions that may not be captured due to incomplete vertical sampling and therefore represents a potential low bias in the mass balance flux estimate. As this contribution reflects a directional bias rather than a symmetric source of uncertainty, it is incorporated only into the positive uncertainty bound. The extrapolated near-surface contribution is not included in the central flux estimate, which continues to be based solely on directly measured concentrations.

A.3 Comments on TDM and UAV methane balance surveys

A.3.1 Key notes from TDM surveys

Table 8-1: Key notes from TDM surveys at each site

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments
Y1	There was good access to the chosen tracer release location which was close to the active tipping area. As an active site, there were plant and vehicle movements during opening hours. But a safe place to work was allocated.	~1 hour	2-3 hours	Yes, the entire plume could be measured in any wind direction.	Historic landfills adjacent to Y1 and a nearby WWTP restricted surveys to certain wind directions. The road network was suitable for surveying most wind directions.	An on-site weather station provided as part of this project was used to plan surveys and for interpreting data.

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments
	Access was granted to work out-of-hours, including after dark.					
Y2	Access onto the landfill itself was not possible due to ground conditions (i.e. no paved routes). Access was also restricted somewhat due to plant movements and the need to allow vehicular access around the site's perimeter road. Out-of-hours access was not	~1 hour	2-3 hours	Yes, the entire plume could be measured in most wind directions.	A large WWTP close to the landfill restricted surveys to certain wind directions. No (accurate) weather station on site.	

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments
	permitted. However, we were permitted to set up close to the site entrance gates once the site had closed to allow after-dark surveys.					
Z	There was good access to the chosen tracer release location which was close to the active tipping area. As an active site, there were plant and vehicle movements during opening	~1 hour	2-3 hours	Yes, the entire plume could be measured in all wind directions and at multiple distances.	None	An on-site weather station provided as part of this project was used to plan surveys and for interpreting data.

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments
	hours. But a safe place to work was allocated and cordoned-off to allow safe working. Access was granted to work out-of-hours, including after dark.					

A.3.2 Key notes from UAV mass balance surveys

Table 8-2: Key notes from UAV surveys at each site

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments.
Y1	Site operators had advised in advance which portion of the site could be accessed. We were able to conduct site visit as planned	It typically takes 10 mins to sign in at the site. It typically takes approximately one hour to conduct test flights in order to set up and validate the automated waypoint flight paths.	A complete UAV survey takes approximately 30-40 minutes, consisting of two flights and one battery swap.	No.	Tree line limited lateral sampling.	

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments.
Z	Site operators had advised in advance which portion of the site could be accessed. We were able to conduct site visit as planned	It typically takes 10 mins to sign in at the site. It typically takes approximately one hour to conduct test flights in order to set up and validate the automated waypoint flight paths.	A complete UAV survey takes approximately 30-40 minutes, consisting of two flights and one battery swap.	No. The entire plume could not be captured. Surveys primarily focused on the active area of the site, as access to the far end was not possible due to ground conditions.	Limited site access due to muddy ground conditions restricted vehicle and operator movement at the far end of the site. For safety reasons, this area could not be accessed, preventing full spatial coverage of the plume. We would only be able to sample the full site if the from one side as we have limitations on how	

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments.
					far we can fly horizontally. This is due to the elongated shape of the site. With the correct certifications, it would be possible to fly further (i.e. Beyond Visual Line-Of-Sight, BVLOS).	
X	Site operators had advised in advance which portion of the site could be accessed. We were able to conduct site visit as planned	It typically takes 10 mins to sign in at the site. It typically takes approximately one hour to conduct test flights in order to	A complete UAV survey takes approximately 30-40 minutes, consisting of two flights and one battery swap.	Yes		

Site	Any issue in accessing site	Typical set up time at this site	Typical survey time at this site	Was it possible to capture the entire plume at this site	Barriers / limitations to completing surveys at this site	Other comments.
		set up and validate the automated waypoint flight paths.				

A.3.3 Note on TDM surveys at Site Y1

This difference in methane flux measured in the two TDM surveys, and the discrepancy in measured emissions between the TDM and UAV survey, may in part be explained by the presence of a secondary methane source downwind of the Site Y1.

A cluster of historic landfills, which were closed in the 1990s and are known to have accepted MSW, lie directly adjacent to Site Y1. A significant amount of methane was measured from these old sites when background screening was carried out during the site selection phase of the study (see report 1).

On the 27th, because of the wind direction, the only available monitoring route was ~3.5 km downwind of Site Y1. This was also directly downwind of the historic landfills.

Measurements made along this monitoring route would, therefore, include methane from Site Y1 and the historic landfills. Because the plumes overlap, it is not possible to separate out the two different sources which will result in a higher calculated methane flux. This is demonstrated in **Figure 8.1**. The Site Y1 methane plume is clearly identifiable, aligned with the tracer gas plume. The right-hand shoulder of the methane plume, however, includes methane from the historic landfills. We know this from the geolocation the concentration measurements when plotted on a map along with the wind direction.

During the survey carried out on the 28th, there was ~60° difference in the wind direction. Although methane plumes from the historic sites were measured, they did not overlap with the plumes from Y1 and could be excluded from the flux analysis. This is demonstrated in **Figure 8.2**, where the methane plumes from the two sources are distinct.

This may explain the difference between the flux of 132 kg/hour measured on 27 November 2025, which included gas from the historic sites, and 107 kg/hour measured on 28 November 2025 which did not. This suggests that ~25 kg/hour is being generated by the historic landfills. In the absence of a dedicated TDM survey from the historic sites, it is possible to check this estimate by applying the same TDM analysis from the survey on the 28th to just the methane from the historic sites (highlighted in red in **Figure 8.2**). This gives an average flux of ~35 kg/hour. Because the historic landfills were 0.5 to 1 km closer to the monitoring location than the tracer release point (i.e. the methane plume dispersion is shorter than the tracer gas dispersion), the flux calculation is not strictly valid, and will result in an overestimation of the amount of methane. However, this analysis is consistent with an estimated flux of approximately 25-30 kg/hour from the historic landfills.

Further TDM surveys at Site Y1 should only be carried out when the wind direction permits the separation of the two methane sources.

The additional methane from the historic sites measured by TDM on the 27th may account for some of the difference between the TDM and UAV results, because the additional methane from the historic sites would not have been measured by the UAV. However, this does not explain the magnitude of the discrepancy, or the significant difference between the TDM and UAV results on the 28th (where the historic sites were not measured by either method). It is likely that there is undersampling of the entire landfill plume by the UAV due to a tree line at this site, which limited lateral sampling (and the minimum height of sampling).

Figure 8.1: TDM tracer gas measurements collected on 27th November 2025

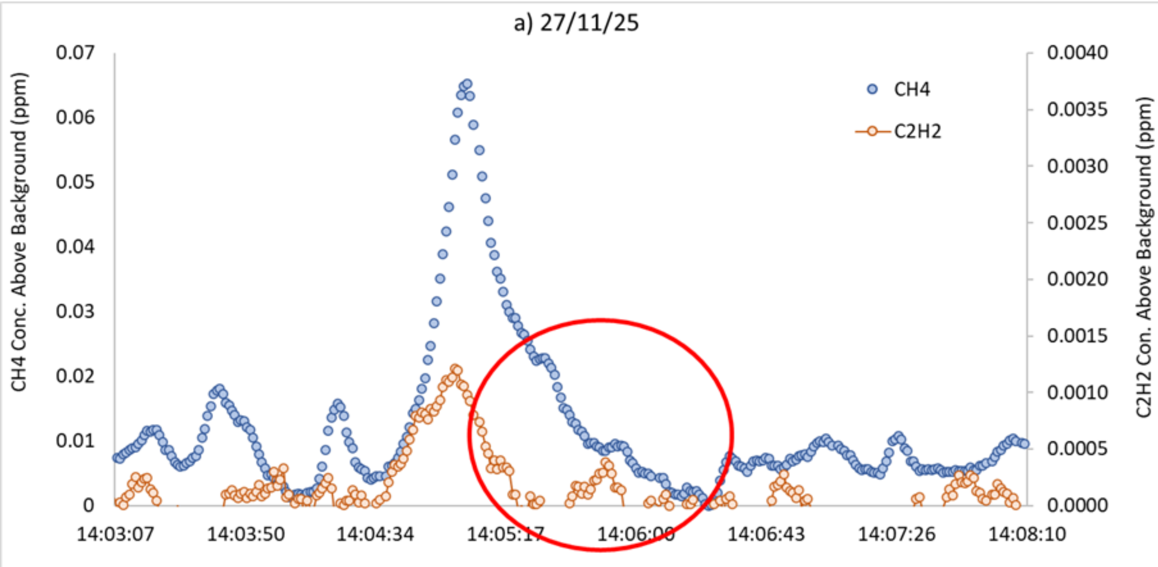
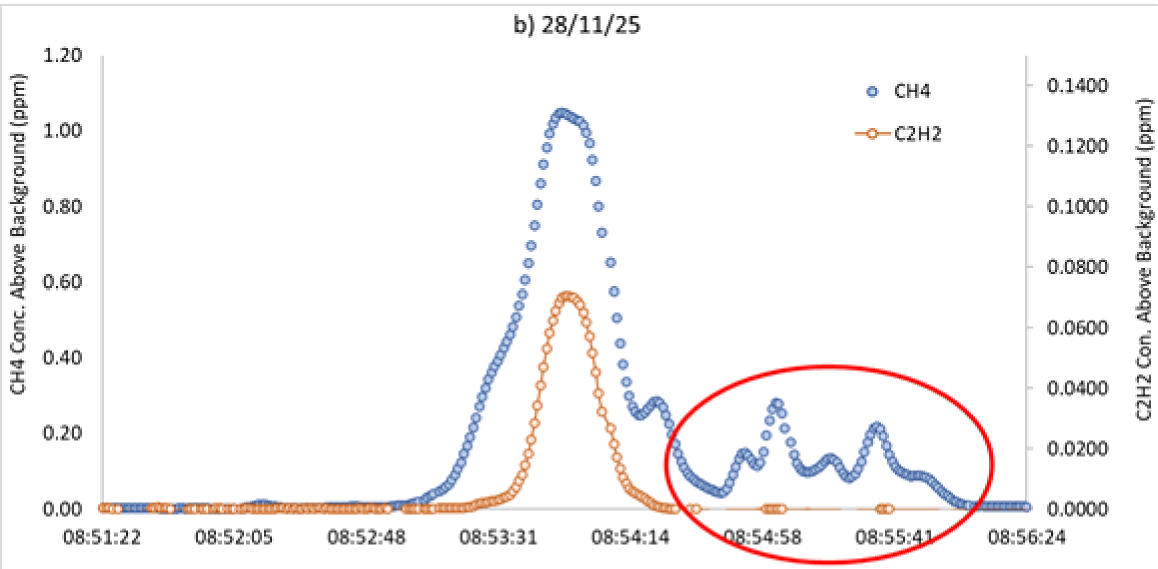


Figure 8.2: TDM tracer gas measurements collected on 27th November 2025



A.3.4 Note on TDM surveys at Site Y2

Site Y2 closed to tipping during the spring of 2025. Following the site closure, after a period of planning, restoration of the landfill commenced summer 2025 and was completed by December 2025. During the restoration period, new gas collection infrastructure was installed, and, at times, the existing gas collection was off-line to allow the new system to be connected.

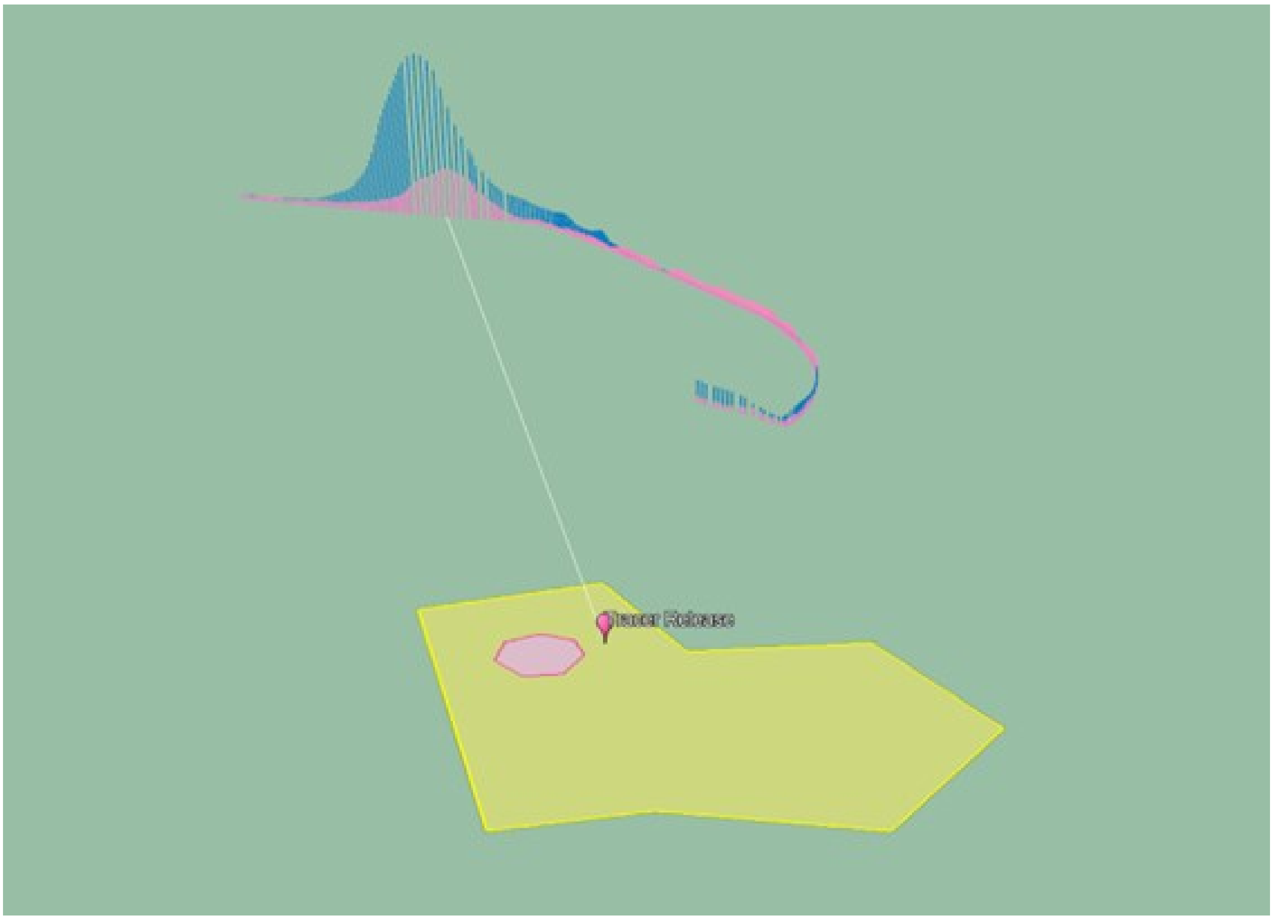
These site operations appear to be reflected in emission measurements carried out over this period. For example, in Survey Y2_T1 carried out in December 2024, the peak methane emission was in line with the operational area as shown in Figure 8.3. In this image, the approximate restored landfill area is shown in yellow, the operational area by the pink polygon, CH4 concentration is shown by the blue graph, C2H2 concentration by the pink graph, and the wind direction shown by the white line. The distance to the monitoring route from the tracer release point was ~ 3.7 km and the calculated emission flux was 126 kg/h.

In Survey Y2_T3 (Figure 8.4), carried out on 14/1/25 on the same monitoring route, the shape and magnitude of the methane plume is different, with two separate plumes: one originating from the tipping area and one from the restored parts of the landfill. The peak methane concentration is also lower, and this is reflected in the measured emission flux of 34 kg/h.

The double-peak is again observed in Survey Y2_T7 (Figure 8.5), carried 26/8/25, after closure, but during restoration. In this survey, the methane flux was 86 kg/h.

In Survey Y2_T9, which took place in December 2025 after all restoration and gas collection infrastructure had been completed, emissions were significantly lower, 31 kg/h, than in the previous surveys where restoration was still under way. In Figure 8.6, the methane concentration measured along the same monitoring route is plotted on the same scale as in Figure 8.5.

Figure 8.3: Methane and tracer gas concentration measured during Survey Y2_T1, 05/12/24



The restored landfill area is shown in yellow, the operational area by the pink polygon, CH4 concentration is shown by the blue graph, C2H2 concentration by the pink graph, and the wind direction shown by the white line.

Figure 8.4: Methane and tracer gas concentration measured during Survey Y2_T3, 14/01/25

Figure 8.5: Methane and tracer gas concentration measured during Survey Y2_T7 26/08/25, during restoration operations.

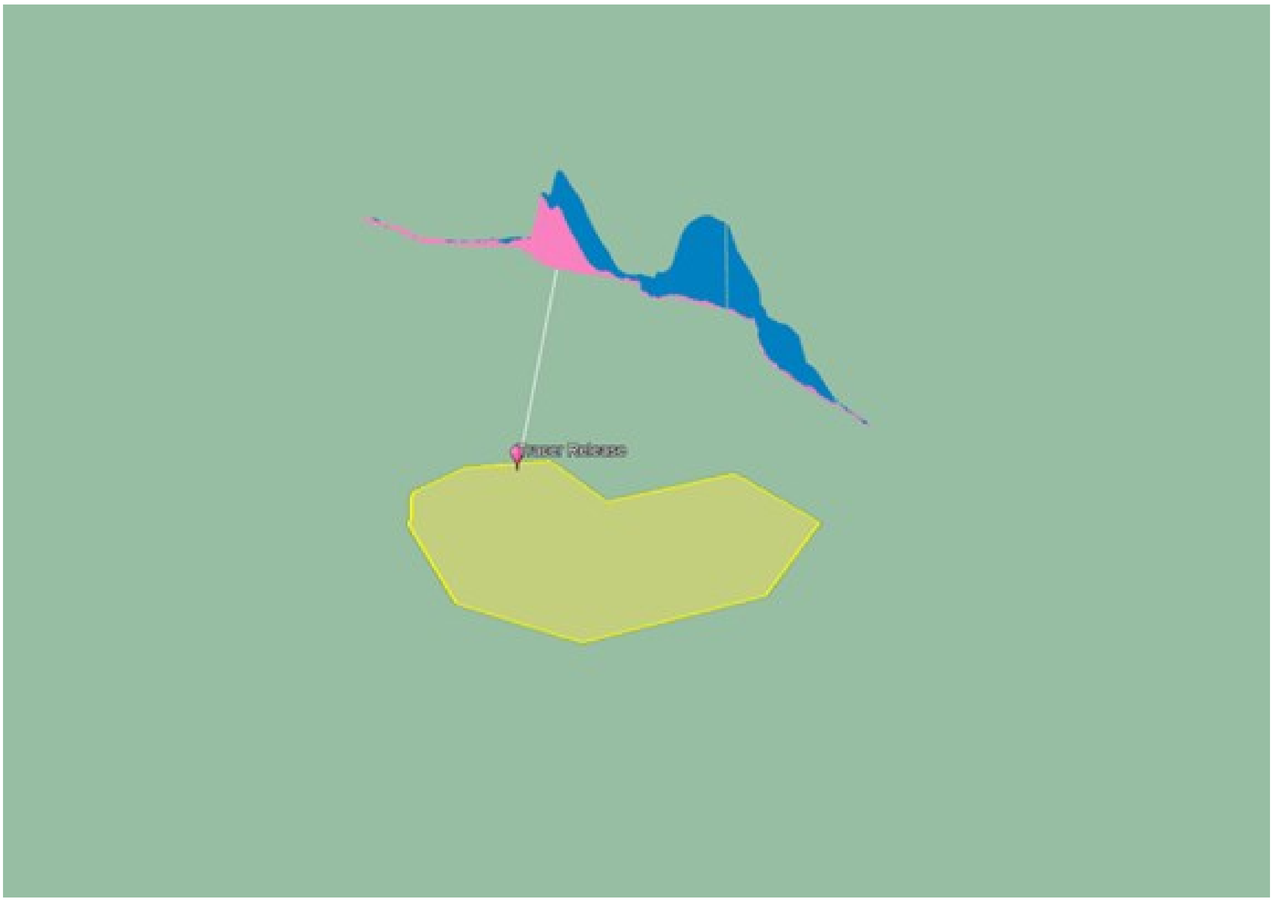


Figure 8.6: Methane and tracer gas concentration measured during Survey Y2_T9 10/12/25, after all restoration had been completed.

A.4 Meteorological conditions

The following tables detailed the meteorological conditions recorded during each survey visit.

A.4.1 TDM

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Y1_T1	19/10/2024	15:25-17:45	13.784	0.149	0	0	1013.479	0.124	1.719	312.2
Y1_T2	19/10/2024	21:30-23:06	10.318	0.277	0	0	1015.606	0.325	1.474	321.1
Y1_T3	10/12/2024	19:20-21:35	5.349	-0.422	0	0.2	1035.451	0.089	4.543	40.0
Y1_T4	09/01/2025	19:10-21:05	0.312	-0.968	0	0	1003.753	0.869	1.972	270.6
Y1_T5	27/02/2025	20:00-22:15	4.113	-0.848	0	0.2	1014.283	0.692	1.853	324.4
Y1_T6	27/11/2025	11:55-14:48	13.000	0.215	0	0	998.310	-0.340	5.551	211.5

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Y1_T7	28/11/2025	08:34 - 11:13	8.622	1.130	0	0	997.178	-0.195	4.589	191.7

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Y2_T1	05/12/2024	07:10-09:45	12.150	-1.662	0.200	4.296	1007.200	-1.018	5.417	220.0
Y2_T2	17/12/2024	12:40-14:45	9.271	0.930	0.000	0.000	1021.629	-0.898	5.556	194.3
Y2_T3	14/01/2025	13:27-15:32	8.150	1.569	0.000	0.000	1033.539	-0.054	3.225	245.6

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Y2_T4	04/02/2025	05:57-8:10	6.163	-0.001	0.100	0.077	1020.450	-0.340	6.701	196.3
Y2_T5	18/03/2025	17:14-19:20	8.082	0.857	-	-	1022.159	-0.393	5.631	84.1
Y2_T6	21/03/2025	10:30-12:36	15.707	1.367	0.000	0.000	1008.113	-0.648	6.074	105.3
Y2_T7	26/08/2025	21:06 - 23:45	19.000	1.435	0.000	0.800	1006.529	0.273	3.135	237.1
Y2_T8	02/10/2025	17:30 - 20:15	16.667	0.573	0.000	0.000	1018.553	-0.759	5.852	185.3
Y2_T9	10/12/2025	12:02-15:00	11.867	0.833	0.000	0.069	1013.667	0.644	6.667	234.7

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Z_T1	20/01/2025	12:54 – 16:10	6.683	-1.215	0.000	0.000	1008.050	-0.992	3.059	227.1
Z_T2	20/01/2025	19:22 – 21:19	5.088	-0.957	0.000	0.000	1012.602	0.592	2.092	227.2
Z_T3	19/03/2025	17:29 – 19:33	1.577	0.096	0.000	0.000	1017.981	-0.019	1.756	184.5
Z_T4	19/03/2025	22:45 – 01:16	5.984	0.058	0.000	0.000	1014.378	-0.330	2.912	150.0
Z_T5	21/10/2025	12:08 – 15:36	12.550	0.400	0.300	0.319	979.600	-0.106	3.216	211.0
Z_T6	22/10/2025	09:34 – 11:14	11.033	-0.200	0.000	1.295	988.100	0.395	4.918	248.6
Z_T7	14/01/2026	12:30 – 15:15	5.712	1.021	0.000	0.005	1001.027	-0.229	5.020	191.9

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Z_T8	15/01/2026	11:25 – 13:00	6.375	0.200	0.000	0.000	992.752	0.351	4.170	178.5

A.4.2 UAV mass balance

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Y1_U1	29/10/2024	13:12 – 13:22 13:36 – 13:43	14.659	-0.045	0.000	0.000	1012.750	0.188	2.281	310.3
Y1_U2	29/10/2024	14:00 – 14:12	14.931	-0.002	0.000	0.000	1012.815	0.139	1.511	296.1

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Y1_U3	29/10/2024	15:24 – 15:36	14.477	0.086	0.000	0.000	1012.985	0.082	1.494	331.5
Y1_U4	29/10/2024	16:00 – 16:20	14.129	0.123	0.000	0.000	1012.933	0.082	1.700	300.7
Y1_U6	30/10/2024	10:20 – 10:34	11.297	0.366	0.000	0.000	1018.046	0.272	1.547	324.5
Y1_U7	30/10/2024	10:47 – 11:01 11:12 – 11:25	11.476	0.385	0.000	0.000	1017.818	0.193	1.128	329.4
Y1_U8	27/11/2025	11:41 – 11:53 12:02 – 12:13	12.152	-0.006	0.000	0.000	999.674	-0.068	5.229	214.8

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Y1_U9	27/11/2025	10:39 – 11:07	12.410	0.074	0.000	0.000	998.980	-0.170	5.761	214.6
Y1_U10	27/11/2025	11:36 – 12:05	13.111	0.222	0.000	0.000	998.359	-0.345	5.842	208.7
Y1_U11	27/11/2025	13:03 – 13:49	13.446	0.342	0.000	0.000	997.614	-0.466	5.221	214.8
Y1_U12	28/11/2025	14:18 – 14:56	8.288	1.120	0.000	0.000	997.180	-0.192	4.399	190.1
Y1_U13	28/11/2025	09:27 – 09:55	9.400	1.149	0.000	0.000	997.062	-0.200	4.998	194.7

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Z_U1	20/01/2025	13:10 – 13:21	6.775	-1.354	0.000	0.000	1008.892	-1.434	3.568	241.5
Z_U2	20/01/2025	13:42 – 13:53	6.942	-1.309	0.000	0.000	1008.667	-1.423	3.638	240.5
Z_U3	20/01/2025	14:26 – 14:39 14:45 – 14:48	6.757	-1.242	0.000	0.000	1008.087	-1.261	3.453	228.3
Z_U4	20/01/2025	15:09 – 15:21	6.669	-1.194	0.000	0.000	1007.869	-0.984	3.257	230.2
Z_U5	21/01/2025	11:17 – 11:29 11:36 – 11:48	5.759	-0.711	0.000	0.000	1003.866	-1.259	1.144	262.3

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Z_U6	21/01/2025	12:45 – 12:56 13:13 – 13:18	6.232	-0.616	0.000	0.000	1003.462	-1.368	2.493	186.0
Z_U7	21/01/2025	14:14 – 14:27 14:36 – 14:46	7.867	-0.492	0.000	0.000	1002.548	-0.963	3.105	253.5
Z_U8	21/10/2025	13:25 – 13:56	12.523	0.406	0.459	0.563	979.441	-0.135	3.037	206.7
Z_U9	22/10/2025	08:47 – 08:59	10.688	-0.199	0.000	1.295	988.100	0.434	4.999	250.5
Z_U10	22/10/2025	09:47 – 10:21	11.465	-0.198	0.000	1.295	988.100	0.337	4.817	246.1

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Z_U11	22/10/2025	10:45 – 11:17	12.090	-0.187	0.000	1.295	988.100	0.256	4.670	242.6
Z_U12	22/10/2025	12:30 – 12:57	13.066	-0.142	0.000	1.085	988.081	0.093	4.831	240.9
Z_U13	14/01/2026	11:05 – 11:32	4.638	1.076	0.000	0.312	1002.465	0.265	3.333	164.6
Z_U14	14/01/2026	12:35 – 13:03	5.378	1.038	0.000	0.034	1001.560	-0.028	4.794	186.0
Z_U15	14/01/2026	13:37 – 14:09	5.899	1.018	0.000	0.000	1000.923	-0.277	5.760	201.0
Z_U16	14/01/2026	14:57 – 15:24	5.694	0.997	0.000	0.000	1000.155	-0.513	4.157	179.2
Z_U17	15/01/2026	9:55 – 10:25	5.664	0.222	0.000	0.000	992.436	0.228	4.211	185.0

Survey ID	Date	Time	Temp (oC)	5-day Temp gradient (oC/day)	Precipitation in previous hour (mm)	Precipitation in previous 24 hours (mm)	Air pressure (kPa)	6-hour air pressure gradient (kPa/h)	Wind speed (m/s)	Wind direction (degrees)
Z_U18	15/01/2026	11:19 – 11:49	6.406	0.202	0.000	0.000	992.800	0.350	4.437	176.3
Z_U19	15/01/2026	12:16 – 12:43	6.385	0.200	0.000	0.000	992.736	0.354	4.065	178.9
Z_U20	15/01/2026	13:29 – 14:00	6.548	0.205	0.000	0.000	992.614	0.232	3.542	174.8

A.5 Assessment of factors affecting methane emissions

Methane flux and methane collection efficiency were evaluated at all four case study sites on multiple occasions. This appendix provides updated analysis for Sites Y1, Y2 and Z. For analysis specific to Site X please see the previous report. This report also includes analysis across all sites including site X. This enables an evaluation to be carried out of the factors that are correlated with changes in methane flux and methane collection efficiency. This in turn may provide pointers to the cause of differences in flux and methane collection efficiency.

Methane flux cannot readily be compared between sites because of differences resulting from factors including the quantity, type and age of waste, historical landfill practices, and the extent of installed controls. In contrast, methane collection efficiency (MCE) is designed to be readily compared between sites. We have therefore evaluated the influence of potentially relevant factors on methane flux at individual sites, and the influence of these factors on MCE at individual sites and at all sites.

A multifactor correlation analysis was carried out in each case, to identify the extent to which each factor was correlated with methane flux and MCE. It was inherently assumed that if any correlation exists, it can be represented as a linear correlation within the range of values observed in each survey.

The potential contribution of each observed factor (weather conditions and operational factors) to the calculated methane flux and MCE for each survey period was evaluated using a multivariate correlation approach. The weather conditions and site operational factors recorded during each survey were tabulated alongside the calculated methane flux and MCE. The aim of this was to determine if the observed factors were significantly correlated with changes in methane flux and MCE. The significance of each observed factor in determining the calculated change in methane flux or MCE (assuming a causal relationship exists) was determined as follows:

(a) Obtain the correlation coefficient of each observed factor with the calculated methane flux or MCE (value A in the tables below)
(b) Calculate the standard deviation of each observed factor as an indication of the variation of each parameter (value B in the tables below)
(c) Multiply A by B to give an indication of how much changes in each observed factor affect the calculated change in methane flux or MCE.

This approach was adopted to enable a focus on parameters which are important in determining methane flux and MCE. For example, some meteorological values have a relatively high numerical value (e.g. atmospheric pressure) but vary to a much more limited extent around these higher values. Considering the product of correlation coefficient and standard deviation enables the influence of each parameter on methane flux and MCE (assuming a causal relationship) to be understood.

The factors considered were divided into environmental factors which were common to all sites, and operational factors which were identified separately for all sites and depended on the relevance of different factors to each site and the availability of information. Operational factors were modelled using a binary system of applying a factor of 0 or 1.

Environmental factors:

- Precipitation in previous hour (mm)
- Precipitation in previous 24 hours (mm)
- Air temperature at the time of the survey(^{o}C)
- Air temperature gradient for the preceding five days (^{o}C/day)
- Air pressure at the time of the survey (kPa)
- Air pressure gradient for the preceding period (kPa/hr)

Previously, the air pressure gradient over a period of 24 hours had been evaluated. Since completion of the previous report, independent studies have indicated that the relevant period for air pressure gradient to affect methane flux is a shorter period, likely to be 6 hours or less. An analysis of several periods was carried out to determine the time period which appeared to be most closely associated with changes in methane flux and MCE, as follows:

- Air pressure gradient for the preceding 24 hours (kPa/hr)
- Air pressure gradient for the preceding 6 hours (kPa/hr)
- Air pressure gradient for the preceding 5 hours (kPa/hr)
- Air pressure gradient for the preceding 4 hours (kPa/hr)
- Air pressure gradient for the preceding 3 hours (kPa/hr)
- Air pressure gradient for the preceding 2 hours (kPa/hr)

Operational factors:

- Site Y1: Tipping taking place
- Site Y2: Flare operating; issue with engines; tipping taking place; open tipping face
- Site Z: Tipping taking place; flaring taking place

The total quantity of methane collected and emitted at Site Y2 was found to be significantly different during Surveys 2 and 3 compared to the total quantity of methane identified during Surveys 1, 4, 5 and 6. The overall quantity during Surveys 2 and 3 was less than half that identified during the other surveys. As a result, these two surveys were treated separately in the correlation analysis. At other sites, there was no evidence for systematic differences in the quantity of methane collected and emitted.

The analysis results are based on the follow equation and should be interpretated as:

$$mf = intercept - c[V1] * V1 + c[V2] * V \ldots . V[\quad] * V[]$$

- mf is the predicted methane flux (the dependent variable).
- intercept is the adjusted starting position for the prediction from 0.
- c[] is the coefficient of each respective independent variable (e.g c[V1] is the calculated coefficient of the first variable. This can be viewed as how much the mf (dependent variable) is changed by a unit change in V [independent variable], for example a temperature coefficient of 2 would mean that the predicted methane flux would double for each temperature increase should all other variables remain the same.
- V (number) is a variable

Each table in this section of analysis presents the coefficients for each variable and its corresponding level of variance (the standard deviation). The potential contribution is coefficient multiplied by the variance. The potential contribution provides a value that reflects the influence that the observed variation in one of the factors would be predicted to have on methane flux or the methane collection efficiency, assuming a causal relationship exists.

A.5.1 Factors correlated with methane flux at individual sites (both TDM & UAV mass balance)

Table 8-3 Factors correlated with methane flux: Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	-5.662	-13.307	-8.350	-4.971	-4.507	-5.091
Temp (°C)	1.989	-10.836	-10.143	-9.721	-9.684	-9.577
5 day T gradient (°C/day)	40.615	-10.524	0.147	9.604	10.707	9.772
Flaring	NA	NA	NA	NA	NA	NA
Tipping	1.780	-7.985	-2.219	1.862	2.356	1.817
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	-1.758	-3.254	0.667	4.385	4.821	4.529

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Air pressure gradient (kPa/hr) (see column for window)	41.168	-21.079	-10.440	-0.992	0.104	-0.822
Correlation coefficient (R^2)	0.170	0.207	0.173	0.158	0.158	0.159
Based on 156 observations						

Table 8-4 Factors correlated with methane flux: Site Y2

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	3.863	3.466	4.796	4.366	-0.238	-1.155
Precipitation in previous 24 hours (mm)	-96.337	-4.082	5.446	15.599	-24.138	-14.919
Temp (°C)	-21.628	-20.066	-22.669	-19.801	10.752	15.324
5 day T gradient (°C/day)	-22.621	97.270	154.696	187.339	180.719	216.123

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Flaring	-13.674	-18.945	-21.513	-20.282	-1.884	4.854
Tipping	33.151	90.026	148.463	182.840	232.669	269.816
Abnormal operation	45.893	11.179	3.097	-4.074	-30.806	-38.439
Air pressure (kPa)	-38.077	-4.482	19.816	40.591	59.834	86.603
Air pressure gradient (kPa/hr) (see column for window)	-48.083	-42.878	-41.840	-38.598	-19.297	-14.640
Correlation coefficient (R^2)	0.869	0.869	0.867	0.864	0.853	0.854
Based on 83 observations						

Table 8-5 Factors correlated with methane flux: Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	15.88543	23.39641	23.20888	21.21172	20.79809	20.41281
Precipitation in previous 24 hours (mm)	-37.6402	-52.9169	-51.8623	-49.1701	-48.9919	-48.3359
Temp (ºC)	26.5463	29.2813	27.28732	19.45822	15.78832	17.03868
5 day T gradient (oC/day)	-5.55146	-17.3685	-15.6104	-20.5895	-34.1065	-25.4936
Flaring	-56.7181	-36.0817	-33.0398	-40.8452	-56.0369	-51.5086
Tipping	-7.32289	21.53764	22.15524	-1.269	-36.8456	-22.3333
Abnormal operation	22.32819	32.3092	29.1095	17.42721	-3.1778	9.9209
Air pressure (kPa)	16.26153	22.93722	21.78994	10.42568	7.145025	6.19961
Air pressure gradient (kPa/hr) (see column for window)	-16.0981	24.56067	25.05689	7.988849	-16.9172	-6.6766
Correlation coefficient (R^2)	0.696	0.698	0.708	0.691	0.695	0.690
Based on 253 observations						

A.5.2 Factors correlated with methane flux at individual sites – TDM only

Table 8-6 Factors correlated with methane flux (TDM only): Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	-6.067	-22.077	-16.074	-12.113	-13.637	-11.740
Temp (°C)	14.708	-0.837	-0.016	-0.798	-0.603	0.522
5 day T gradient (°C/day)	61.346	-42.248	-31.537	-15.662	-12.672	-6.286
Flaring	NA	NA	NA	NA	NA	NA
Tipping	6.045	-17.004	-9.353	-2.626	-2.143	0.218
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	-4.772	-15.133	-10.758	-3.745	-1.475	1.989
Air pressure gradient (kPa/hr) (see column for window)	71.536	-45.283	-34.857	-20.356	-17.371	-11.833
Correlation coefficient (R^2)	0.380	0.450	0.440	0.409	0.452	0.481
Based on 136 observations						

Table 8-7 Factors correlated with methane flux (TDM only): Site Y2

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	3.863	3.466	4.796	4.366	-0.238	-1.155
Precipitation in previous 24 hours (mm)	-96.337	-4.082	5.446	15.599	-24.138	-14.919
Temp (°C)	-21.628	-20.066	-22.669	-19.801	10.752	15.324
5 day T gradient (°C/day)	-22.621	97.270	154.696	187.339	180.719	216.123
Flaring	-13.674	-18.945	-21.513	-20.282	-1.884	4.854
Tipping	33.151	90.026	148.463	182.840	232.669	269.816
Abnormal operation	45.893	11.179	3.097	-4.074	-30.806	-38.439
Air pressure (kPa)	-38.077	-4.482	19.816	40.591	59.834	86.603
Air pressure gradient (kPa/hr) (see column for window)	-48.083	-42.878	-41.840	-38.598	-19.297	-14.640
Correlation coefficient (R^2)	0.869	0.869	0.867	0.864	0.853	0.854
Based on 83 observations						

Table 8-8 Factors correlated with methane flux (TDM only): Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	32.246	33.820	36.064	34.969	35.849	35.478
Precipitation in previous 24 hours (mm)	-42.469	-44.871	-47.237	-46.151	-47.177	-46.832
Temp (ºC)	35.326	30.429	37.112	34.197	32.910	35.170
5 day T gradient (ºC/day)	-70.511	-80.897	-80.512	-80.150	-97.584	-88.030
Flaring	-19.159	-16.024	-8.323	-12.001	-22.623	-19.492
Tipping	4.257	-5.154	10.361	4.274	-25.748	-12.659
Abnormal operation	-59.479	-72.387	-70.692	-69.823	-95.594	-82.276
Air pressure (kPa)	67.776	64.501	76.469	70.718	74.183	74.226
Air pressure gradient (kPa/hr) (see column for window)	-4.280	-5.239	5.692	1.264	-20.233	-11.009
Correlation coefficient (R^2)	0.770	0.770	0.770	0.770	0.776	0.771
Based on 211 observations						

A.5.3 Factors correlated with methane flux at individual sites – UAV only

Table 8-9 Factors correlated with methane flux (UAV only): Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	NA	NA	NA	NA	NA	NA
Temp (°C)	-232.986	-117.104	1.536224	21.92353	21.74308	1.123218
5 day T gradient (°C/day)	237.1549	-191.237	-10.1862	3.939092	3.068982	1.166396
Flaring	NA	NA	NA	NA	NA	NA
Tipping	NA	NA	NA	NA	NA	NA
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	-433.601	122.8138	19.43564	21.10771	22.78091	12.96555
Air pressure gradient (kPa/hr) (see column for window)	126.0328	-83.4785	-6.99934	0.546369	1.947924	11.21522
Correlation coefficient (R^2)	0.461	0.431	0.059	0.042	0.048	0.096
Based on 20 observations						

Table 8-10 Factors correlated with methane flux (UAV only): Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-336.492	-263.91	-277.072	-203.373	19.25142	-89.3346
Precipitation in previous 24 hours (mm)	-248.808	-289.274	-247.524	-110.177	191.9699	-2.06714
Temp (°C)	101.3413	127.7542	110.7951	115.3652	100.8293	46.70793
5 day T gradient (°C/day)	-1431.31	-1331.84	-1382.4	-1047.85	-36.864	-459.394
Flaring	NA	NA	NA	NA	NA	NA
Tipping	NA	NA	NA	NA	NA	NA
Abnormal operation	2160.034	2127.267	2159.741	1780.385	463.0486	881.9037
Air pressure (kPa)	-3747.74	-3358.65	-3515.7	-2705.48	-156.677	-1241.34
Air pressure gradient (kPa/hr) (see column for window)	-130.362	141.0305	44.33577	9.464878	-32.4585	-36.175
Correlation coefficient (R^2)	0.868	0.874	0.872	0.871	0.893	0.890
Based on 42 observations						

A.5.4 Factors correlated with MCE at individual sites (TDM & UAV mass balance)

Table 8-11 Factors correlated with MCE: Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	-0.001	0.011	0.001	-0.006	-0.006	-0.004
Temp (°C)	-0.008	0.022	0.020	0.020	0.020	0.020
5 day T gradient (°C/day)	-0.095	0.013	-0.010	-0.029	-0.028	-0.024
Flaring	NA	NA	NA	NA	NA	NA
Tipping	0.000	0.016	0.004	-0.004	-0.004	-0.002
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	0.020	0.018	0.009	0.002	0.002	0.004
Air pressure gradient (kPa/hr) (see column for window)	-0.098	0.036	0.013	-0.005	-0.005	-0.001
Correlation coefficient (R^2)	0.157	0.172	0.148	0.145	0.145	0.144
Based on 156 observations						

Table 8-12 Factors correlated with MCE: Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-0.026	-0.034	-0.033	-0.031	-0.030	-0.030
Precipitation in previous 24 hours (mm)	0.072	0.087	0.085	0.082	0.082	0.081
Temp (°C)	-0.039	-0.045	-0.042	-0.033	-0.029	-0.031
5 day T gradient (°C/day)	0.012	0.020	0.019	0.025	0.041	0.030
Flaring	0.101	0.079	0.076	0.086	0.104	0.098
Tipping	0.010	-0.027	-0.025	0.004	0.046	0.028
Abnormal operation	-0.036	-0.051	-0.046	-0.031	-0.007	-0.024
Air pressure (kPa)	-0.033	-0.044	-0.041	-0.028	-0.025	-0.023
Air pressure gradient (kPa/hr) (see column for window)	0.014	-0.030	-0.028	-0.008	0.022	0.009
Correlation coefficient (R^2)	0.827	0.830	0.834	0.826	0.828	0.826
Based on 253 observations						

A.5.5 Factors correlated with MCE at individual sites – TDM only

Table 8-13 Factors correlated with MCE (TDM only): Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	-0.001	0.031	0.018	0.010	0.014	0.010
Temp (°C)	-0.034	-0.001	-0.003	-0.001	-0.002	-0.004
5 day T gradient (°C/day)	-0.130	0.085	0.063	0.030	0.026	0.013
Flaring	NA	NA	NA	NA	NA	NA
Tipping	-0.010	0.037	0.021	0.007	0.007	0.002
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	0.026	0.046	0.037	0.022	0.019	0.012
Air pressure gradient (kPa/hr) (see column for window)	-0.152	0.092	0.070	0.040	0.035	0.025
Correlation coefficient (R^2)	0.276	0.343	0.332	0.297	0.348	0.383
Based on 136 observations						

Table 8-14 Factors correlated with MCE (TDM only): Site Y2

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-0.009	-0.007	-0.011	-0.009	0.002	0.004
Precipitation in previous 24 hours (mm)	0.162	-0.068	-0.090	-0.108	-0.012	-0.048
Temp (°C)	0.052	0.042	0.048	0.036	-0.037	-0.042
5 day T gradient (°C/day)	0.041	-0.267	-0.408	-0.482	-0.466	-0.572
Flaring	0.056	0.066	0.072	0.066	0.022	0.009
Tipping	-0.020	-0.177	-0.322	-0.410	-0.528	-0.626
Abnormal operation	-0.139	-0.045	-0.025	-0.003	0.061	0.076
Air pressure (kPa)	0.057	-0.034	-0.094	-0.146	-0.191	-0.263
Air pressure gradient (kPa/hr) (see column for window)	0.123	0.106	0.103	0.092	0.046	0.038
Correlation coefficient (R^2)	0.894	0.891	0.887	0.882	0.866	0.870

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Based on 83 observations						

Table 8-15 Factors correlated with MCE (TDM only): Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-0.050	-0.049	-0.051	-0.050	-0.051	-0.051
Precipitation in previous 24 hours (mm)	0.074	0.073	0.075	0.073	0.075	0.075
Temp (ºC)	-0.057	-0.055	-0.061	-0.057	-0.056	-0.059
5 day T gradient (ºC/day)	0.113	0.112	0.112	0.112	0.133	0.123
Flaring	0.043	0.046	0.038	0.043	0.056	0.054
Tipping	0.000	0.005	-0.010	-0.002	0.035	0.023
Abnormal operation	0.104	0.104	0.103	0.102	0.134	0.121
Air pressure (kPa)	-0.119	-0.116	-0.127	-0.120	-0.125	-0.126
Air pressure gradient (kPa/hr) (see column for window)	-0.001	0.003	-0.007	-0.001	0.025	0.017
Correlation coefficient (R^2)	0.871	0.871	0.872	0.871	0.875	0.873
Based on 211 observations						

A.5.6 Factors correlated with MCE at individual sites – UAV only

Table 8-16 Factors correlated with MCE (UAV only): Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	NA	NA	NA	NA	NA	NA
Temp (°C)	0.583	0.304	0.006	-0.047	-0.047	0.002
5 day T gradient (°C/day)	-0.579	0.492	0.036	-0.002	0.000	0.005
Flaring	NA	NA	NA	NA	NA	NA
Tipping	NA	NA	NA	NA	NA	NA
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	1.071	-0.311	-0.050	-0.054	-0.058	-0.035
Air pressure gradient (kPa/hr) (see column for window)	-0.312	0.211	0.019	-0.001	-0.004	-0.027
Correlation coefficient (R^2)	0.456	0.442	0.067	0.048	0.052	0.097
Based on 20 observations						

Table 8-17: Factors correlated with MCE (UAV only): Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	0.410	0.330	0.346	0.237	-0.061	0.097
Precipitation in previous 24 hours (mm)	0.329	0.398	0.341	0.144	-0.259	0.021
Temp (°C)	-0.128	-0.161	-0.139	-0.144	-0.124	-0.050
5 day T gradient (°C/day)	1.780	1.698	1.756	1.262	-0.092	0.530
Flaring	NA	NA	NA	NA	NA	NA
Tipping	NA	NA	NA	NA	NA	NA
Abnormal operation	-2.707	-2.715	-2.749	-2.180	-0.411	-1.039
Air pressure (kPa)	4.637	4.255	4.441	3.239	-0.178	1.419
Air pressure gradient (kPa/hr) (see column for window)	0.159	-0.183	-0.057	-0.009	0.047	0.050
Correlation coefficient (R^2)	0.948	0.975	0.957	0.938	0.956	0.945
Based on 42 observations						

A.5.7 Factors correlated with MCE at all sites

Table 8-18 Factors correlated with MCE: All sites

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-0.016	-0.022	-0.023	-0.023	-0.024	-0.024
Precipitation in previous 24 hours (mm)	0.067	0.068	0.070	0.070	0.071	0.073
Temp (°C)	-0.014	-0.018	-0.020	-0.021	-0.023	-0.025
5 day T gradient (°C/day)	0.055	0.064	0.065	0.065	0.066	0.067
Flaring	0.027	0.019	0.016	0.014	0.011	0.006
Tipping	-0.036	-0.035	-0.038	-0.038	-0.039	-0.042
Abnormal operation	-0.062	-0.082	-0.082	-0.081	-0.078	-0.074
Air pressure (kPa)	0.006	0.011	0.011	0.010	0.010	0.010
Air pressure gradient (kPa/hr) (see column for window)	0.032	-0.006	-0.012	-0.013	-0.017	-0.024
Correlation coefficient (R^2)	0.622	0.603	0.606	0.608	0.612	0.623
Based on 587 observations						

Table 8-19 Factors correlated with MCE: All sites (TDM only)

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-0.013	-0.017	-0.018	-0.018	-0.019	-0.019
Precipitation in previous 24 hours (mm)	0.070	0.071	0.072	0.074	0.076	0.077
Temp (°C)	-0.020	-0.025	-0.027	-0.029	-0.032	-0.033
5 day T gradient (°C/day)	0.061	0.069	0.069	0.070	0.071	0.072
Flaring	0.028	0.020	0.017	0.013	0.007	0.004
Tipping	-0.055	-0.054	-0.056	-0.058	-0.059	-0.060
Abnormal operation	-0.064	-0.079	-0.079	-0.077	-0.072	-0.068
Air pressure (kPa)	0.002	0.008	0.007	0.007	0.006	0.006
Air pressure gradient (kPa/hr) (see column for window)	0.026	-0.006	-0.011	-0.016	-0.022	-0.027
Correlation coefficient (R^2)	0.648	0.634	0.637	0.642	0.650	0.662
Based on 500 observations						

Table 8-20 Factors correlated with MCE: All sites (UAV only)

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	0.007	-0.019	-0.016	-0.014	-0.011	-0.009
Precipitation in previous 24 hours (mm)	-0.043	-0.092	-0.098	-0.108	-0.087	-0.093
Temp (ºC)	-0.088	-0.115	-0.113	-0.114	-0.095	-0.092
5 day T gradient (ºC/day)	-0.091	-0.060	-0.073	-0.087	-0.066	-0.073
Flaring	NA	NA	NA	NA	NA	NA
Tipping	NA	NA	NA	NA	NA	NA
Abnormal operation	-0.194	-0.321	-0.283	-0.268	-0.228	-0.227
Air pressure (kPa)	-0.013	-0.058	-0.057	-0.060	-0.053	-0.055
Air pressure gradient (kPa/hr) (see column for window)	0.083	-0.059	-0.011	0.023	0.037	0.039
Correlation coefficient (R^2)	0.918	0.913	0.910	0.915	0.931	0.917
Based on 87 observations						

A.6 Estimated change in methane storage by survey

A.6.1 Site Y1

Table 8-21 Estimated change in methane storage at Y1: TDM

Survey No.	Date	Total methane generated (kg/h)	Average methane generated (kg/h)	Estimated change in methane storage (kg/h)
Y1_T1	29/10/2024	407	388	-19
Y1_T2	29/10/2024	402	388	-13
Y1_T3	10/12/2024	413	388	-25
Y1_T4	09/01/2025	384	388	4
Y1_T5	27/02/2025	327	388	61
Y1_T6	27/11/2025	403	388	-14
Y1_T7	28/11/2025	383	388	6

Table 8-22 Estimated change in methane storage at Y1: UAV mass balance

Survey No.	Date	Total methane generated (kg/h)	Average methane generated (kg/h)	Estimated change in methane storage (kg/h)
Y1_U_291024	29/10/2024	362	339	-23
Y1_U_301024	30/10/2024	374	339	-35
Y1_U_271125	27/11/2025	306	339	33
Y1_U_281125	28/11/2025	314	339	25

A.6.2 Site Y2

Table 8-23 Estimated change in methane storage at Y2: TDM

Survey No.	Date	Total methane generated (kg/h)	Average methane generated (kg/h)	Estimated change in methane storage (kg/h)
Y2_T1	05/12/2024	578	453	-125
Y2_T2	17/12/2024	212	453	241
Y2_T3	14/01/2025	246	453	207
Y2_T4	04/02/2025	477	453	-24
Y2_T5	18/03/2025	442	453	11
Y2_T6	21/03/2025	534	453	-81
Y2_T7	26/08/2025	404	453	49
Y2_T8	02/10/2025	371	453	82
Y1_T9	10/12/2025	365	453	88

A.6.3 Site Z

Table 8-24 Estimated change in methane storage at Z: TDM

Survey No.	Date	Total methane generated (kg/h)	Average methane generated (kg/h)	Estimated change in methane storage (kg/h)
Z_T1	20/01/2025	630	565	-65
Z_T2	20/01/2025	604	565	-39
Z_T3	19/03/2025	534	565	31

Survey No.	Date	Total methane generated (kg/h)	Average methane generated (kg/h)	Estimated change in methane storage (kg/h)
Z_T4	19/03/2025	577	565	-12
Z_T5	21/10/2025	606	565	-41
Z_T6	22/10/2025	455	565	110
Z_T7	14/01/2026	502	565	63
Z_T8	15/01/2026	613	565	-47

Table 8-25 Estimated change in methane storage at Z: UAV mass balance

Survey No.	Date	Total methane generated (kg/h)	Average methane generated (kg/h)	Estimated change in methane storage (kg/h)
Z_U_200125	20/01/2025	502	464	-38
Z_U_210125	21/01/2025	558	464	-93
Z_U_211025	21/10/2025	484	464	-19
Z_U_221025	22/10/2025	426	464	38
Z_U_140126	14/01/2026	410	464	54
Z_U_150126	15/01/2026	406	464	58

A.7 Assessment of factors affecting methane storage

A.7.1 Factors correlated with methane storage at individual sites – TDM & UAV mass balance

Table 8-26 Factors correlating with methane storage (TDM & UAV): Site X

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	12.759	6.199	6.753	5.825	4.534	2.198
Precipitation in previous 24 hours (mm)	-33.416	-68.730	-71.163	-80.146	-72.321	-56.524
Temp (°C)	15.789	16.352	15.984	18.296	17.299	14.117
5 day T gradient (°C/day)	153.792	-55.354	-63.606	-86.329	-74.847	-52.177
Flaring	NA	NA	NA	NA	NA	NA
Tipping	-63.516	31.263	34.687	45.716	38.691	26.944
Abnormal operation	NA	NA	NA	NA	NA	NA

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Air pressure (kPa)	161.206	-20.404	-31.907	-56.153	-54.879	-43.997
Air pressure gradient (kPa/hr) (see column for window)	-103.969	-54.529	-50.931	-44.136	-45.236	-50.741
Correlation coefficient (R^2)	0.961	0.953	0.946	0.936	0.931	0.941
Based on 95 observations						

Table 8-27 Factors correlating with methane storage (TDM & UAV): Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	35.104	NA	NA	NA

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous 24 hours (mm)	26.923	37.135	9.776	33.885	35.449	33.644
Temp (°C)	-4.461	10.144	16.564	9.354	8.956	7.005
5 day T gradient (°C/day)	-43.100	18.228	NA	10.668	8.417	3.101
Flaring	NA	NA	-0.929	NA	NA	NA
Tipping	-11.582	1.298	NA	-3.294	-2.966	-4.841
Abnormal operation	NA	NA	-18.708	NA	NA	NA
Air pressure (kPa)	-21.602	-18.420	25.953	-20.927	-22.395	-25.107
Air pressure gradient (kPa/hr) (see column for window)	-46.188	27.592	35.104	19.981	17.651	12.404
Correlation coefficient (R^2)	0.742	0.768	0.770	0.765	0.775	0.781
Based on 156 observations						

Table 8-28 Factors correlating with methane storage (TDM & UAV): Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-4.581	-11.924	-12.443	-11.331	-11.429	-11.040
Precipitation in previous 24 hours (mm)	10.419	26.654	27.154	25.680	26.210	25.458
Temp (ºC)	-23.204	-12.888	-14.692	-10.223	-8.386	-9.981
5 day T gradient (ºC/day)	-20.358	3.826	1.558	5.160	17.972	6.776
Flaring	26.432	8.630	5.136	10.554	23.861	16.343
Tipping	-8.465	-8.756	-16.706	-1.478	29.072	8.007
Abnormal operation	-64.979	-55.085	-58.200	-50.681	-31.664	-48.566
Air pressure (kPa)	21.893	30.975	27.968	34.430	34.627	35.498
Air pressure gradient (kPa/hr) (see column for window)	22.492	-5.652	-11.369	-0.428	21.028	6.188

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Correlation coefficient (R^2)	0.471	0.451	0.457	0.450	0.465	0.451
Based on 253 observations						

A.7.2 Factors correlated with methane storage at individual sites – TDM only

Table 8-29 Factors correlating with methane storage (TDM only): Site X

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-110.239	-156.450	-177.676	-129.456	-102.687	122.475
Precipitation in previous 24 hours (mm)	-4.138	53.885	52.222	25.024	-15.660	8.427
Temp (°C)	18.113	-28.025	-37.622	-32.776	-22.480	41.344

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
5 day T gradient (ºC/day)	120.016	128.637	-76.464	-111.319	-206.647	815.041
Flaring	NA	NA	NA	NA	NA	NA
Tipping	-409.442	-292.950	-130.414	-57.334	24.549	-528.798
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	-17.689	60.297	-61.969	-78.747	-147.610	551.987
Air pressure gradient (kPa/hr) (see column for window)	216.891	138.468	112.479	61.075	43.715	-91.247
Correlation coefficient (R^2)	0.977	0.982	0.983	0.980	0.978	0.983
Based on 70 observations						

Table 8-30 Factors correlating with methane storage (TDM only): Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	29.776	48.813	41.106	36.643	38.410	36.367
Temp (°C)	-10.871	8.333	7.499	8.370	8.144	6.764
5 day T gradient (°C/day)	-77.886	47.707	33.150	15.167	11.703	4.583
Flaring	NA	NA	NA	NA	NA	NA
Tipping	-11.966	15.533	5.688	-1.941	-2.499	-5.112
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	-18.745	-6.770	-12.751	-20.700	-23.330	-27.265
Air pressure gradient (kPa/hr) (see column for window)	-87.979	54.052	40.038	23.601	20.142	13.958

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Correlation coefficient (R^2)	0.795	0.821	0.814	0.804	0.819	0.832
Based on 136 observations						

Table 8-31 Factors correlating with methane storage (TDM only): Site Y2

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-4.381	-3.596	-4.264	-3.658	0.295	0.174
Precipitation in previous 24 hours (mm)	76.840	1.538	-2.453	-7.216	29.413	11.103
Temp (°C)	40.174	35.360	34.631	30.487	3.800	6.470
5 day T gradient (°C/day)	61.668	-42.548	-87.090	-109.707	-95.822	-137.102
Flaring	-26.988	-24.562	-24.259	-26.438	-42.778	-43.940

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Tipping	16.857	-39.482	-89.825	-117.314	-152.464	-183.883
Abnormal operation	4.255	37.570	46.404	53.327	75.552	77.739
Air pressure (kPa)	78.337	46.523	25.732	9.661	-2.755	-26.439
Air pressure gradient (kPa/hr) (see column for window)	41.432	34.580	31.935	28.254	11.521	11.621
Correlation coefficient (R^2)	0.953	0.953	0.952	0.951	0.949	0.950
Based on 83 observations						

Table 8-32 Factors correlating with methane storage (TDM only): Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	-32.660	-37.975	-40.514	-39.286	-39.816	-39.411
Precipitation in previous 24 hours (mm)	40.508	48.027	50.664	49.442	50.119	49.725
Temp (°C)	-34.227	-27.508	-34.904	-31.720	-29.550	-31.600
5 day T gradient (°C/day)	74.599	98.914	98.614	97.680	114.916	105.207
Flaring	-31.012	-43.331	-52.195	-48.645	-36.712	-40.199
Tipping	-2.984	7.802	-9.339	-3.775	28.264	14.605
Abnormal operation	82.369	109.973	108.790	107.139	132.389	118.739
Air pressure (kPa)	-58.168	-58.490	-72.013	-65.642	-67.215	-66.922
Air pressure gradient (kPa/hr) (see column for window)	10.306	4.482	-7.667	-3.574	19.347	9.696

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Correlation coefficient (R^2)	0.497	0.493	0.495	0.492	0.502	0.494
Based on 211 observations						

A.7.3 Factors correlated with methane storage at individual sites – UAV mass balance only

Table 8-33 Factors correlating with methane storage (UAV only): Site X

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	159.311	161.138	168.846	189.468	211.201	NA
Precipitation in previous 24 hours (mm)	4758.546	4716.218	5060.881	5909.973	6818.552	202.043
Temp (°C)	-101.345	-99.571	-99.952	-125.747	-161.408	6365.945

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
5 day T gradient (ºC/day)	4516.809	4827.140	5171.966	6045.037	6997.046	-175.302
Flaring	NA	NA	NA	NA	NA	6568.469
Tipping	NA	NA	NA	NA	NA	NA
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	200.912	205.160	215.803	235.429	262.826	NA
Air pressure gradient (kPa/hr) (see column for window)	371.873	20.546	18.657	18.968	9.195	236.821
Correlation coefficient (R^2)	1	1	1	1	1	1
Based on 25 observations						

Table 8-34 Factors correlating with methane storage (UAV only): Site Y1

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	NA	NA	NA	NA	NA	NA
Precipitation in previous 24 hours (mm)	NA	NA	NA	NA	NA	NA
Temp (°C)	265.092	128.122	-2.784	-23.304	-22.596	1.938
5 day T gradient (°C/day)	-267.514	207.393	9.437	-4.201	-3.061	-0.955
Flaring	NA	NA	NA	NA	NA	NA
Tipping	NA	NA	NA	NA	NA	NA
Abnormal operation	NA	NA	NA	NA	NA	NA
Air pressure (kPa)	489.981	-133.585	-21.606	-23.840	-25.717	-13.714
Air pressure gradient (kPa/hr) (see column for window)	-142.275	90.520	6.783	-1.059	-2.622	-13.291

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Correlation coefficient (R^2)	0.487	0.425	0.073	0.061	0.068	0.120
Based on 20 observations						

Table 8-35 Factors correlating with methane storage (UAV only): Site Z

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Precipitation in previous hour (mm)	383.230	293.067	308.780	232.644	-15.101	99.629
Precipitation in previous 24 hours (mm)	282.748	319.558	273.603	128.506	-208.866	-3.192
Temp (°C)	-104.587	-135.070	-115.830	-121.342	-105.473	-47.463
5 day T gradient (°C/day)	1624.012	1485.165	1546.097	1200.749	75.319	520.825
Flaring	NA	NA	NA	NA	NA	NA
Tipping	NA	NA	NA	NA	NA	NA

Observation	Air Pressure Gradient 24h: Potential contribution (A × B)	Air Pressure Gradient 6h: Potential contribution (A × B)	Air Pressure Gradient 5h: Potential contribution (A × B)	Air Pressure Gradient 4h: Potential contribution (A × B)	Air Pressure Gradient 3h: Potential contribution (A × B)	Air Pressure Gradient 2h: Potential contribution (A × B)
Abnormal operation	-2394.863	-2329.480	-2370.559	-1983.329	-519.366	-958.871
Air pressure (kPa)	4250.724	3740.868	3927.725	3093.767	258.130	1402.021
Air pressure gradient (kPa/hr) (see column for window)	153.546	-159.835	-50.546	-12.471	34.464	38.704
Correlation coefficient (R^2)	0.790	0.903	0.827	0.742	0.795	0.762
Based on 42 observations						

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