BIOGAS CO_2 & CH_4 emissions with UAS

Lessons learned from a UAS survey of methane emissions from multiple biogas plants in France

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MATERIAL & METHODS

BIOGAS PROCESSING AND ASSOCIATED SOURCES

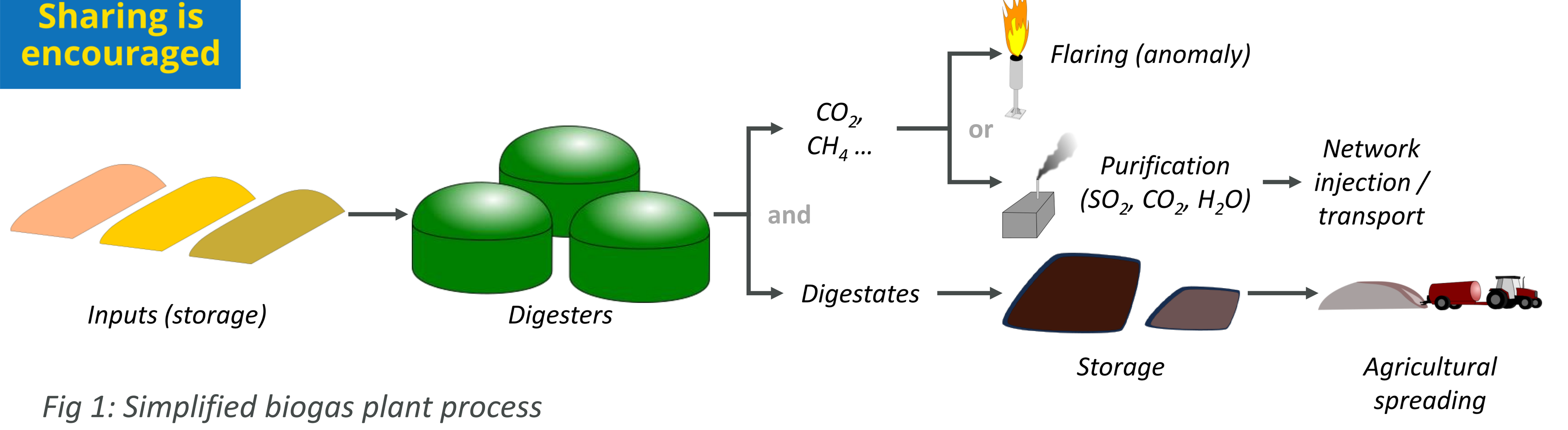


Fig 1: Simplified biogas plant process

Potential sources can be :
- Caused by defect (gas bearing pipes and other containment, digesters, piping and gas storage)
- Not caused by defect (digestate storage units without gas collection, purification units, ventilation)

FIELD CONSTRAINTS

Obstacles (trees, buildings, streets, train lines, aerial electrical lines) determine favourable wind directions
Sites dimensions (typically 100m to 500m length) impose long transects, leading to difficulties as to (i) legal UAS regulations (maximum distance between UAS and pilot), (ii) wireless signal range for real time concentrations visualisation, (iii) UAS autonomy
Multiplicity and diversity of sources: point/diffuse, continuous/sporadic, low/elevated
Sources overlapping: internal (animal breading farms, composting platforms) or external
Acceptability by sites owners

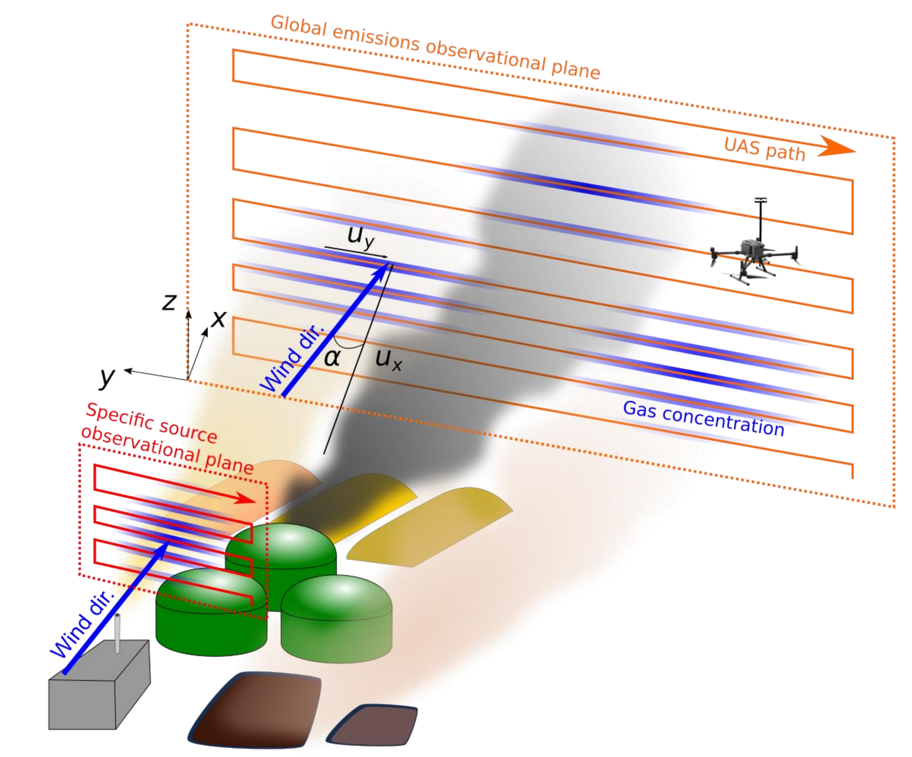


Fig 2: Schematic representation of the monitoring protocol

MASS BALANCE METHOD

Validated for emissions down to 0.01 g.s^{-1} (*Bonne et al., 2024*)

Flight protocol
Multiple horizontal transects, up to the top of the plume, covering an entire plume section, orthogonal to wind direction, downwind of the source

Different applications
- **Outside of the site for global site emissions,** with large transects covering all plumes of the biogas plant at once
- **At short distance** eventually inside the site **for specific sources emissions,** only under wind conditions ensuring no plume overlap

Source emissions flux Q (g.s^{-1}) calculation

$$Q = \int_{plane} C \cdot U dydz$$

C: concentration enhancement; U: wind speed (m.s^{-1}) component orthogonal to monitoring plane

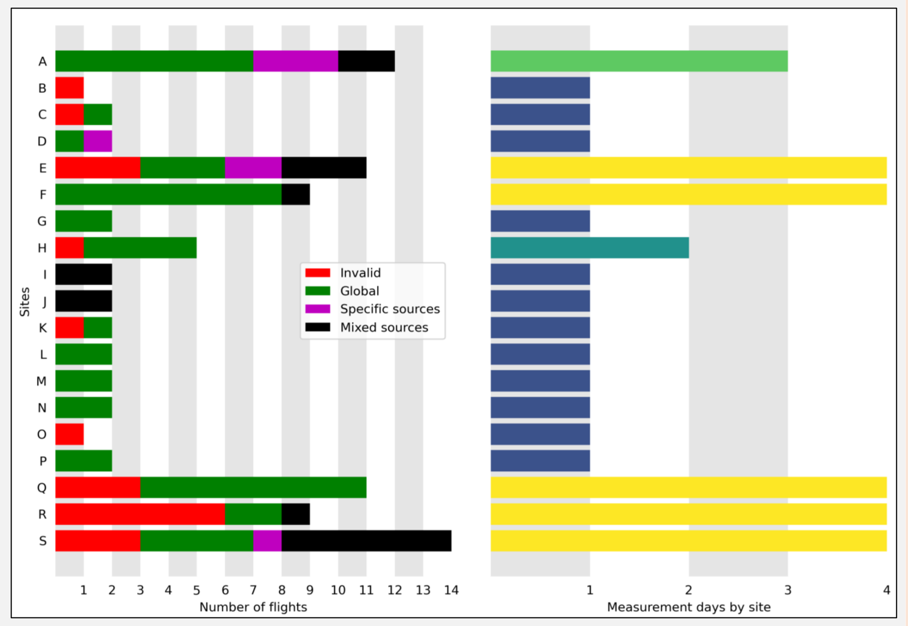
INSTRUMENTATION

Drone DJI M350 recording attitude and position (RTK GPS)
AURORA instrument: in situ CO_2 & CH_4 open-path laser absorption spectrometer at 200 Hz, with **Trisonica-mini 2D ultrasonic anemometer** for wind speed and direction measurements

FIELD CAMPAIGN

Since Dec. 2023 (on-going, results until April 2025)

19 agricultural biogas plants (named from A to S) :
- In the Grand Est region, France, <60 km from Reims
- Biogas valorisation: injection into the network
- Effluent storage with/without coverage and gas capture
- Sites productions : 125 to 500 Nm^3.h^{-1}
- Plant areas from 0.6 to 5 ha



> Fig 3: Flights statistics by site for each categories of sources monitored and success of monitoring (left) and number of monitoring days by site (right)

HIGHS AND LOWS

Ideal case (ex. A): monitoring plane almost orthogonal to the wind, with CO_2 and CH_4 enhancements well above noise level entirely captured horizontally and vertically
22% of all quantifications rejected:
- 17% of CH_4 and 18% of CO_2 quantifications had truncated plumes (ex. B), either due to data transmission troubles, obstacles or flight regulation limits
- 6% of flights with identified or suspected parasite plumes (ex. C), despite reconnaissance survey of the surroundings to determine favourable wind sectors without parasite sources

18% of quantifications cannot be attributed with certainty (ex. D): neither a global nor a specific source quantification
Other misjudgements of the plume and wind conditions sporadically encountered: changes of focus during a flight, or inadequate orientation of the transects compared to wind direction

A/ Successful global plume monitoring

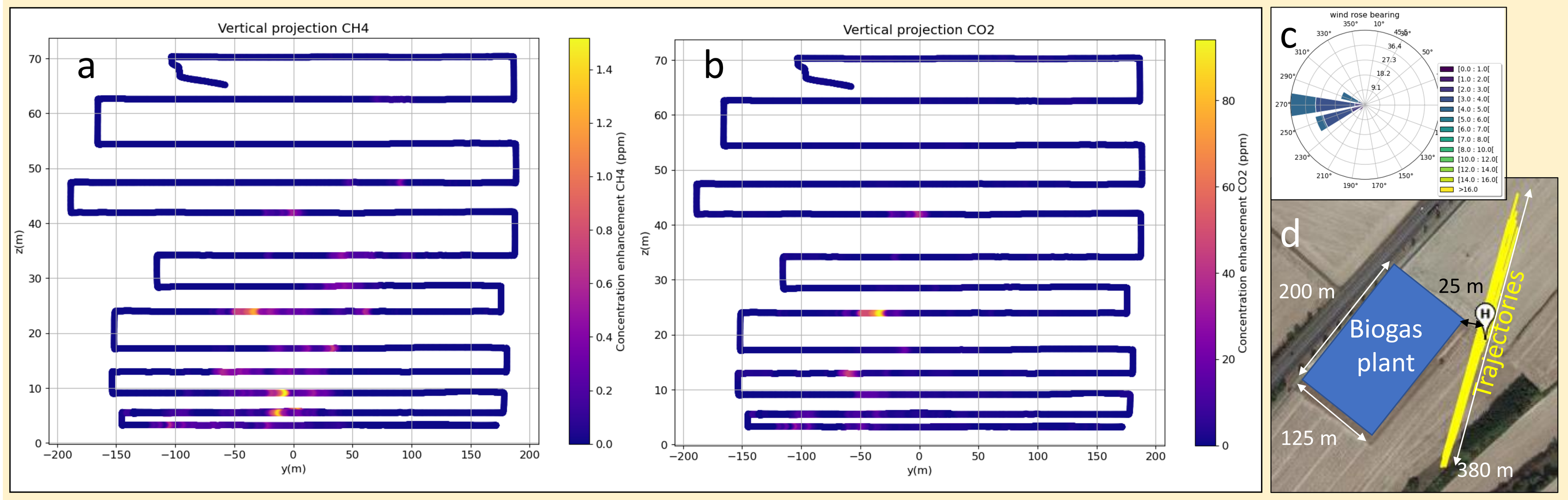


Fig 4: First flight on 2024-03-22 on site N: vertical projections of (a) CH_4 & (b) CO_2 enhancements above background (ppm); (c) wind speeds and directions; (d) map of trajectories (yellow) and site location (blue)

B/ Horizontally or vertically truncated plumes

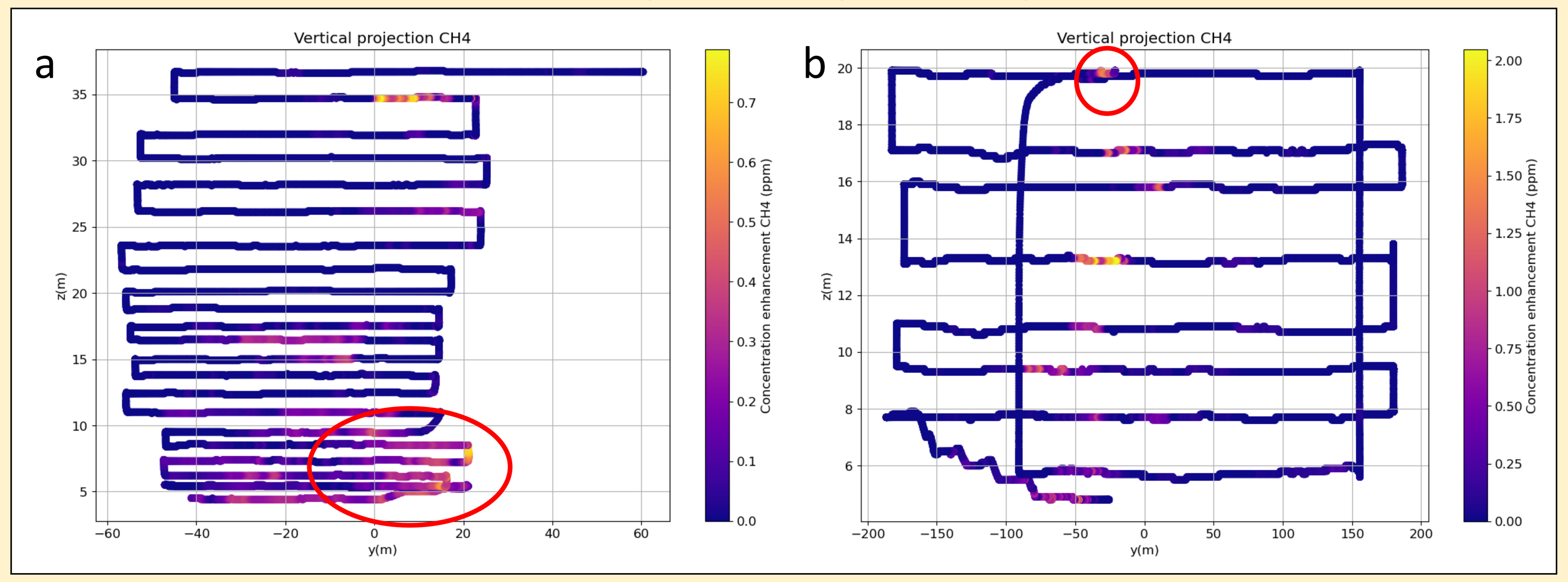


Fig 5: Idem fig 4a for flights with horizontally (a) and vertically (b) truncated CH_4 plumes (red circles)

C/ Overlapping parasite plumes

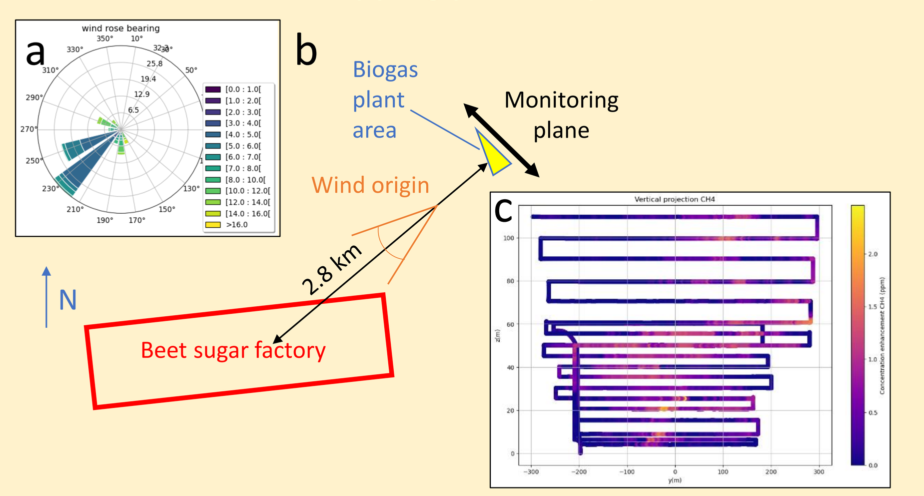


Fig 6: Flight with parasite plume (a) idem fig 4c; (b) schematic representation of wind conditions, flight path and biogas plant and parasite site locations; (c) idem fig 5

D/ Emissions from unidentified portion of site

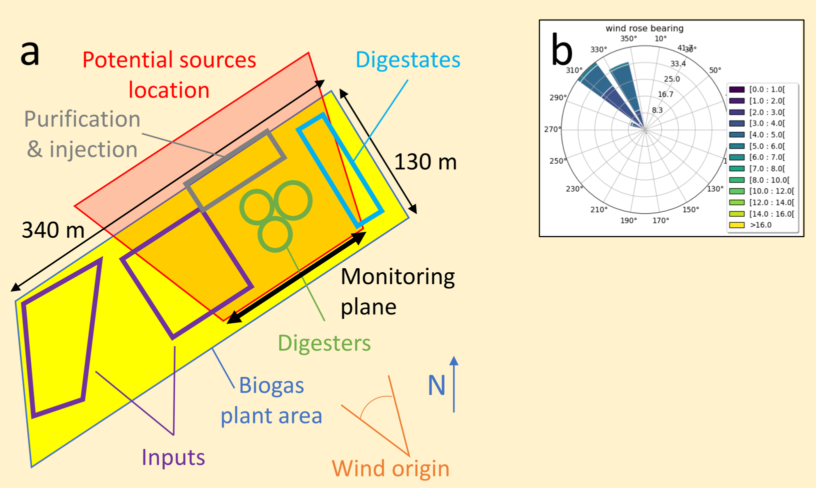


Fig 7: (a) Schematic representation of wind origin, flight path and biogas plant elements (with open digestate lagoon) (b) wind speed and directions

BIOGAS PLANTS EMISSIONS QUANTIFICATIONS

Large variability between sites: mean emission by site from 24 to 366 g_{CO_2}.s^{-1} and 0.4 to 6.8 g_{CH_4}.s^{-1} (fig 8).
Large temporal variability for the same sites when monitored several times during different days (fig 8).

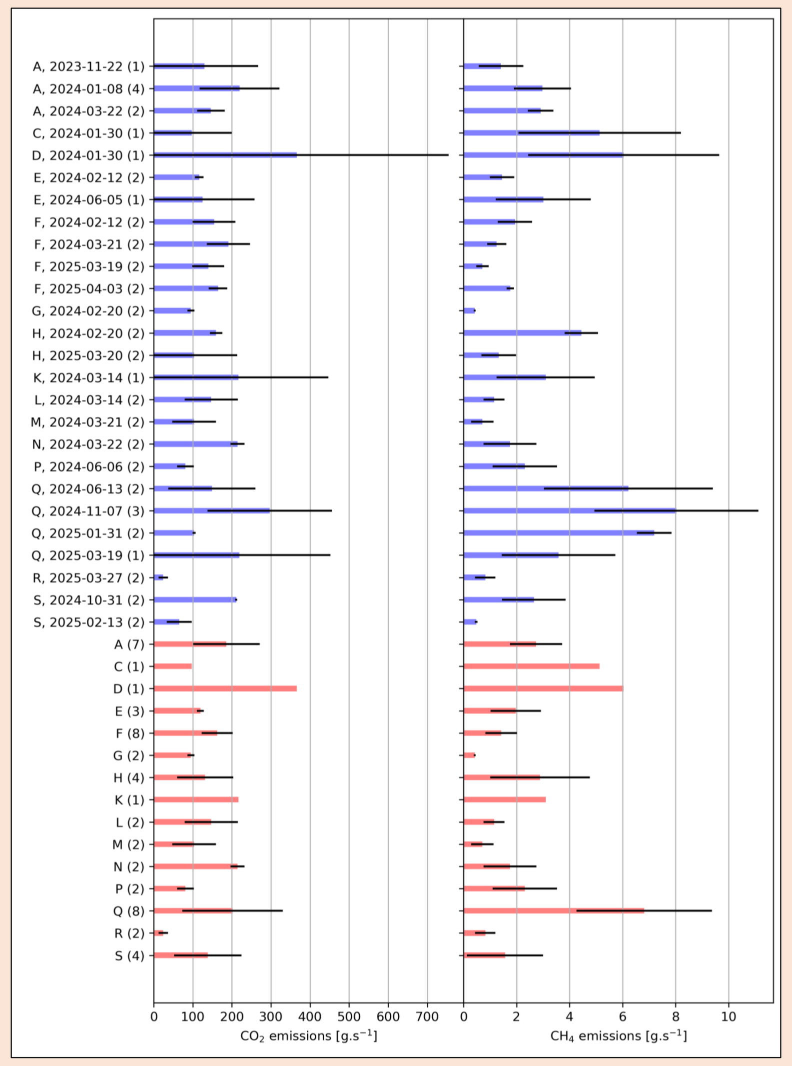


Fig 8: Global CO_2 and CH_4 emissions for each quantification flight (blue) and averaged by site (red)

$$CH_{4\,loss}(\%) = 100 \cdot \frac{CH_{4\,emissions}}{CH_{4\,production} + CH_{4\,emissions}}$$

(*Fredenslund et al. 2022*)

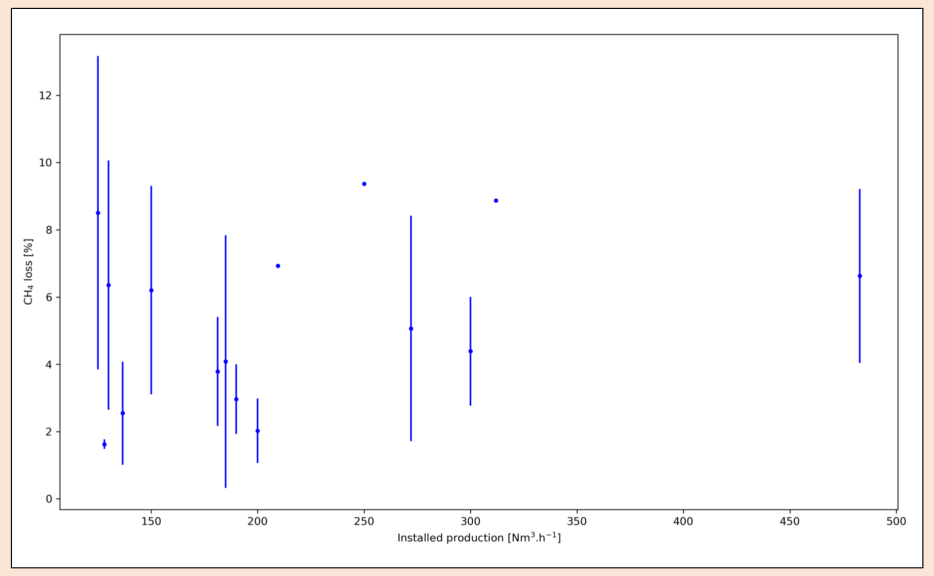


Fig 9: CH_4 losses (%) vs installed productions (Nm^3.h^{-1}). Error bars represent the standard deviation between all global quantifications flights. Sites with unique quantification show no error bar

CH_4 losses (fig 9) from 1.6 to 9.3 % between sites with mean value of 5.3%: coherent with to *Fredenslund et al. 2022* for low and moderated productions.
No dependency with installed production, contrary to *Fredenslund et al. 2022* showing a scale factor with lower CH_4 losses for higher productions.

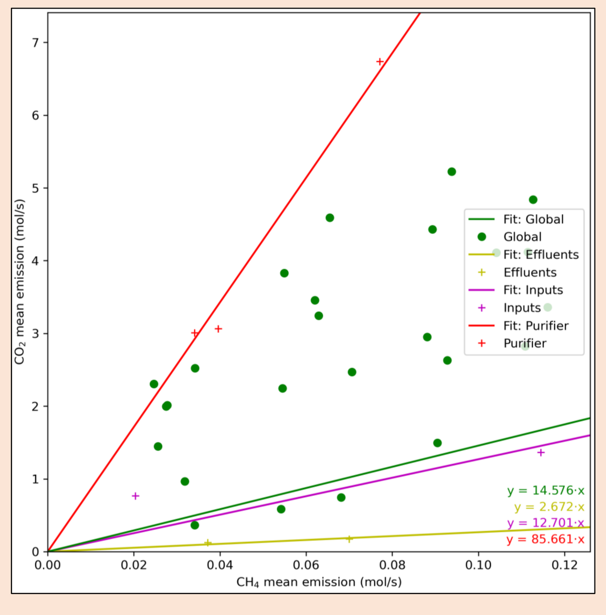


Fig 10: CO_2 versus CH_4 emissions (mol/s) for global quantifications and specific sources: effluents, inputs or purifiers; and associated linear regressions

Various CO_2/CH_4 ratios are observed for global plant emissions (fig 10).
Specific sources reveal contrasted CO_2/CH_4 ratios for each type of source (though with low statistics): this tends to explain the variability of global plants ratios by different predominance of sources within sites.
Mean values of CH_4 emissions from inputs, purifiers and effluents are relatively similar and the sum of these emissions are comparable with average global sites emissions (although not compared for the same sites and low statistics). Biogas purification units seem to be a predominant source of biogenic CO_2 emissions.

Source type (number of quantifications)	CH_4 (g/s)	CO_2 (g/s)
Global (49)	2.8 ± 2.4	156 ± 87
Inputs (2)	1.1 ± 1.1	47 ± 19
Purifiers (3)	0.8 ± 0.4	188 ± 94
Effluents (2)	0.9 ± 0.4	7 ± 2

Table 1: CO_2 and CH_4 emissions (g/s) for different types of source averaged for all sites

CONCLUSIONS, BEST PRACTICES & PERSPECTIVES

Conclusions
- ✓ CH_4 losses are coherent with literature (Fredenslund et al. 2022)
- ✓ Contributions of the different sources within the sites have specific signatures in CO_2/CH_4 ratios
- ✓ Main contributors of CH_4 emissions might be inputs, effluents and purifiers

Best practices
- Strong reconnaissance survey of surroundings, including parasite sources several kilometres upwind
- Planification of measurements (selection of targeted plants) based on meteorological predictions of wind speeds and directions
- Maximize transects lengths and altitude range to capture all plumes and avoid focusing on a single plume not representative of the global site emissions
- Data transmission range should be adapted to site dimensions for manual navigation based on real time concentrations. Otherwise, operate with pre-defined flight paths and autonomous navigation to avoid misinterpretation of plumes by operators

Perspectives
- Alternative modelling approaches (LES, Gaussian/Lagrangian plume inversion)
- Sample diversification (larger productions spectrum, cogeneration, extend to other regions)

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- Fredenslund, A. M., Gudmundsson, E., Falk, J. M., Scheutz, C.: The Danish national effort to minimise methane emissions from biogas plants, Waste Management, Volume 157, 2023, Pages 321-329, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2022.12.035.

Abstract
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