Landfills & Decarbonization: Challenges and Insights

25/11/2025

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CH_4 emission: the stakes for landfill

CH_4 contributes to ~30% of total warming [(1)]

CH_4 Global Warming Potential (GWP) is 72 times higher than CO_2 [(2)]

COP26 Global Methane Pledge aims to reduce methane emissions by 30% [(2)]

(1) International Energy Agency (IEA) (2023), Global Methane Tracker 2023. IEA, Paris
(2) www.globalmethanepledge.org

GHG emission in landfill sites: what is the challenge for SUEZ?

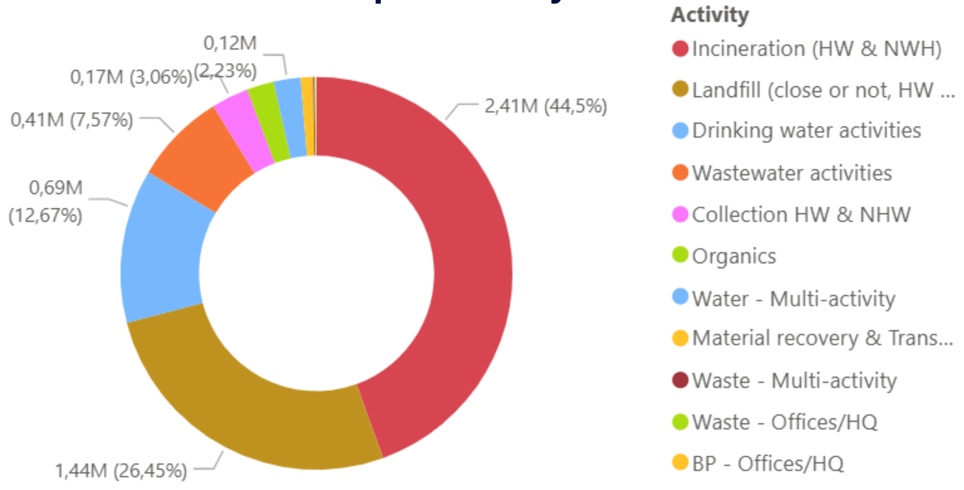
- Waste management, and in particular landfill sites, is the **third largest source (18%)** of anthropogenic methane emissions worldwide (IPCC AR6).

- Landfill waste accounts for 3% of emissions reported by France in 2023, or 11.4MT CO2 (CITEPA).

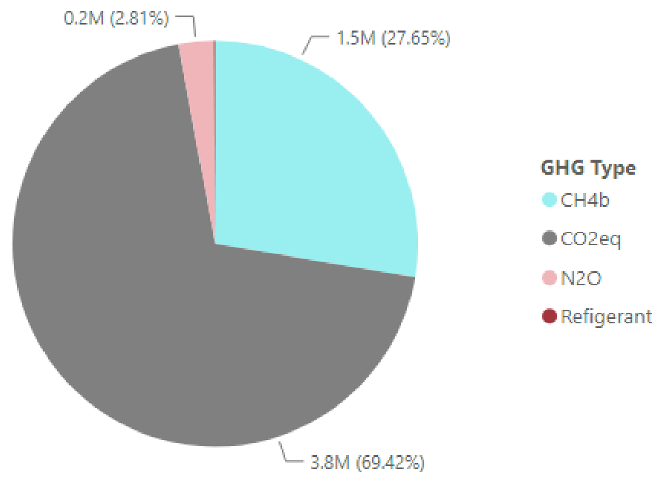
- Within the **SUEZ** scope, **Landfills** are the **second largest source of direct emissions** of GHG, accounting for 1.5 MTCO2e in 2024.

→ SUEZ roadmap: 26% reduction in GHG emissions by 2030*

SUEZ GHG emission for 2024 (Scope 1&2) per activity



GHG Type for 2024 (Scope 1&2)



*For Waste activities excluding waste to energy compared to 2021 pro forma perimeter

GHG emission: the stakes

- GHG quantification and reporting often rely on national or international **emission factors from literature** overlooking site-specific operational conditions.

- Industrial emissions are complex, combining **diffuse, stake, and fugitive sources**. With diffuse emissions being the hardest to measure.

- MonGHG – SUEZ Climate Innovation Program since 2016: test and develop **quick measurement methods** to assess GHG site level in a few hours

  → Enhancing emission **understanding, reporting accuracy, and process optimization**

Application field:

Waste Water treatment *(CH_4, N_2O, CO_2)*

Agriculture (composting, methanization…) *(CH_4, N_2O, CO_2)*

Landfill, Mining, Oil & gas… *(CH_4)*

Partnership SUEZ & LSCE

Financé par l'Union européenne
NextGenerationEU

LSCE
LABORATOIRE DES SCIENCES DU CLIMAT & DE L'ENVIRONNEMENT

Technology chain to quantify biogaz emissions

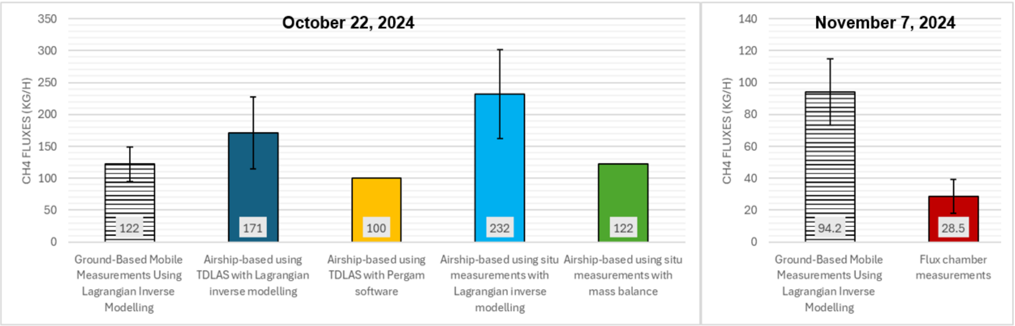
- ✓ Sensors (TLDAS, FID, MOS…)
- ✓ Measurement protocol (fixe, mobile, drone, satellite…)
- ✓ Modeling (mass balanced, reverse modeling, statistic..)

→ **More than a dozen of methodology for landfill**

LSCE : Scientific Laboratory of CEA – CNRS FRANCE

Collaboration with SUEZ since 2016 (2 thesis – 3 research engineers)

- → Testing & validation of measurement methods and instruments
- → Testing of continuous measurements
- → Development of new emission quantification models
- → +25 Publications and conferences (2)



(2) *Broquet, G., Laurent, O, Vogel, F., Allegrini, E., Kelly, R.., Ciais, P. and al: Detection and long-term quantification of methane emissions from an active landfill, Atmos. Meas. Tech., 17, 1229–1250, https://doi.org/10.5194/amt-17-1229-2024, 2024.*

Partnership to develop solutions

- Public authorities
- Universities and laboratory
- Start up, sensor provider, satelite operators, control…

INERIS maîtriser le risque pour un développement durable
Citepa Guider l'action Air & Climat
GHGSAT
LSCE Laboratoire des Sciences du Climat & de l'Environnement
cea
cnrs
ABSOLUT Sensing Monitor · Understand · Predict
origins.earth
ABB
FLUX LAB gas detection measurement
TRACE TRAcking Carbon Emissions
CARBON MAPPER
BUREAU VERITAS 1828
Aeromon
HyLight
GASTraQ
kunak SENSING ANYWHERE
AERIS TECHNOLOGIES
UAVIA
LI-COR

SCAN360 – GHG
THE METHODOLOGY

The methodology

STEP 1 – CH_4 CONCENTRATIONS MEASUREMENTS (1-2 DAYS)

- Use of high precision (5 ppb) / high frequency (1 Hz) CH_4 analyser
- Use of weather station to characterize wind and turbulence
- Map CH_4 concentration within the site to characterize main sources and locate hot-spots
- Map CH_4 concentrations downwind to the site to characterize plume transects
- LDAR and OGI measurement

STEP 2 – EMISSION QUANTIFICATION

- Use of 3D reverse dispersion modelling for quantification
- Quantify source distribution and localization

STEP 3 – COMPARISON WITH MODELS, UPDATE EMISSION FACTORS

- Prioritization of emission sources
- Proposal of mitigation solutions
- GHG assessment, IPCC, SimCET model (by Lemunier et al 2013)

SOLARIMPULSE EFFICIENT SOLUTION SEPTEMBER 2020

How does it look like ?

STEP 1 – CH_4 CONCENTRATIONS MEASUREMENTS

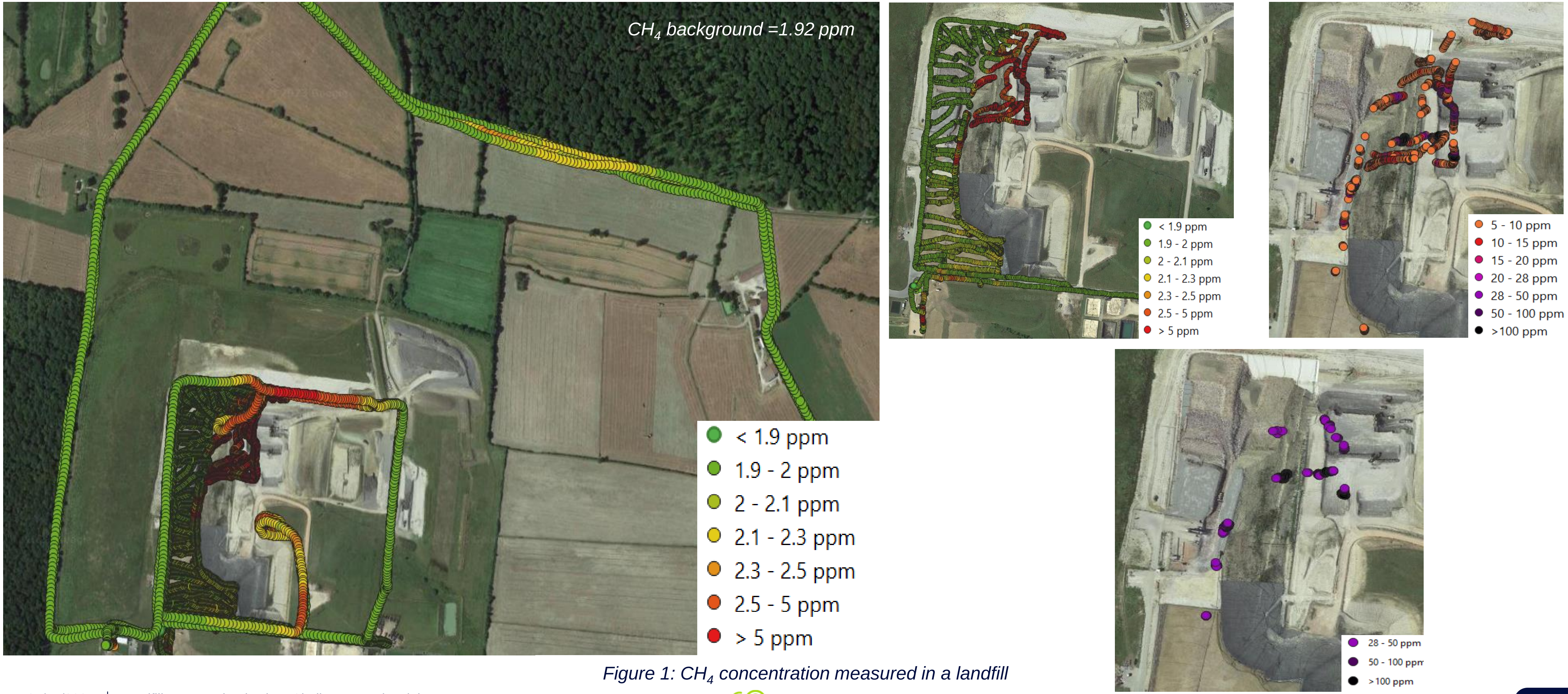
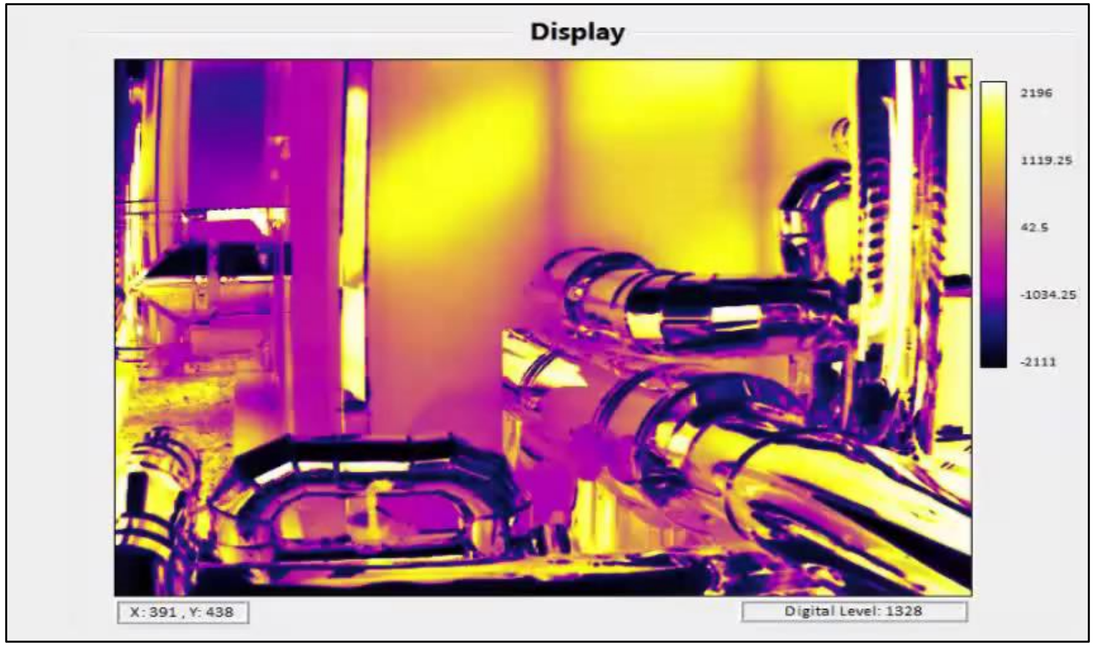


Figure 1: CH_4 concentration measured in a landfill

How does it look like ?

STEP 1 – CH_4 LDAR AND OGI MEASUREMENT



Fondo

- *Tª fondo*
- *características de materiales*
- *emisividad*
- *reflectividad*

Meteorología

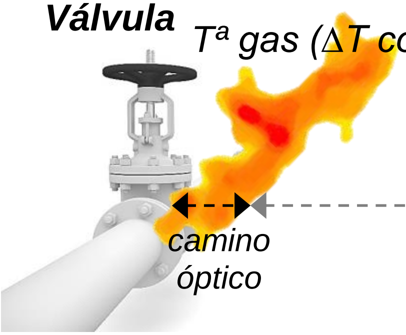
- *Tª ambiente*
- *nubosidad*
- *lluvia*

ppm gas

Velocidad y dirección del viento

Válvula

Tª gas (ΔT con fondo)



camino óptico

distancia al objetivo

Fuga gas

- *composición química*
- *Tª de ebullición/presión de vapor*
- *Tº de proceso*
- *ratio de emisión (kg/h)*

Cámara IR pasiva

- *resolución (640x480)*
- *lente óptica (mm)*
- *ratio captura (fps)*
- *sensibilidad térmica*
- *respuesta espectral (LWIR 7-13,5 um)*

Reverse modeling based on PMSS

PMSS (Parallel Micro-SWIFT-SPRAY) atmospheric dispersion model, a numerical tool developed by ARIA Technologies for 35 years.

It combines the 3D diagnostic flow model PSWIFT and the 3D Lagrangian particle dispersion model PSPRAY. Simulations are performed from the mesoscale to the microscale, where buildings are explicitly represented [(1)]

PMSS can handle huge urban areas thanks to highly efficient parallelization [(2)]

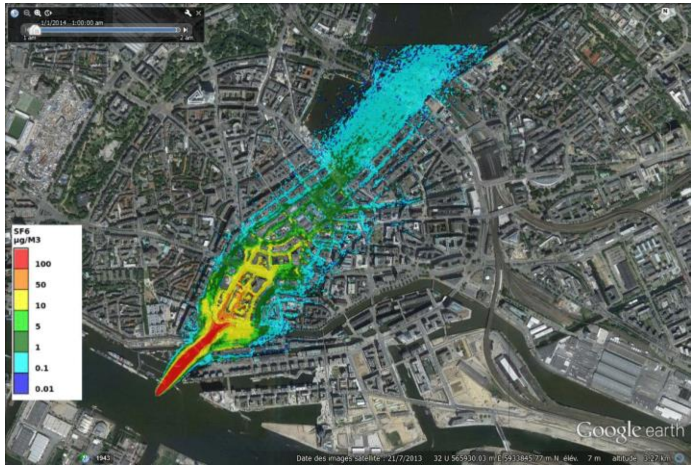
PMSS aims to provide results close to the **accuracy of CFD models** with significantly **faster computation times**.

Through mathematical inversion, emission fluxes are estimated for each identified zone, with a **resolution of 1 kg/h of CH_4**.

PMSS = 3D Atmospheric Lagragian dispersion model
→ Precise local-scale representation of the plume

Complex terrain	Building effects	Diff. Weather sources

[(1)] *(Tinarelli et al., 2013; Armand et al., 2021)* [(2)] *(Oldrini et al., 2019; 2021)*



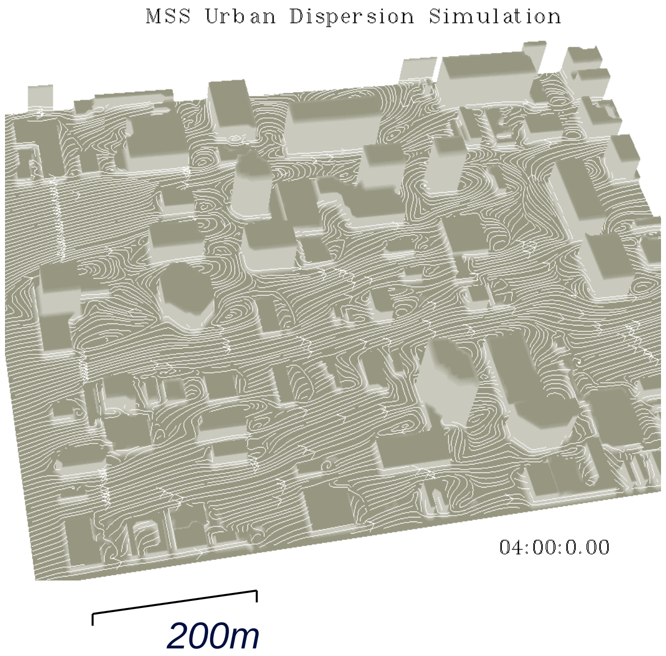
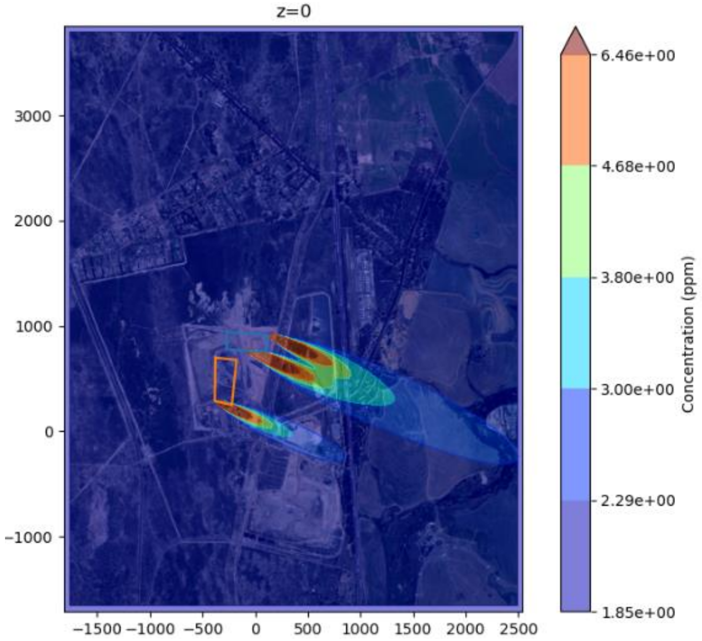


Figure : examples of atmospheric dispersion model used by Aria technologies

How does it look like ?

STEP 2 – EMISSION QUANTIFICATION



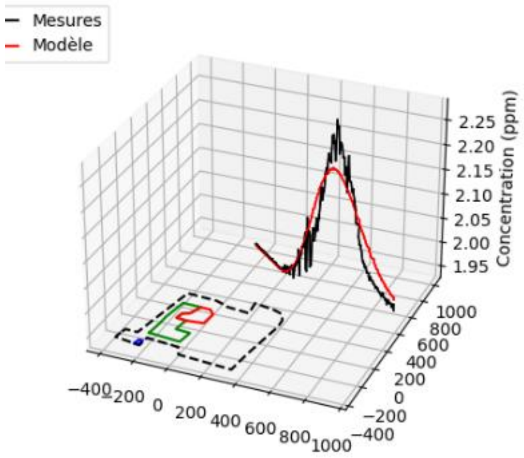
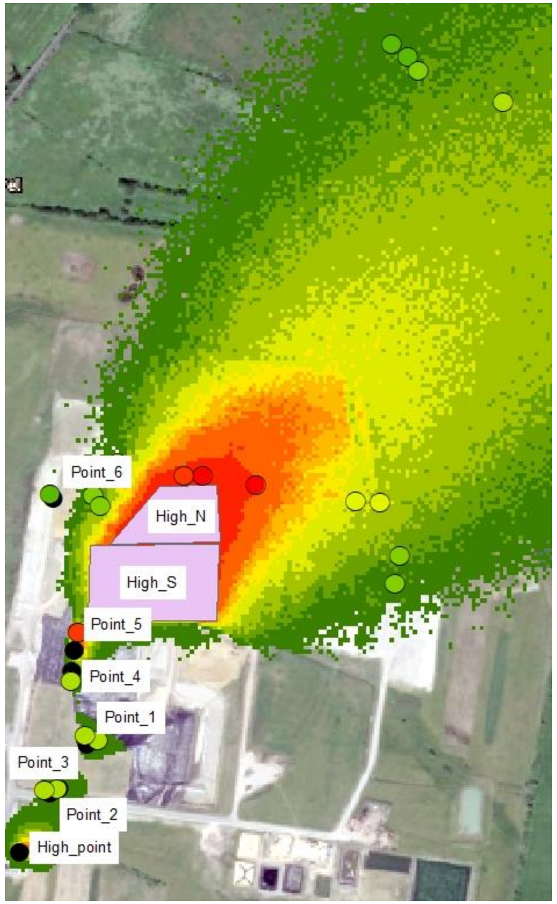


Figure: example of CH_4 concentration plume modeled with Gausian approach with its sources distribution in a landfill

Sources	Emission (t/day)	Emission (Nm3/h 50% CH4)
Zone 1	18.7	2,179
Zone 2	5.0	583
Total	**23,7**	**2,762**

Gaussian-based reverse modelling



SOURCE	Emission (kg/h)	Contribution
High_N	23.8	36%
High_S	39.2	59%
Point 1	1.34	2%
Point 2	0.12	0%
Point 3	0.0006	0%
Point 4	0.0072	0%
Point 5	1.04	2%
Point 6	0.004	0%
Point High	0.84	1%
TOTAL	66.35	

Figure: example of CH_4 concentration plume modeled with Lagrangian approach with its sources distribution in a landfill

PMSS Lagrangian-based reverse modelling

SCAN360 – GHG
SOLUTION AND USE CASES

Worldwide use case

Performance validation

- Validation controlled gas release – **Uncertainty of 4 - 8 %**
- Comparison with other methods and research institutes

Deployment

3 continents, 6 countries, +30 sites from 25 to 150 ha

- **Use case n°1 – South Africa :** Quantify the biogas potential and size the biogas network
- **Use case n° 2 – France :** Innovative continuous quantification of diffused biogas

Use case 1: South Africa landfill

NON-HAZARDOUS DOMESTIC AND COMMERCIAL WASTE

- Started in 1974 – 600 kT/year waste – 100ha
- SUEZ acquired the site in 2022
- Biogas is captured with 5 wells and 1 Flare - 125 Nm^3/h

- Location next to municipal landfill and agricultural activities

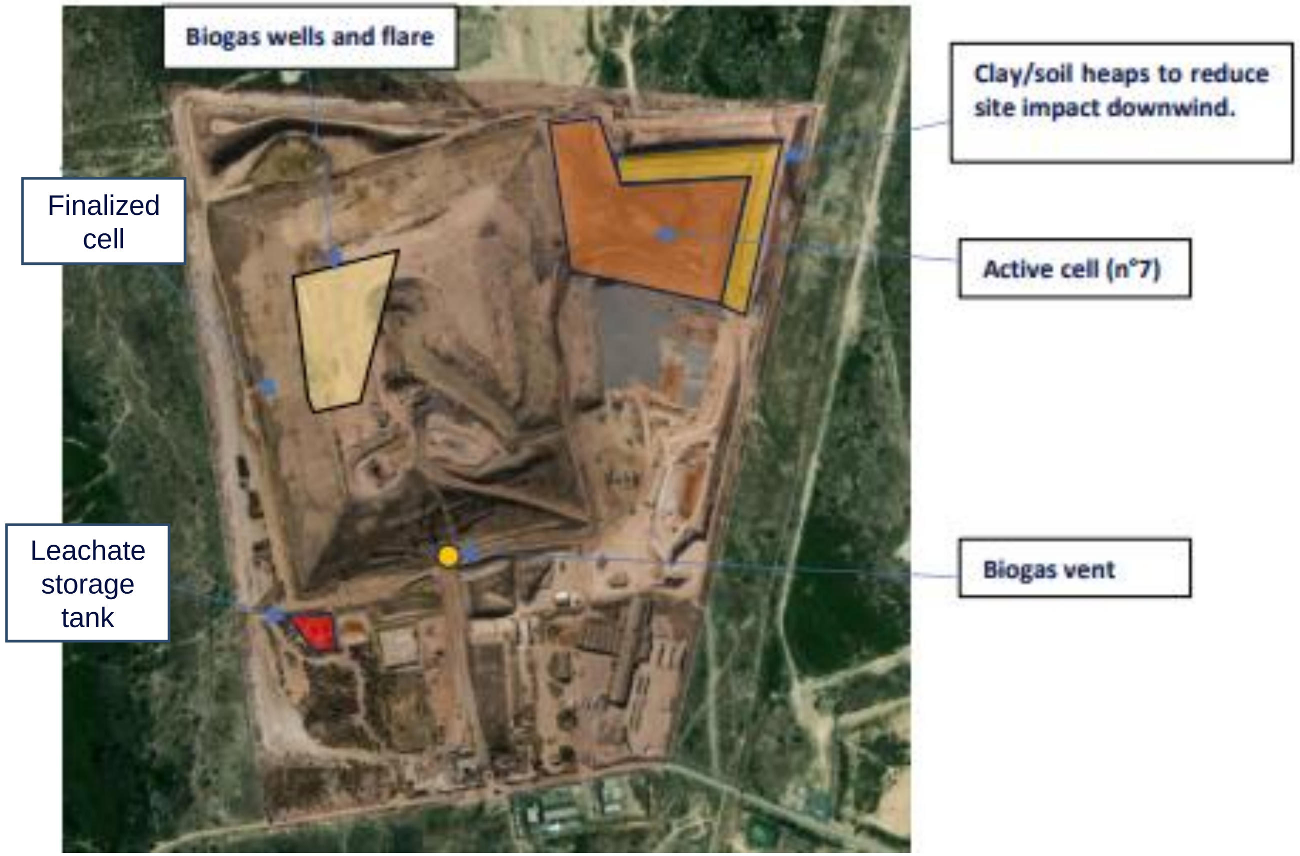


Figure : Landfill configuration

Use case 1: South Africa landfill

- **1) Identification of emission sources and prioritization**

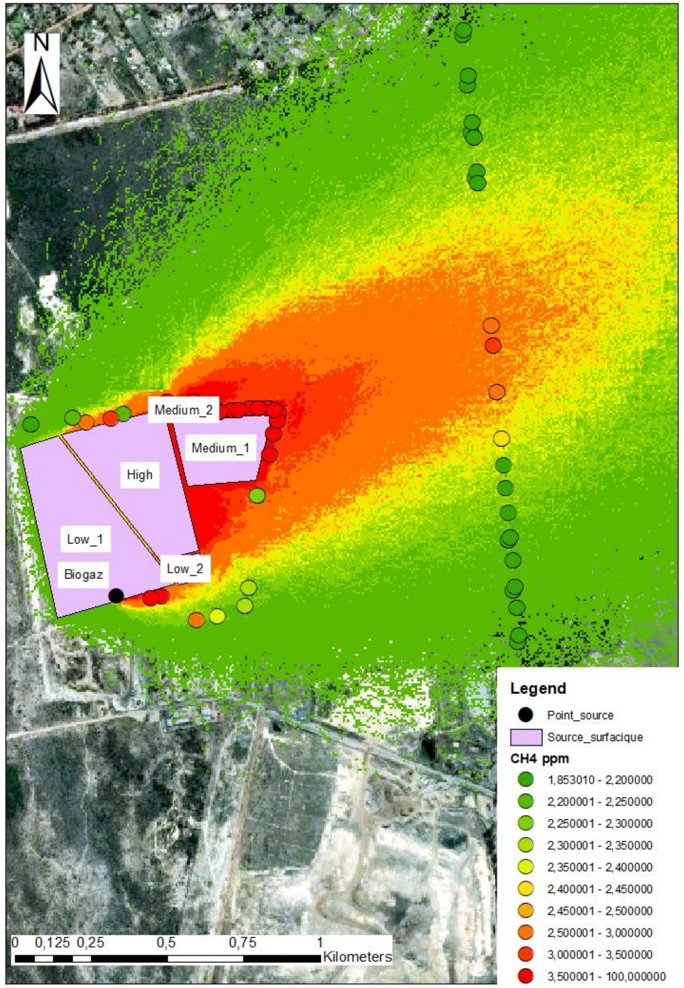
  2 surveys 2023 & 2024

  In-depth understanding of operational issues and identification of sources of external emissions

- **2) Quantification of the site's emissions**

  Sources distribution

Source	Emission (Nm3/h biogaz 50% CH4)
Medium	618
Low_1	47
Low_2	12
High_1	2067
High_2	8
High_3	66
High_4	62
Medium_2	20
Low_3	63
Biogaz	0
Total	2963.6



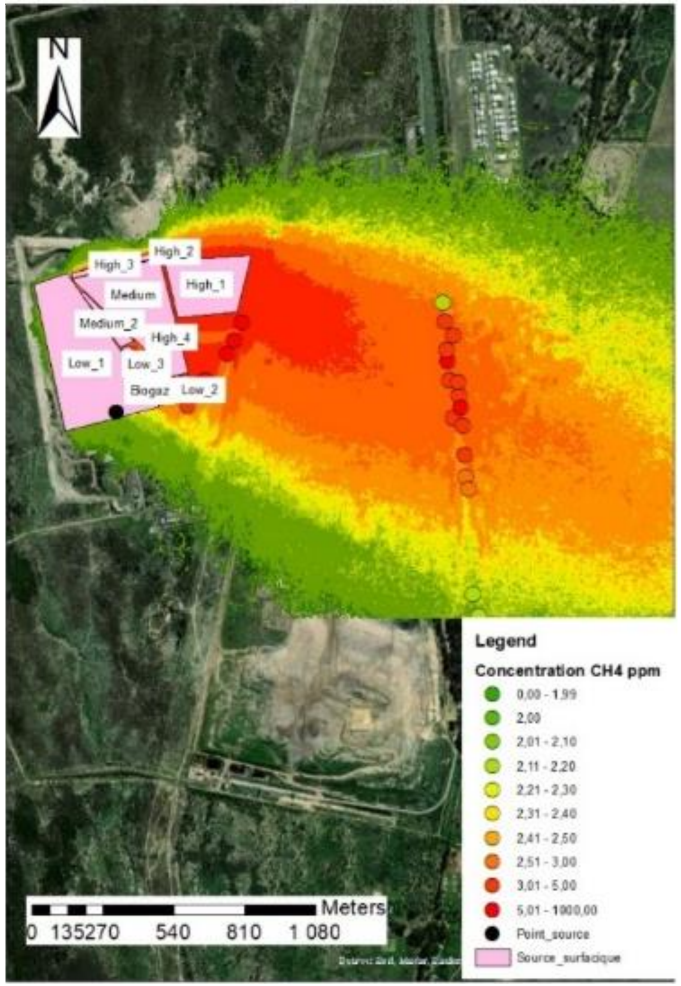


Figure : results of the CH_4 atmospheric plume dispersion

Use case n°1 – South Africa Landfill

- **3) Recalibration and installation sizing**

Additional inputs: waste composition and tonnage, rainfall, temperature…

Validation of production models coefficient

→ Modification of the biogas network

→ Justify an M€ investment in a gas engine or biomethane purifier on site for energy production

- **4) Commissioning biogas network and recovery units**

1250 Nm^3/h up to 1600 Nm^3/h recovery solution in 2026 for selling credit carbon (under study)

→ Biogas recovery eq of >150k TCO_2 / year use for green energy

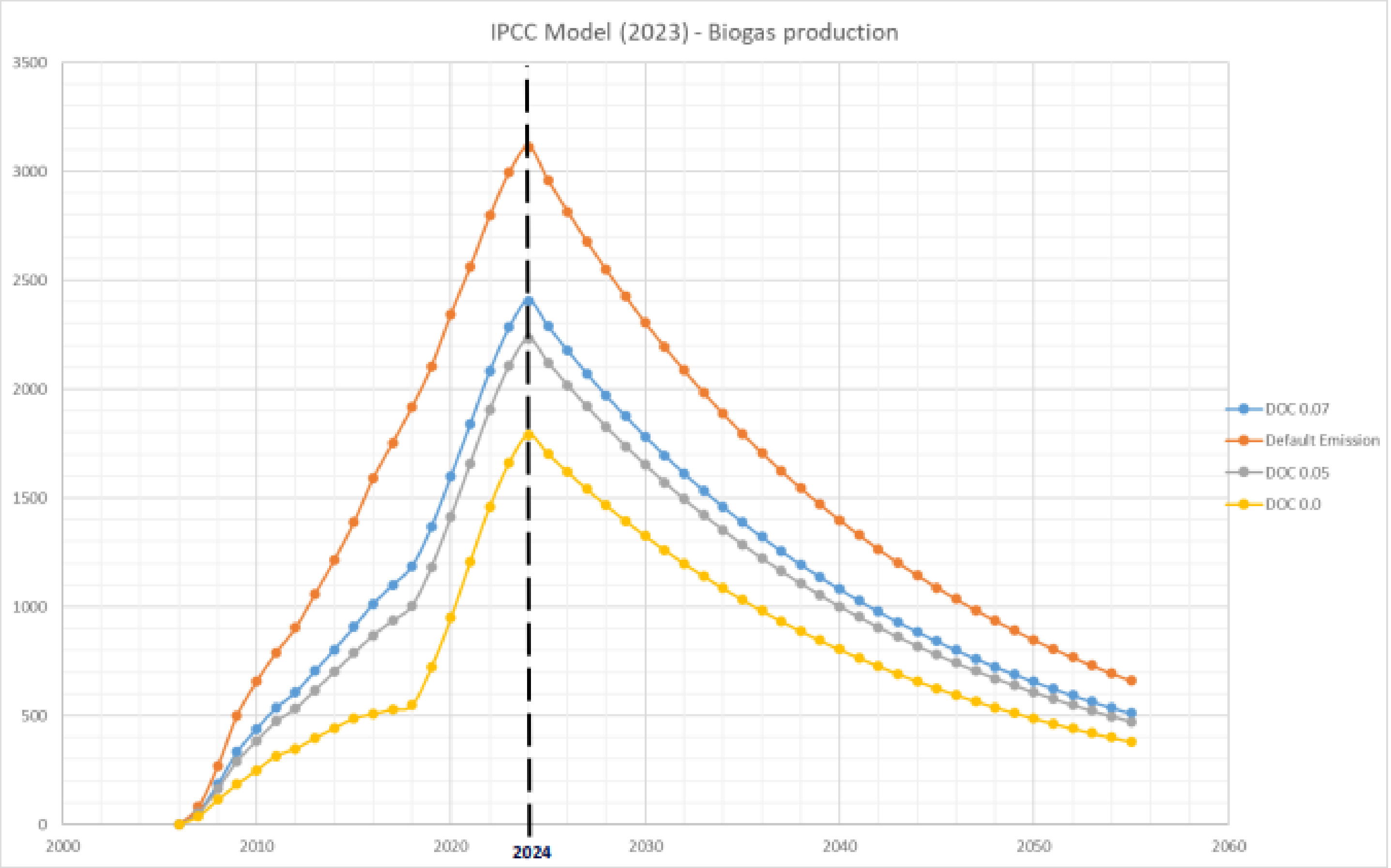


Figure : Example of biogas production and extraction simulation based on IPCC model

** IPCC Model: refers to the methodologies and models used by the Intergovernmental Panel on Climate Change (IPCC) to estimate greenhouse gas (GHG) emissions from landfills based on waste composition, degradable organic carbon, methane generation rate, methane oxidation factor…*

Use case 2: France continuous quantification

NON-HAZARDOUS DOMESTIC AND COMMERCIAL WASTE

- Started in 2016 – 90 kT/year waste – 80he
- Biogas recovery with:
  - Biogas upgrade - 500 Nm^3/h
  - Flare – 1 000 Nm^3/h

- Monthly diffused gas assessment from 2024 to 2026

- **SENSOR NETWORK:**

CH_4: 1 unit OF-CEAS sensor (Optical Feedback Cavity Enhanced Absorption Spectroscopy)
3 units TLDAS (tunable diaode laser absorption spectroscopy)
4 units MOS (metal-oxide semiconductor)
H_2S: 3 units eV (electro Chemical)
Weather: 1 unit ultrasonic + 1 unit 3D

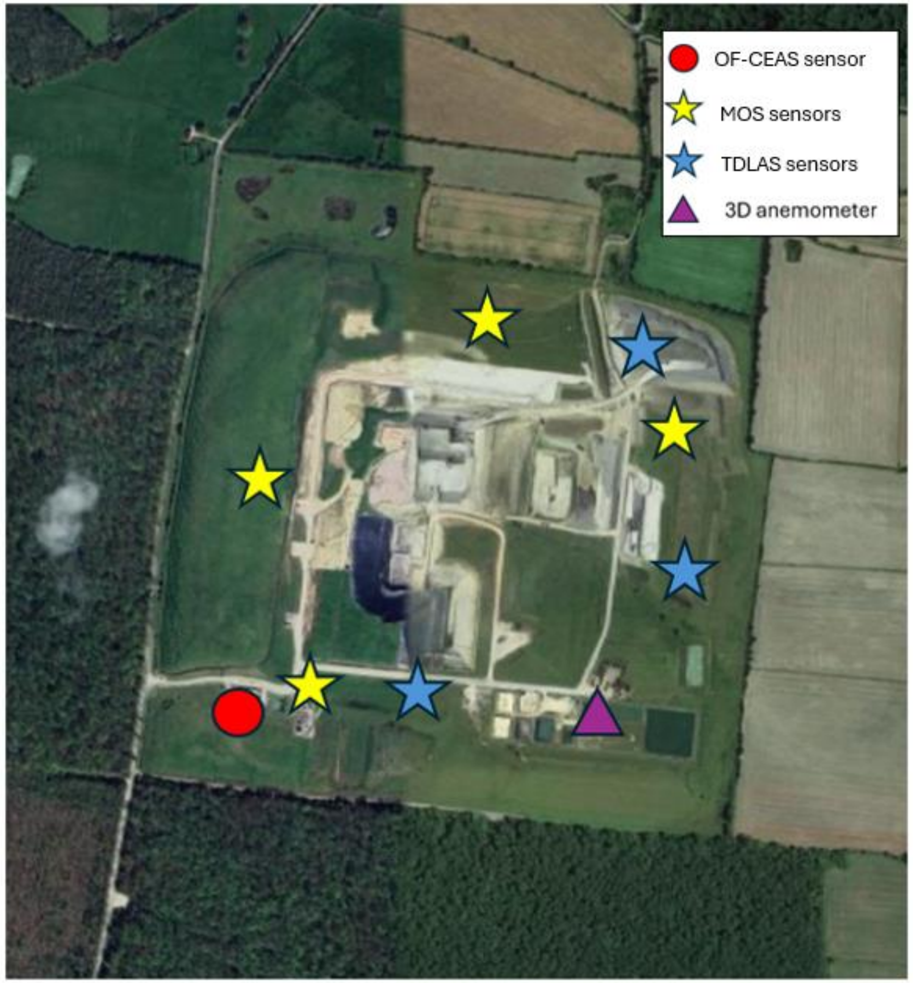


Figure 1 : Sensors configuration in experimental landfill

Use case 2: France continuous quantification

- **Continuous monitoring biogas emission thanks to CH_4 sensor network and reversed modeling**

This work validates the integration of sensor network and dispersion modeling in an inverse framework as a promising approach for real-time sources estimates, distributed methane quantification on landfill sites

- **85% Hourly biogas flux quantification of *100kg CH_4/h* (2)**

The deployment of a 3- and 7-sensor network demonstrated that distributed systems could generate up to eight times more usable hourly data than the fixed OF-CEAS setup

- **Balance cost/accuracy of sensor**

The performance of new "low-cost" sensor reach the balance to be used in continuous inversed modeling tool

→ **Bridge the gap of spot campaign for a improve:**

Understanding of emissons
Accuracy of **GHG reporting**
Biogas recovery

(2) Romand C, Oberti O, Broquet G, Laurent O et al: Innovative biogas emission landfill monitoring and quantification thanks to 3D modeling and new generation of CH4 sensor network. 20th International symposium on waste management and sustainable landfilling, Sardinia 2025.

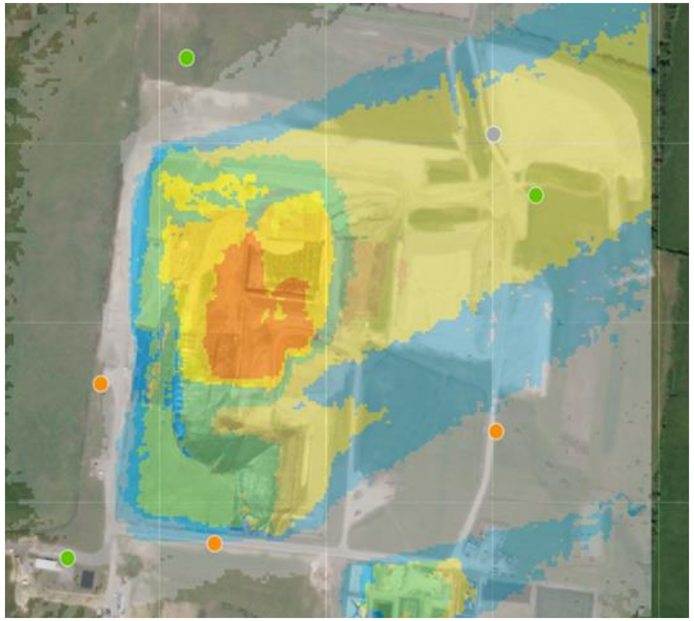


Figure : Illustration of continuous measurement and quantification in landfill

Conclusiones

1. **De la metodología a una norma internacional**
   - Trabajo en curso con pruebas de intercomparación y estudio de evaluación

2. **Directiva de la UE sobre vertederos y BREF sobre vertederos**
   - Se deben definir, validar y armonizar entre los Estados miembros de la UE los métodos de control de las emisiones para las mejores técnicas disponibles (MTD). Trabajo en curso hasta 2030.

3. **Correlación de la monitorización continua con el modelo IPCC de potencial de biogás**
   - A falta de una caracterización fiable de los residuos y de tener en cuenta las condiciones operativas cambiantes, las mediciones de las emisiones añadidas a los volúmenes de biogás capturados proporcionarán datos fiables y continuos que podrán introducirse en los modelos para hacerlos más sólidos. De este modo, el protocolo del IPCC sobre emisiones fugitivas podrá revisarse para reflejar con mayor precisión las emisiones reales.

4. **Cero emisiones netas: objetivo para la explotación de vertederos**
   - De este modo, los operadores podrán definir planes de acción para controlar mejor sus emisiones y optimizar el uso del biogás como fuente de energía con bajas emisiones de carbono.

GRACIAS POR SU ATENCIÓN

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Liste des publications et présentations sur les activités issues de la collaboration entre LSCE et SUEZ (CH4 et CO2).

Publications

Rivera-Martinez, R., Kumar, P., Laurent, O., Broquet, G., Caldow, C., Cropley, F., Santaren, D., Shah, A., Mallet, C., Ramonet, M., Rivier, L., Juery, C., Duclaux, O., Bouchet, C., Allegrini, E., Utard, H., and Ciais, P.: Using metal oxide gas sensors to estimate the emission rates and locations of methane leaks in an industrial site: assessment with controlled methane releases, Atmos. Meas. Tech., 17, 4257–4290, https://doi.org/10.5194/amt-17-4257-2024, 2024.

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Shah, A., Laurent, O., Lienhardt, L., Broquet, G., Rivera Martinez, R., Allegrini, E., and Ciais, P.: Characterising the methane gas and environmental response of the Figaro Taguchi Gas Sensor (TGS) 2611-E00, Atmos. Meas. Tech., 16, 3391–3419, https://doi.org/10.5194/amt-16-3391-2023, 2023.

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Kumar, P., Broquet, G., Caldow, C., Laurent, O., Gichuki, S., Cropley, F., et al. (2022) Near-field atmospheric inversions for the localization and quantification of controlled methane releases using stationary and mobile measurements. *Quarterly Journal of the Royal Meteorological Society*, 148(745), 1886–1912. Available from: https://doi-org.insu.bib.cnrs.fr/10.1002/qj.4283

Kumar, P., Broquet, G., Yver-Kwok, C., Laurent, O., Gichuki, S., Caldow, C., Cropley, F., Lauvaux, T., Ramonet, M., Berthe, G., Martin, F., Duclaux, O., Juery, C., Bouchet, C., and Ciais, P.: Mobile atmospheric measurements and local-scale inverse estimation of the location and rates of brief CH4 and CO2 releases from point sources, Atmos. Meas. Tech., 14, 5987–6003, https://doi.org/10.5194/amt-14-5987-2021, 2021.

Rivera Martinez, R.; Santaren, D.; Laurent, O.; Cropley, F.; Mallet, C.; Ramonet, M.; Caldow, C.; Rivier, L.; Broquet, G.; Bouchet, C.; et al. The Potential of Low-Cost Tin-Oxide Sensors Combined with Machine Learning for Estimating Atmospheric CH_4 Variations around Background Concentration. *Atmosphere* **2021**, *12*, 107. https://doi.org/10.3390/atmos12010107

Lian, J., Laurent, O., Chariot, M., Lienhardt, L., Ramonet, M., Utard, H., Lauvaux, T., Bréon, F.-M., Broquet, G., Cucchi, K., Millair, L., and Ciais, P.: Development and deployment of a mid-cost CO_2 sensor monitoring network to support atmospheric inverse modeling for quantifying urban CO_2 emissions in Paris, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-125, 2024.

Liste des publications et présentations sur les activités issues de la collaboration entre LSCE et SUEZ (CH4 et CO2).

In prep

Kumar, P. et al.: Atmospheric inversions for long-term monitoring of CH4 emissions from a French landfill using different types of in-situ measurements. Manuscript under preparation for publication.

Shah, A. et al.: Measuring acetylene with the Picarro G2203 gas analyser and its use as a tracer to quanitfy methane emissions

Depelchin, T. et al.: Atmospheric Monitoring and characterization of the N2O and CH4 emissions from a wastewater treatment plant

Conf papers

Allegrini, E., Lozano, M., Kumar, P., Shah, A., Laurent, O., Broquet, G., Ciais, P., Kerkar, M., Mauguen, G., Nibart, M., David, V., Buty, D., Oberty, O.: Assessing biogas emissions from 5 landfills: measurements and predictive gas models comparison and lessons learned. 19th International symposium on waste management and sustainable landfilling, Sardinia 2023.

Presentations 1/2

Gichuki, S., Kumar, P., Cropley, F., Broquet, G., Yver-Kwok, C.,Laurent, O., Ramonet, M., Berthe, G., Martin, F., Lauvaux, T., and Ciais, P.: The Lacq controlled release experiment: detection and quantification of controlled gas leaks using CRDS (cavity ring down spectroscopy) measurement with a local-scale dispersion model. Industrial Methane Measurement Conference, Rotterdam, Netherlands. 2019.

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Fontanier, B., Kumar, P., Broquet, G., Caldow, C., Laurent, O., Yver-Kwok, C., Cropley, F., Shah, A., Lozano, M., Defratyka, S., Gichuki, S., Lauvaux, T., Berthe, G., Martin, F., Noirez, S., Duclaux, O., Juery, C., Bouchet, C., and Ciais, P. and the TRACE team: Evaluation of the performance of different short-range atmospheric dispersion models for the monitoring of CH4 emissions from industrial facilities, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-13010, https://doi.org/10.5194/egusphere-egu21-13010, 2021.

Rivera Martinez, R., Santaren, D., Laurent, O., Cropley, F., Mallet, C., Broquet, G., Ramonet, M., Caldow, C., Kumar, P., Fontanier, B., Shah, A., Lienhardt, L., Lozano, M., Lauvaux, T., Rivier, L., Bouchet, C., Juery, C., and Ciais, P.: Reconstruction of high frequency methane peaks from measurements of metal oxide low-cost sensors using machine learning, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-16027, https://doi.org/10.5194/egusphere-egu21-16027, 2021.

Liste des publications et présentations sur les activités issues de la collaboration entre LSCE et SUEZ (CH4 et CO2).

Presentations 2/2

Kumar, P., Broquet, G., Shah, A., Laurent, O., Caldow, C., Yver-Kwok, C., Cropley, F., Tamagnone, S., Fontanier, B., Lienhardt, L., Lozano, M., Defratyka, S., Gichuki, S., Lauvaux, T., Rivera, R., Allegrini, E., Bouchet, C., Kelly, R., Berthe, G.,Martin, F., Noirez, S., Duclaux, O., Juery, C., Pineau, F., Ventre, O., Ramonet, M., Ciais, P.: Monitoring CH4 emissions from active landfill and industrial sites using different types of atmospheric measurements, ICOS Science Conference 2022.

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