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GERG
THE EUROPEAN GAS RESEARCH GROUP

GERG R&D on Methane Emissions

Amélie Louvat, GRTgaz on behalf of GERG
R&D Project manager

February 2024, PRCI REX

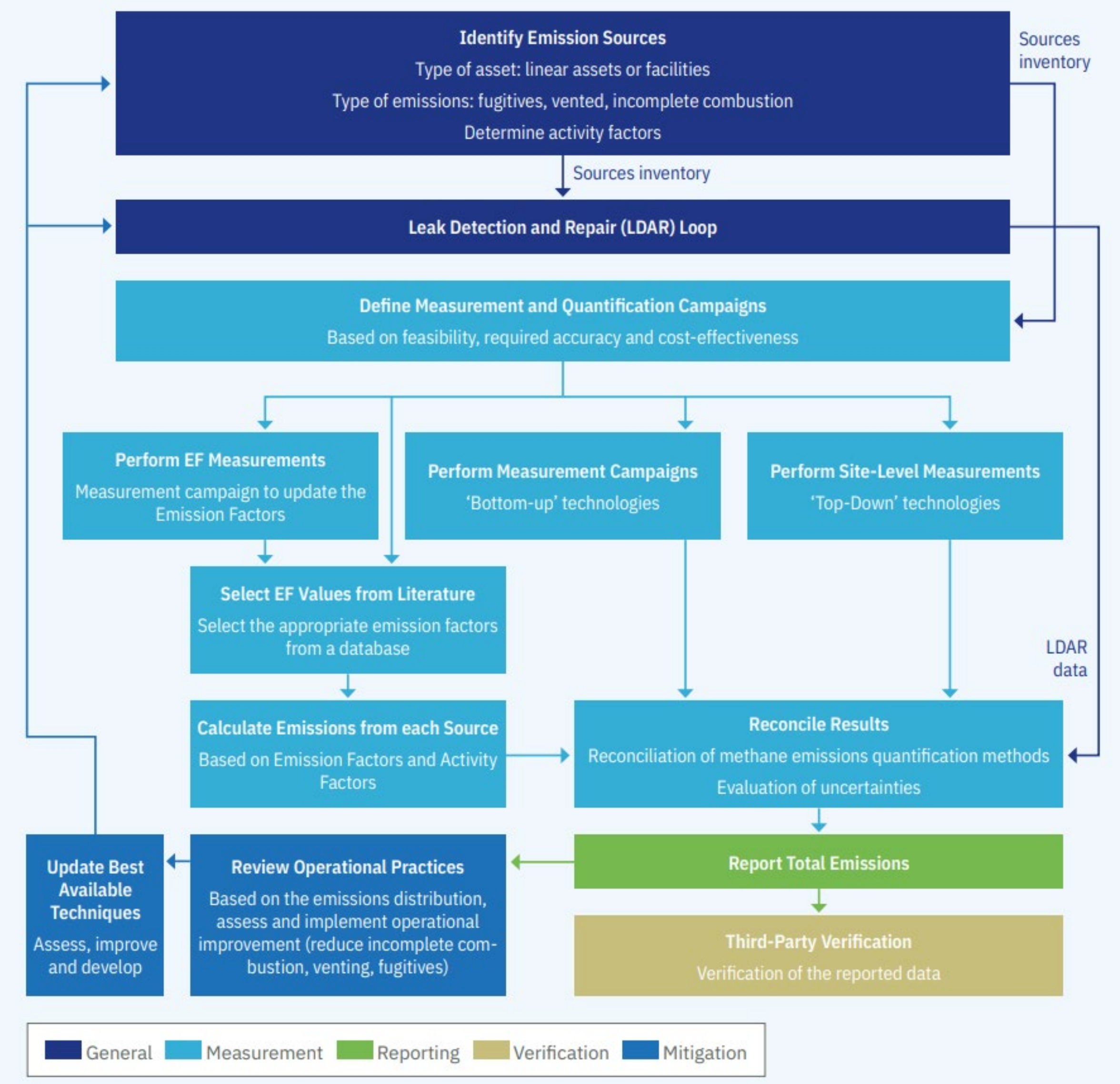
San Diego
February 28th 2024

LEADING PIPELINE RESEARCH
Pipeline Research Council International

Methane Emissions

- High Profile topic in EU: Regulation on methane emissions reduction in the energy sector presented @ COP 28
- Mandates methane emissions MRV & independent verification, LDAR, ban on routine venting & flaring, refers to OGMP 2.0 until CEN Standards are developed
- Methane emissions is one of GERG's priorities: significant projects completed / underway – living methane emissions roadmap established
- GERG Methane Emissions Management Roadmap

Methane Emissions Roadmap Overview



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Recent & Current Methane Emissions Projects

- MEEM - Methane Emission Estimation Method – starting point for mid- & down-stream reporting template of OGMP 2.0 (DBI)
- Gas migration in soil from a network leakage – correlation for leak rate including soil parameters (GDF SUEZ & OGE)
- Quantifying underground leakages from gas pipelines – suction method (KIWA)
- Measurement of methane emissions from the transmission system (Gaz System)
- Methane emissions site-level quantification “Top-Down technologies”: Phase I followed by Phases II.A & II.B (GRTgaz, Enagas)
- Gas sampling & analysis: best practices & emissions mitigation (GRTgaz)

OVERVIEW

GERG Projects on site-level methane emission quantification technologies

Series of step-wise projects launched recently by GERG focusing on site-level technologies: > 750 kEUR

Phase I
State of the art study of site level technologies
Lead by RICE (GRTgaz)
2020

Phase II.A.
Technology Benchmark of site level technologies
Lead by Enagas
2021

Phase II.B.
Source and site level reconciliation. Test in a site in operation
Lead by Enagas
2022

Final aim is be to elaborate a set of guidelines to be applied when top-down methodologies are used, establishing a harmonised approach within EU (midstream sector) for the application of top-down in combination with bottom-up estimations






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TOP-DOWN METHODOLOGIES: SITE LEVEL QUANTIFICATION OF METHANE EMISSIONS

Series of projects focusing on site level technologies for Mid-Stream Gas Infrastructure

Preprint: [AMTD - Assessment of current methane emissions quantification techniques for natural gas midstream applications (copernicus.org)]

PHASE II.A.

Technology Benchmark of site-level technologies

Lead by Enagas

Blind assessment for methane quantification methodologies:

"Top-Down European Challenge"

LSCE
LABORATOIRE DES SCIENCES DU CLIMAT & DE L'ENVIRONNEMENT

Report for GERG

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Top-down methodologies: site level quantification of methane emissions

Phase II.A: Technology Benchmark for site level methane emissions quantification

Final Report
April 2022

https://doi.org/10.5194/amt-2023-97
Preprint. Discussion started: 10 July 2023

Atmospheric Measurement Techniques Discussions
EGU

Assessment of current methane emissions quantification techniques for natural gas midstream applications

Yunsong Liu[1,2], Jean-Daniel Paris[1,2], Gregoire Broquet[1], Violeta Bescós Roy[3], Tania Meixus Fernandez[3], Rasmus Andersen[4], Andrés Russu Berlanga[3], Emil Christensen[4], Yann Courtois[6], Sebastian Dominok[7], Corentin Dussenne[6], Travis Eckert[8], Andrew Finlayson[9], Aurora Fernández de la Fuente[5], Catlin Gunn[10], Ram Hashmonay[11], Juliano Grigoleto Hayashi[10], Jonathan Helmore[9], Soeren Honsel[12], Fabrizio Innocenti[9], Matti Irjala[13], Torgrim Log[14,15], Cristina Lopez[6], Francisco Cortés Martínez[5], Jonathan Martinez[16], Adrien Massardier[17], Helle Gottschalk Nygaard[4], Paula Agregan Reboredo[5], Elodie Rousset[6], Axel Scherello[12], Matthias Ulbricht[7], Damien Weidmann[10,18], Oliver Williams[10], Nigel Yarrow[9], Murès Zarea[19], Robert Ziegler[20], Jean Sciare[2], Mihalis Vrekoussis[2,21], Philippe Bousquet[1]

[1]Laboratoire des Sciences du Climat et de l'Environnement (LSCE/IPSL), CEA-CNRS-UVSQ, Université Paris-Saclay, Gif-sur-Yvette, 91191, France
[2]Climate and Atmosphere Research Center (CARE-C), the Cyprus Institute, Nicosia, 2113, Cyprus
[3]Enagás, S.A. Paseo de los Olmos, Madrid, 19 28005, Spain
[4]Dansk Gasteknisk Center a/s Dr. Neergaards Vej 5B 2970 Hørsholm
[5]SENSIA Solutions, Av. Gregorio Peces Barba, 1, Leganés, Madrid, 28919, Spain
[6]GRTgaz RICE, 1-3, rue du Commandant d'Estienne d'Orves, Villeneuve-la-Garenne, 92390, France
[7]ADLARES GmbH, Oderstraße 65, Teltow, 14513, Germany
[8]SeekOps, 1205 Sheldon Cove, TX 78753, Austin
[9]National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, UK
[10]MIRICO, Unit 6 Zephyr Building, Eighth St, Didcot OX11 0RL, UK
[11]OPGAL, HaNapah St 11, Karmiel, Israel
[12]Open Grid Europe GmbH, Gladbecker Straße 404, Essen, 45326, Germany
[13]Aeromon Oy, Enterinportti 1, Helsinki, 00240, Finland
[14]GASSCO, Bygnesvegen 75, Kopervik, 4250, Norway
[15]Department of Safety, Chemistry and Biomedical Laboratory Sciences, Western Norway University of Applied Sciences, Haugesund, 5528, Norway
[16]Bureau Veritas Emissions Services, ZA LENFANT, 405 rue Emilien Gautier CS60401, AIX EN PROVENCE CEDEX, 13591, France
[17]Bureau Veritas Exploration, ZA LENFANT, 405 rue Emilien Gautier CS60401, AIX EN PROVENCE CEDEX, 13591, France
[18]STFC Rutherford Appleton Laboratory, Space Science and Technology Department, Didcot, Oxfordshire, OX110QX, UK
[19]ENGIE Research & Innovation, 1 Place Samuel de Champlain, Courbevoie, 92400, France
[20]JRC Energy Institute, P.O.Box2, Petten, 1755ZG, Netherlands
[21]University of Bremen, Institute of Environmental Physics and Remote Sensing (IUP) & Center of Marine Environmental Sciences (MARUM), Bremen, D-28359, Germany

Correspondence to: Yunsong Liu (yunsongliu@yeah.net)

Abstract. Methane emissions from natural gas systems are increasingly scrutinized and accurate reporting requires site- and source-level measurement-based quantification. We evaluate the performance of ten available, state-of-the-art CH_4 emission quantification approaches against a blind controlled release experiment at an inerted natural gas compressor station in 2021. The experiment consisted of 17 blind, 2-hour releases at single or multiple simultaneous exhaust points. The controlled

1

SITE LEVEL QUANTIFICATION OF METHANE EMISSIONS

Phase II.A: Technology benchmark

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enagas

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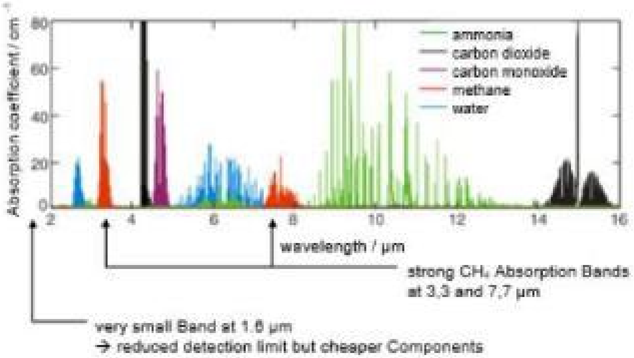
Background – Site Level Technologies

- In situ (in and around the plume)
- Remote (from a distance, without contact with the plume)

- Passive (measure changes in background energy, e.g. reflected sunlight)
- Active (transmits burtsts of energy in the direction of interest, *e.g. laser* beam)



Several different **sensing instruments**, including optical gas imaging and laser absorption spectroscopy, take advantage of absorption features of methane for detection and measurement (typically between 1,6 and 3,3 µm).

The 1650 nm absorption line is a fairly powerful source, easier to generate than the one at 3300 nm. It is not in the liquid water spectrum and therefore does not interfere with this species. The average infrared line at 3300 nm has a wider range and makes it possible to achieve a higher sensitivity than the line at 1650 nm. There may be interference with water.

Methane Sensitive Sensor

Site level emission rate quantification
techniques to measure ambient air concentrations of methane, calculate methane flux based on atmospheric conditions, and attribute emissions to a facility or region

Platform
(e.g. drone, aircraft, truck…)

Quantification model
From concentration to flow rate

Conclusions of the state of the art study:
lack of information on quantification accuracy of new technologies

The **sensor placement** determines from where a methane concentration is measured, and therefore what data can be used to calculate emission flow rates. Measuring equipment **can be fixed on site, mobile on the surface, airborne in drones or aircraft, and in different space orbits**. The placement determines the spatial and temporal resolution of what the sensor is able to detect.

To determine flow rates, a model is used to calculate backwards towards the emission point, based on factors such as wind, atmospheric conditions and background methane concentration.
The quantification methods only give estimates, and there are **multiple factors which contribute to uncertainty**: sensor precision, the quantity and spatial extent of measurement data, micrometeorological conditions and background concentration variability, besides difficulty of the models to replicate actual gas dispersion in the atmosphere.
Even with well-designed measurement campaigns, using precise sensors under ideal conditions, there will be significant errors in the estimations of flow rates.

Phase II.A: GERG 'Technology Benchmark for site level methane emissions quantification'

A first-of-its-kind research project covering midstream assets was launched

Blind controlled release tests
To analyse the quantification accuracy / performance of most promising site-level technologies

Funding Partners

ADVISORY BOARD to validate the scope and test program and to contribute to the data analysis of the results
Internationally recognized experts from Authorities and Institutions, Academia, Industry and Civil Society

Project Definition

Inerted and isolated Compressor Station

9 most promising site-level technologies

3 bottom-up

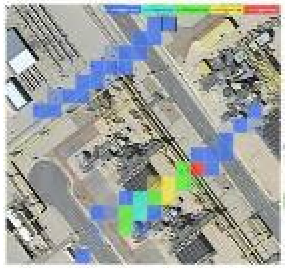
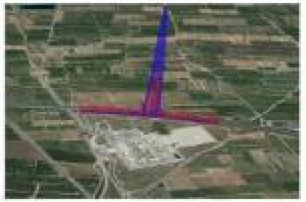
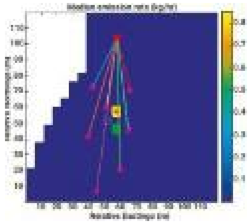
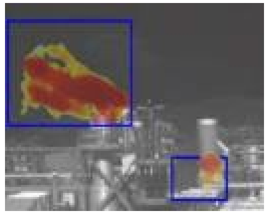
Independent analysis to assess accuracy and repeatability

Tests organization and coordination

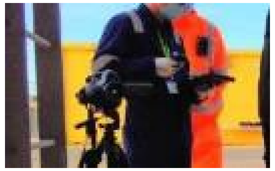
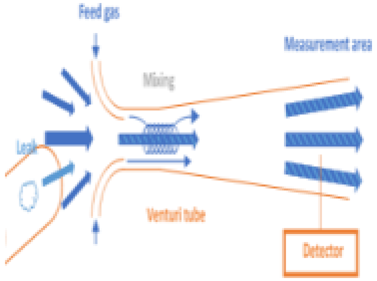
Releases plan determined by a collaborative team

17 blind tests with controlled releases of methane (1 week)

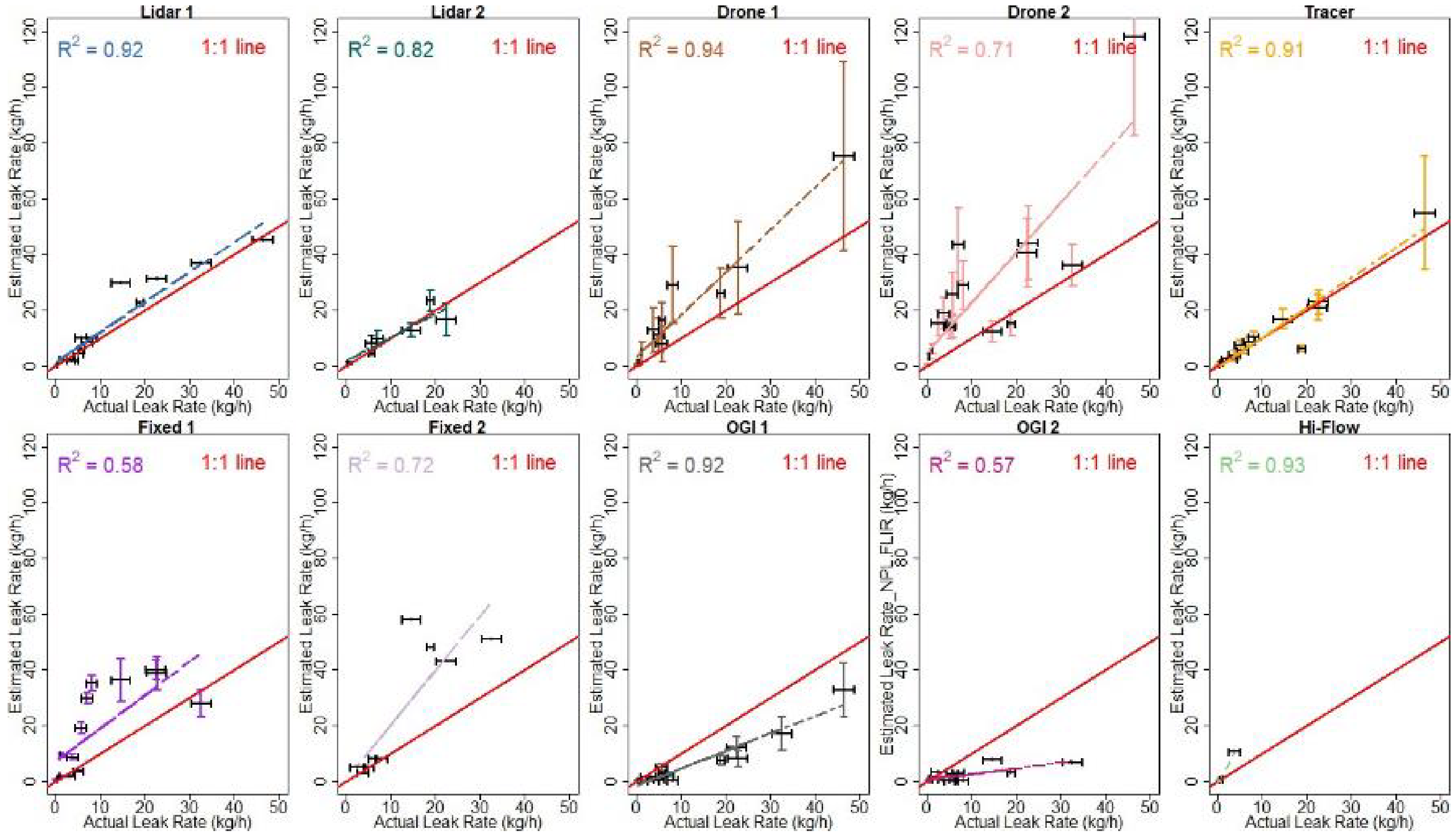
Technologies involved: site level

	Top Down / Site Level Technologies					Continous Monitoring	
	AEROMON	CHARM (OGE)	DIAL (NPL)	SeekOps	Tracer Gas Methodology (DGC)	MIRICO	Sensia
Picture of the equipment							
Picture of their measurements							
Sensor used	Tunable Diode Laser Spectrometry (TDLS). NDIR and MOS sensors were also implemented, but NDIR failed to detect methane in majority of tests and MOS failed to detect methane in a few tests.	LiDAR DIAL (by Adlares). Measurements (IR-DIAL) provide directly the georeferenced total column density of methane (in ppm*m). Background concentration is subtracted.	Differential Absorption Lidar (DIAL). Laser is operated at two wavelengths (one is absorbed by methane and the other not). The difference in the absorption is used to calculate methane concentration.	SeekIR sensor (an in-situ turnable diode laser absorption spectrometer). Concentration is mesaured in ppmv.	Concentration of methane and acetylene measured with a ultra portable gas analyzer: off-axis integrated cavity output spectroscopy (OA-ICOS) by Los Gatos Research + Garmin GPS recevier.	The instrument is based on a patented technology called laser dispersion spectroscopy (LDS) operating in the midIR region. LDS is measuring the change in frequency of the returned light, making it insensitive to weather conditions (rain, fog, snow or dust).	Two OGI cameras were used; Carolyne fyl (an uncooled LWIR detector) and Mileva 33-F (cooled MWIR detector).
Platform used	Drone: UAV Matrice 300 RTK from DJI	Helicopter (AirLloyd)	Truck	Drone: DJI M300 UAS	Van	Sensor with rotating scanning head, 360° horizontal coverage and ±10° vertical.	Unmanned cameras

Technologies involved: bottom up

	Bottom up/source Level		
	FLIR OGI	OPGAL OGI	Venturi Prototype
Picture of the equipment			
Picture of their measurements			
Equipment used	FLIR OGI camera + QL320 tablet for direct quantification	OPGAL uses EyeCGas 2.0, a handed Optical Gas Imaging (OGI) Camera. It was specifically designed for gas leak detection for the Oil and Gas industry.	A venturi tube, supplied by a compressed air cylinder, generates a vacuum suction near the gas leak diluting it in a controlled and defined flow rate. A methane detector, placed downstream, measures the concentration of methane in the outgoing flow.

Analysis of results



Summary of results: estimated vs actual leak rate and linear regression

Including uncertainty indicated by technology providers

Liu et al., in prep 2022

Conclusions

- Only three technologies obtained average errors below 50 % (LiDAR 1 and 2, Tracer).
  - ‘LiDAR’ requires deployment of helicopter or heavy truck.
  - ‘Tracer’ requires localised emissions to obtain this performance.

- Most of site level methodologies are not able to precisely locate the source of the emissions.

- Several techniques will be further limited in other mid-stream contexts (e.g. LNG terminals or industrial clusters with several emitters).

Further work is needed to determine how these technologies can be applied to reconcile with bottom-up estimates

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GERG PROJECT
Top-Down Methodologies: site level

quantification of methane emissions

Phase II.B.
"Source and Site Level Reconciliation"

Pilot Project focused on Reconciliation in an EU Midstream Facility

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PHASE II.B.

Source and site level reconciliation

Lead by Enagás

1

Measurements in a Compressor Station in Belgium

fluxys

- Source Level: Measurement-based quantification by recognized provider for all the identified sources in the site.
- Site Level: Top Down quantification by different providers, selected based on previous phase results.

Pilot Project focused on Reconciliation in the Midstream in EU

2

Reconciliation assessment report by independent academia scientist

MAAZ MAPS

Dr. H. Maazallahi (associated to Utrecht University)

Utrecht University

Prof. Dr. T. Roeckmann: reviewer of the report

Currently in progress

3

Recommendations for a harmonizing methane emissions Reconciliation process in the EU's Gas Midstream sector, based in OGMP Guidance Documents

OGMP

Guidance document: Reconciliation and Uncertainty (U&R) in methane emissions estimates for OGMP2.0

Guidance document:
Reconciliation and Uncertainty (U&R) in methane emissions estimates for OGMP2.0

Phase II.B. Site and source level reconciliation

Partners

enagas

engie

fluxys

GASSCO

gasunie

GERG
THE EUROPEAN GAS RESEARCH GROUP

GRTgaz

medgaz

nationalgrid

OGE

sedigas

snam

storengy

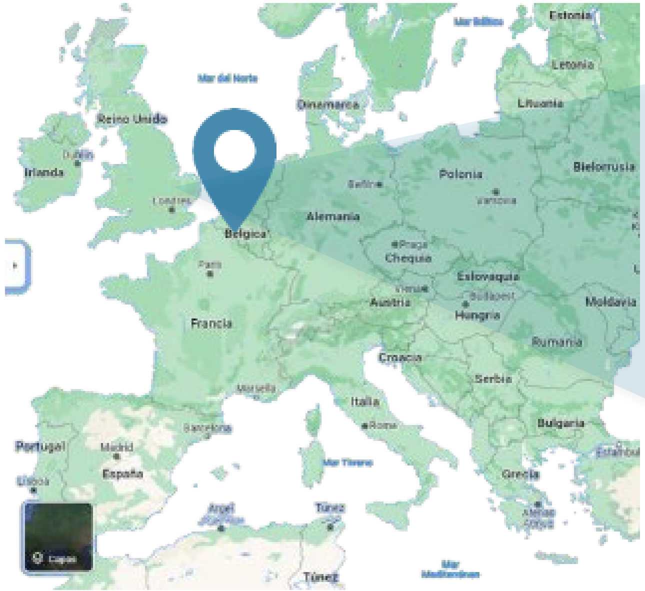
Synergrid

uniper

Phase II.B. Site and source level reconciliation

Compressor Station in Belgium

fluxys



Small plant ➔ Ideal for testing different technologies, first pilot on this methodology proposal for reconciliation.

- ✓ 4 electrically driven compressors and 23 meters high vent stack
- ✓ Compressors not in operation. Compressors depressurized (mode 1) + 1 compressor pressurized (mode 2).

Phase II.B. Site and source level reconciliation

Four independent tests took place in two days for two different operational modes

	Day 0 - Monday 16/05	Day 1 - Tuesday 17/05	Day 2 - Wednesday 18/05
7:00		Arrival+Time for preparation	Arrival+Time for preparation
8:00		8.00h. Organisational/safety briefing	TEST #3 - Day 2. Mode 1. (D2M1)
9:00		TEST #1 - Day 1. Mode 1. (D1M1)	TEST #3 - Day 2. Mode 1. (D2M1)
10:00		TEST #1 - Day 1. Mode 1. (D1M1)	TEST #3 - Day 2. Mode 1. (D2M1)
11:00		TEST #1 - Day 1. Mode 1. (D1M1)	TEST #3 - Day 2. Mode 1. (D2M1)
12:00	Installation	Lunch/ Compressor Pressurization	Lunch /Compressor Pressurization
13:00	Installation	Lunch/ Compressor Pressurization	Lunch /Compressor Pressurization
14:00		TEST # 2 - Day 1. Mode 2. (D1M2)	TEST # 4 - Day 2. Mode 2. (D2M2)
15:00		TEST # 2 - Day 1. Mode 2. (D1M2)	TEST # 4 - Day 2. Mode 2. (D2M2)
16:00		TEST # 2 - Day 1. Mode 2. (D1M2)	TEST # 4 - Day 2. Mode 2. (D2M2)
17:00			
18:00			Desintallation /mobilisation

Mode 1: All compressors are **un**presurized

Mode 2: One of the compressors (C1) is **presurized**

Test organization and field coordination managed by a collaborative team

fluxys
enagas
BUREAU VERITAS

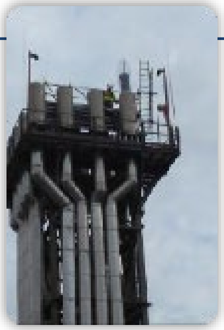
Phase II.B. Site and source level reconciliation

Exhaustive Bottom-Up quantification

Vents/fugitives at open ended lines

Detection with OGI (FLIR GFX320) and FID analyzer (TVA 2020).

Quantification with bagging or anemometer.



Fugitives emissions

- ✓ Inventory of potential leaking components. Detection with FID (TVA 2020)
- ✓ Quantification:
  - ✓ Bagging (EPA 95 procedure) for all leaks > 50,000 ppm.
  - ✓ For the rest of the leaks, 1/3 was quantified with bagging and the rest with EN 15446 correlation factors = EPA Method 21.
  - ✓ QOGI (FLIR GFX320) for 5 inaccessible leaks.

	Nº components in the LDAR database
Accessible	17,779
Inaccessible	803
Total	18,582

Incomplete combustion

- ✓ 3 burners (small boilers, for heating purposes).
- ✓ Only present during start and stops. Detection and concentration measurement using FID analyser and anemometer for quantification.

Phase II.B. Site and source level reconciliation

Phase II.B. Site and source level reconciliation

Bottom up methods –analysis

Comparison of Correlation factors vs Bagging
Comparison of HFSniffer (prototype) vs Bagging
Comparison of Correlation factors vs QOGI
Comparison of different methods for INDIVIDUAL estimations
Comparison of different methods for TOTAL estimation
Vent stack quantification – comparison of methods
Seals quantification – comparison of methods

Key Messages

- Bigger leaks with a concentration > 50,000 ppm represent most of the emission rate related to fugitives
- Indicate the gas composition the day of the measurements is key as many methods quantify VOCs emissions
- For the annual reporting, variability of fugitivess at the vents due to blow down valves needs to be taken into account.
- Correlation factors tend to overestimate fugitives for leaks < 100,000 ppm

Phase II.B. Site and source level reconciliation

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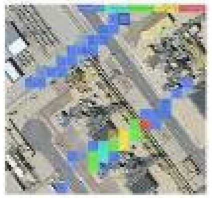
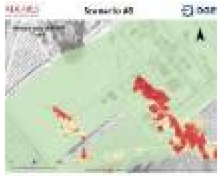
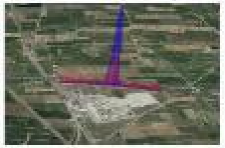
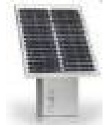
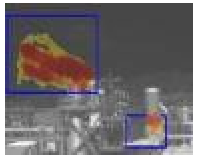
Technologies involved for the reconciliation

Top-down/site-level technologies

	AEROMON	CHARM	DIAL (NPL)	ABB Mobile Guard	ABB HoverGuard	Tracer Gas Methodology (DGC)
Picture of the equipment						
Picture of their measurements				no results in previous phase	no results in previous phase	
Sensor used	Tunable Diode Laser Spectrometry (TDLS). NDIR and MOS sensors were also implemented, but NDIR failed to detect methane in majority of tests and MOS failed to detect methane in a few tests.	LiDAR DIAL (by Adlares). Measurements (IR-DIAL) provide directly the georeferenced total column density of methane (in ppm*m). Background concentration is subtracted.	Differential Absorption Lidar (DIAL). Laser is operated at two wavelengths (one is absorbed by methane and the other not). The difference in the absorption is used to calculate methane concentration.	Off-Axis Integrated Cavity Output Spectroscopy (OA–ICOS)	Off-Axis Integrated Cavity Output Spectroscopy (OA–ICOS)	Concentration of methane and acetylene measured with a ultra portable gas analyzer: off-axis integrated cavity output spectroscopy (OA-ICOS) by Los Gatos Research + Garmin GPS recevier.
Platform used	Drone: UAV Matrice 300 RTK from DJI	Helicopter (AirLloyd)	Truck	Car	Drone: DJI 600 Pro	Van

Continous monitoring

Sensia	Sensirion
	
	didn't participate in previous phase
Two OGI cameras were used; Carolyne fyl (an uncooled LWIR detector) and Mileva 33-F (cooled MWIR detector).	MOx sensors
Unmanned cameras	Unmanned fixed sensors across the site (downwind potential sources)

Bottom up/ Source level Technologies

OPGAL OGI


HFS tested for 30 leaks

High Flow Sniffer


Fluxsense was also included in the tests. They were not able to submit results.

Phase II.B - tests on operating sites – Zelzate CS

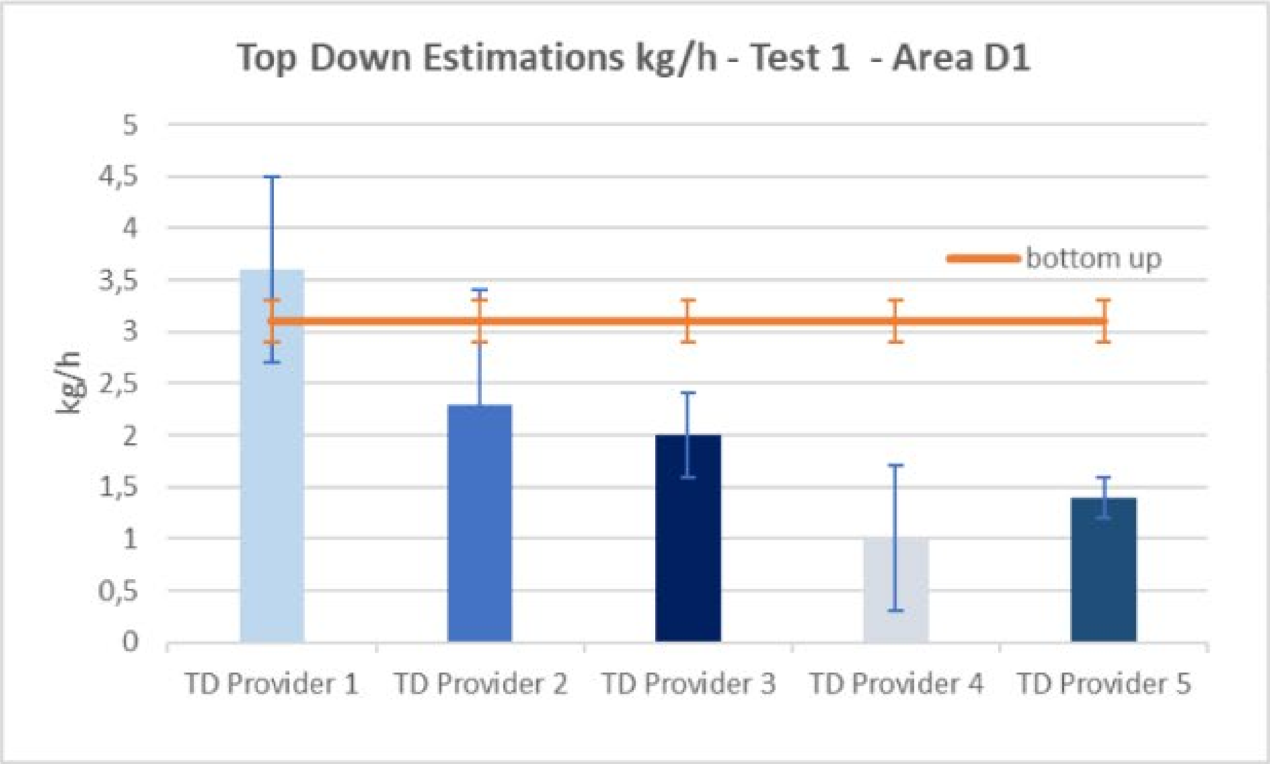
Tests took place in May 2022

Full results will be available in the upcoming months

Photos Fluxys Belgium - David Samync

Phase II.B. Site and source level reconciliation

Reconciliation at area level: example for area D1 (vent stack)



Provider 1 – Overlap for Area D1 (mode 1) ✓

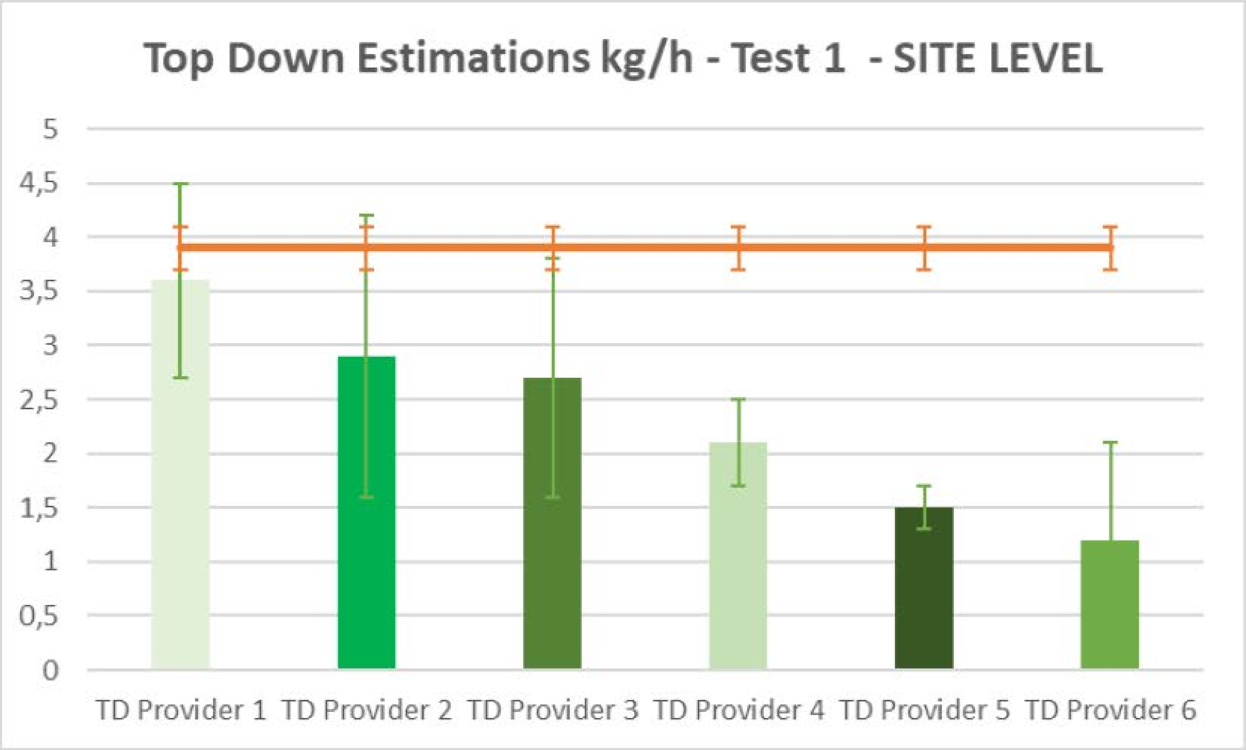
Provider 2 – Overlap for Area D1 (mode 1) ✓

Provider 3, 4 & 5 no overlap

- ✓ **Provider 3:** QOGI at large distance, what normally results in underestimation
- ✓ **Provider 4:** car based methods not appropriate for quantification of plumes at elevated sources
- ✓ **Provider 5:** systematic underestimation in all tests observed.

Phase II.B. Site and source level reconciliation

Reconciliation at site level: example for test 1 (Day1-Mode 1)



Provider 1 and 3 – Overlap

However, here site level data is the sum of area level data and combined uncertainty → area level reconciliation is the level to be verified.

Provider 2 – Overlap

However vent stack most likely not included. No overlap if we compare emissions excluding D1.

Provider 4, 5 & 6 no overlap

Site level data is the sum of area level data and combined uncertainty → area level reconciliation is the level to be verified.

Reconciliation at area level provided us with more information that the site level analysis
Otherwise site level comparison may imply errors that compensate each other

Practical Recommendations for Snapshot Reconciliation

Recommendations to operators

Blowdown Operations are performed for safety reasons, after stop of the compressors or for maintenance operations.

- **Emissions for these events are reported using engineering calculations** (this allows accurate quantification).
- **Verification with site level methods is not possible**, there is no technology provider able to quantify this plume due to its variable nature* (they directly depend on the pressure levels on the pipe).

Blow down events quantification can't be included in the verification/reconciliation process

→

Traceability of data used in the BU calculations for blowdown operations is key

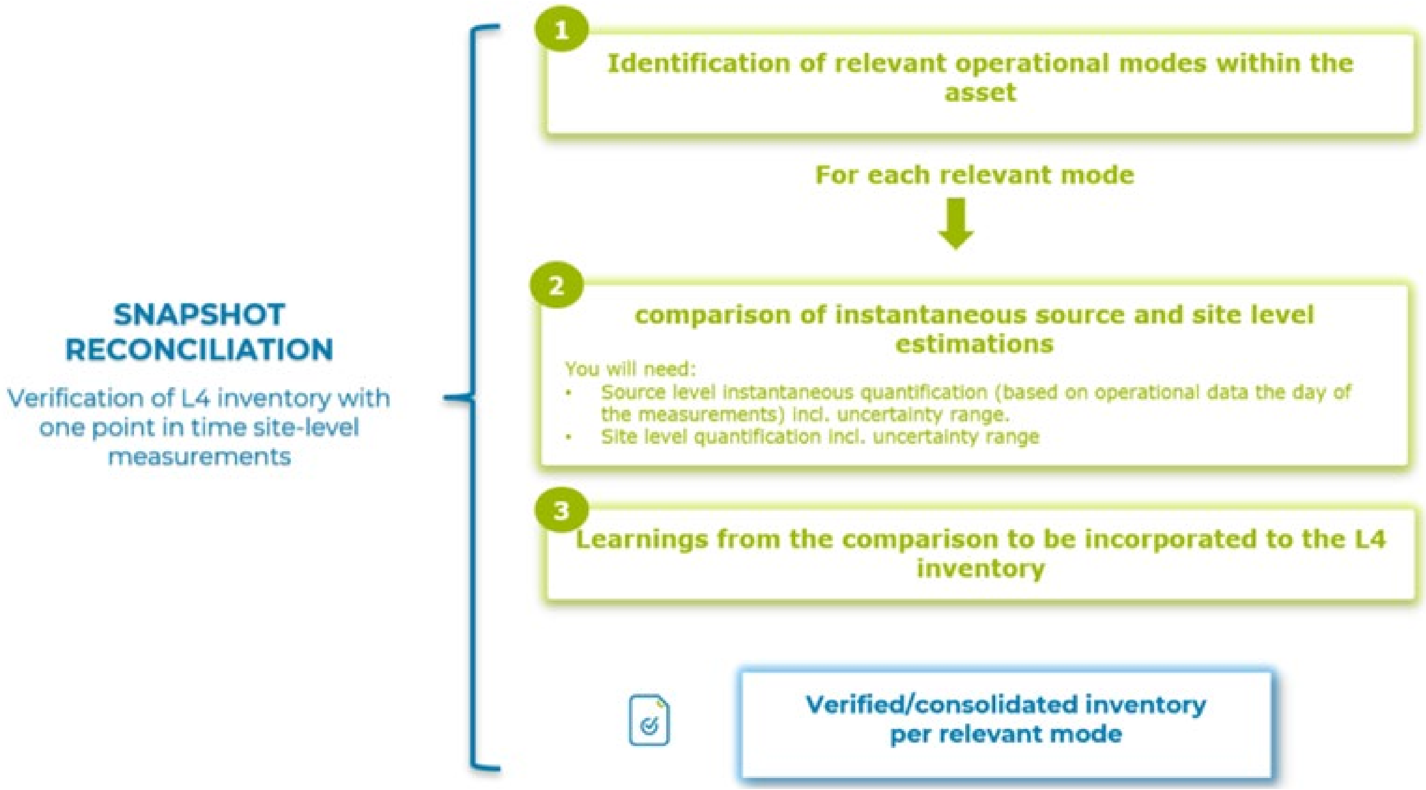
e.g. operators to archive number of events, operational parameters (gas pressure and temperature…).

*Due to their size and their non constant nature, they can only be quantified as for now with thermodynamic calculations based on pressure, volume and temperature of the gas vented at these blow down operations.

Snapshot Reconciliation, our preferred approach for verification

Methodology proposal

We understand that ***snapshot/instantaneous reconciliation*** is **aligned with *U&R TGD*** as for this site there is **detailed temporal information about emissions / operational parameters in L4 inventory**. We believe it's also the case for most of EU compressor stations.



Snapshot reconciliation, an approach that can be considered, provided operator has temporal information of emissions / operational parameters on L4 data for the asset

Given the current lack of published reference studies in midstream asset son other approaches such as *aggregated annual asset-level reconciliation*, we advocate for flexibility in producing consolidated inventories in the coming years.

Practical Recommendations for Snapshot Reconciliation

Conclusion

We are working on recommendations to support midstream operators the generation of a consolidated level 5 inventory

- ✓ **We believe the purpose of the comparison should be to shed light on which improvements on quantification should be prioritised each year.**
- ✓ **Snapshot reconciliation not only based on overlap of approaches can be an appropriate methodology for achieving this.**
- ✓ **As long as enhancements are made in the source-level L4 inventory, the process can be considered successful.**

Upcoming ME Projects – Opportunities for Collaboration

- **New: Hi-Flow Sampling – HFS - devices performance testing**
- **Project championed by NPL & Bureau Veritas, covering Metrology, Implementation, Performance Evaluation & Standardisation aspects**
- **Scope of Work:**
  - Draft **common Hi Flow technology implementation procedure** allowing intercomparison and repeatability
  - Define **experimental protocol and performance characteristics to be assessed**
  - Assess performance of each "new" HFS device based on controlled releases and real cases
  - **Develop & propose minimum performance standards**
  - Develop an example **measurement uncertainty calculation for HFS**, based on the influence of the performance characteristics determined during testing
- **Planned Testing: a) laboratory tests, b) controlled release tests using traceable leaks and c) real world measurements**
- **Deliverables:**
  - Performance data and uncertainty for the tested HFS devices
  - Data and proposed draft procedures to feed into a new CEN Technical Specification document on HFS
- **Technologies: commercial ones - Hetek, Semtech, The Sniffers, …, RICE/GRTgaz prototype**
- **Budget: ~305 kEUR, technology providers would contribute in-kind**
- **Open call to collaboration & interested participants – Please get in touch with GERG Secretariat: miguel.ballesteros@gerg.eu & mures.zarea@engie.com**

REX2024
PRCI Research Exchange

ME Topics of interest – Opportunities for Collaboration

- Updating EPA method 21 correlations between concentration & flow rate for methane leaks
- Reconciliation between source-level and site-level measurements
- How to account for emissions variability in establishing annual emission estimates
- Continuous monitoring technologies
- H2 emissions – an EC co-sponsored project in contracting stage

- Open call to collaboration & interested participants – Please get in touch with GERG Secretariat: miguel.ballesteros@gerg.eu & mures.zarea@engie.com

GERG
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Appendices

CONTEXT

TOP-DOWN METHODOLOGIES: SITE LEVEL QUANTIFICATION OF METHANE EMISSIONS

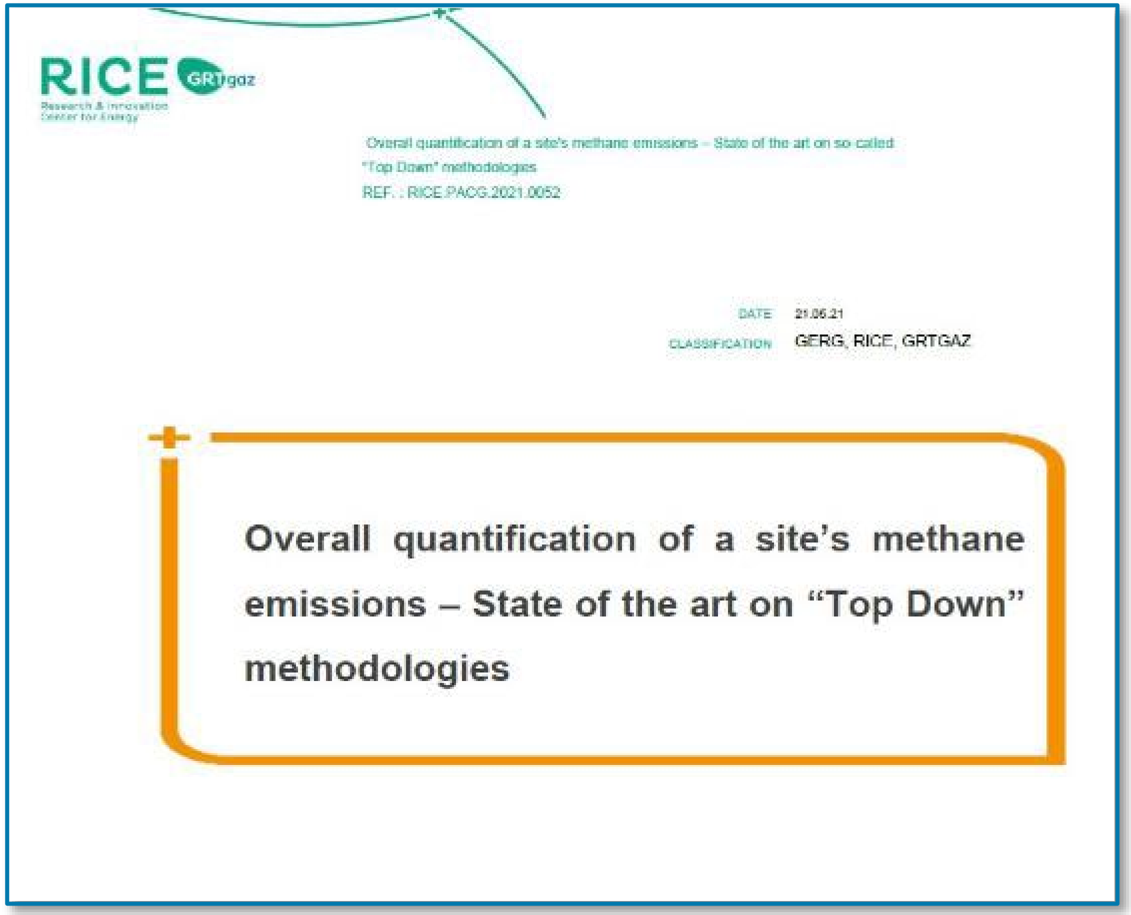
Series of projects focusing on site level technologies for Mid-Stream Gas Infrastructure

PHASE I

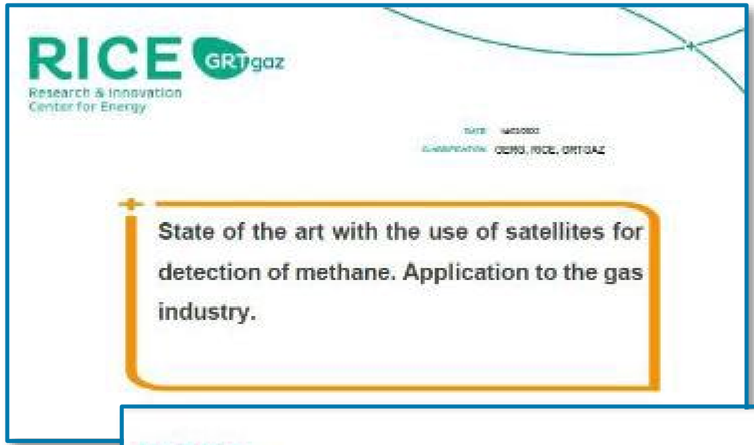
State of the art study of site level technologies

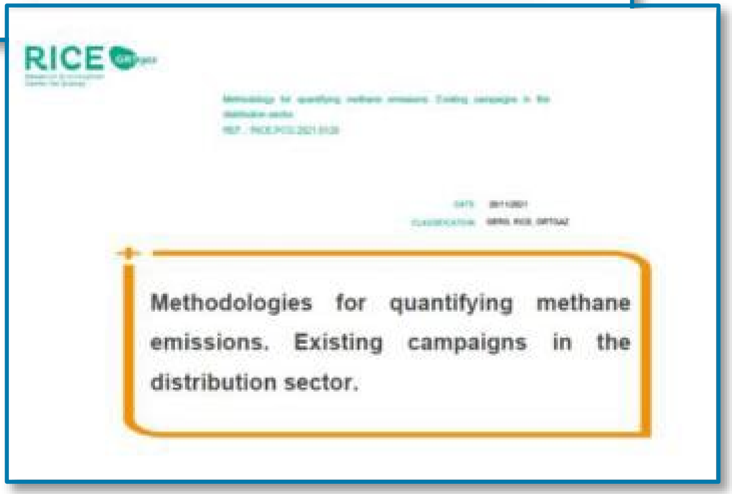
Lead by RICE (GRTgaz)

Review of existing data on Top-down methodologies


Overall quantification of a site's methane emissions – State of the art on so called "Top Down" methodologies
REF. : RICE.PACG.2021.0052
DATE 21.06.21
CLASSIFICATION GERG, RICE, GRTGAZ

Overall quantification of a site's methane emissions – State of the art on "Top Down" methodologies


State of the art with the use of satellites for detection of methane. Application to the gas industry.


Methodologies for quantifying methane emissions. Existing campaigns in the distribution sector.

4

Project Definition

Mothballed and Isolated Compressor Station

9 most promising site-level technologies

3 bottom-up

Independent analysis to assess accuracy and repeatability

17 blind tests with controlled releases of methane (1 week)

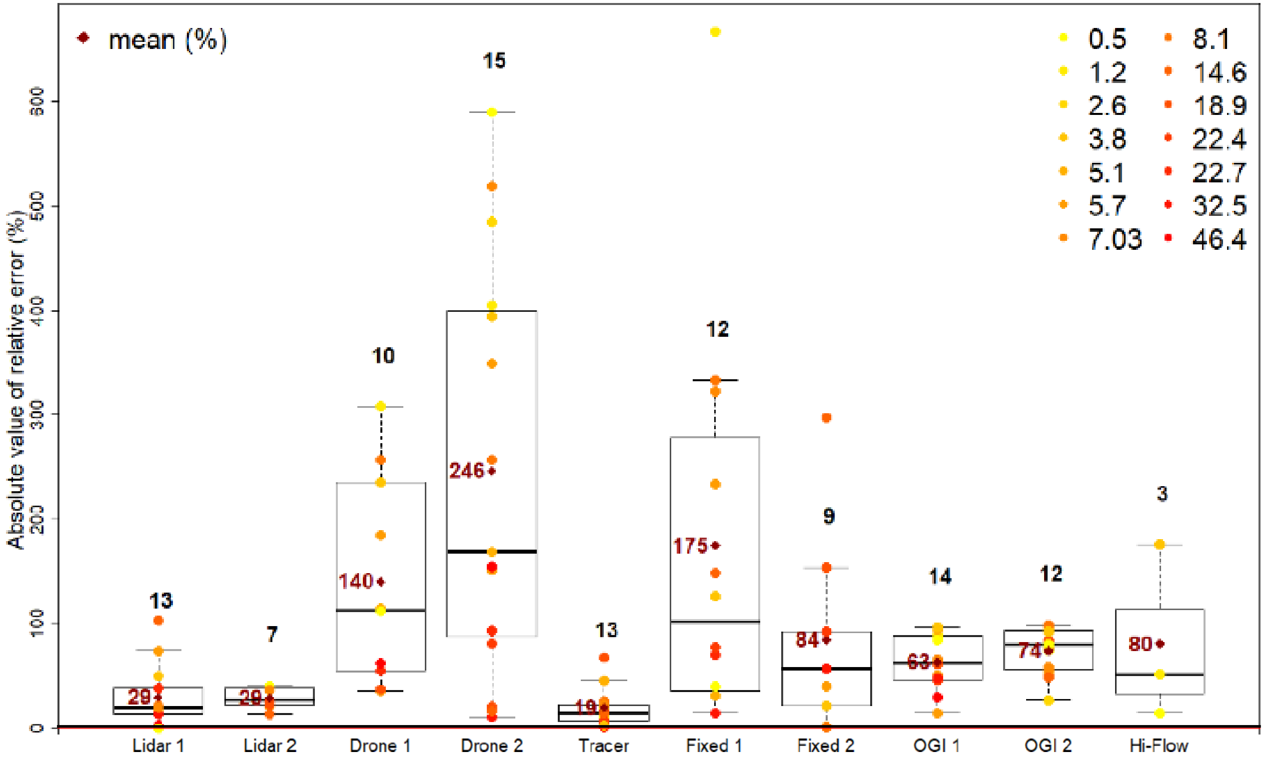
Technologies involved

Identifier	Technologies
Drone 1	TDLS
Lidar 1	Helicopter borne DIAL LiDAR
Tracer	Tracer release
Fixed 1	Integrated path scans
Lidar 2	Truck borne DIAL LiDAR
OGI 1	Hand-held OGI
Drone 2	SeekIR
Fixed 2	Fixed OGI
OGI 2	Hand-held OGI

A prototype of a Hi Flow Sampler (Hi-Flow) was also tested in some releases, to assess its accuracy for fugitives' quantification

*Two additional technologies were tested by they didn't provide any results (measurement technique to be optimised).

Analysis of results



The dots correspond to the total flow rates of the different tests
0.5 – 46.4 (kg/h)

Absolute value of the relative errors (ARE, %) on the quantification estimated for each test

Bars indicate median and interquartile range of the distributions

Number of points accounted for in the statistical distribution of each provider is indicated on top of each bar plot

Lower releases: **0.01 kg/h and 0.1 kg/h are not included in the assessment of accuracy**, the objective of these releases was to assess the detection/quantification thresholds

Liu et al., preprint 2023

Analysis of results

	1	2	3	4	5	6	7	8	10	11	12	13	14	16	17	average ARE
Drone 1		187%	308%	55%	37%		37%	62%	113%	258%		113%		236%		**140%**
LiDAR 1	18%	2%		38%	75%		20%	3%	18%	21%	13%	1%	19%	50%	104%	**29%**
Tracer	10%		9%	1%	6%	7%	68%	18%	44%	26%		21%	22%	3%	15%	**19%**
OGI 2	29%	95%	75%		54%		84%		96%	99%	79%	81%	57%	92%	49%	**74%**
OGI 1	45%	51%	89%	68%	13%	46%	61%	29%	94%	97%	48%	84%	66%	97%		**63%**
Drone 2	493%	153%	404%	94%	352%	81%	20%	155%	167%	258%	11%	594%	518%	394%	16%	**246%**
Fixed 2	95%	41%				92%	154%		2%	1%	57%			21%	298%	**84%**
Fixed 1	30%		665%	71%	236%	78%			32%	335%	14%	41%	322%	126%	148%	**175%**
LiDAR 2		20%			33%	26%	16%					47%	37%		13%	**29%**

Absolute value of the relative errors (ARE, %) per release

(3 colors scale)

Analysis of results

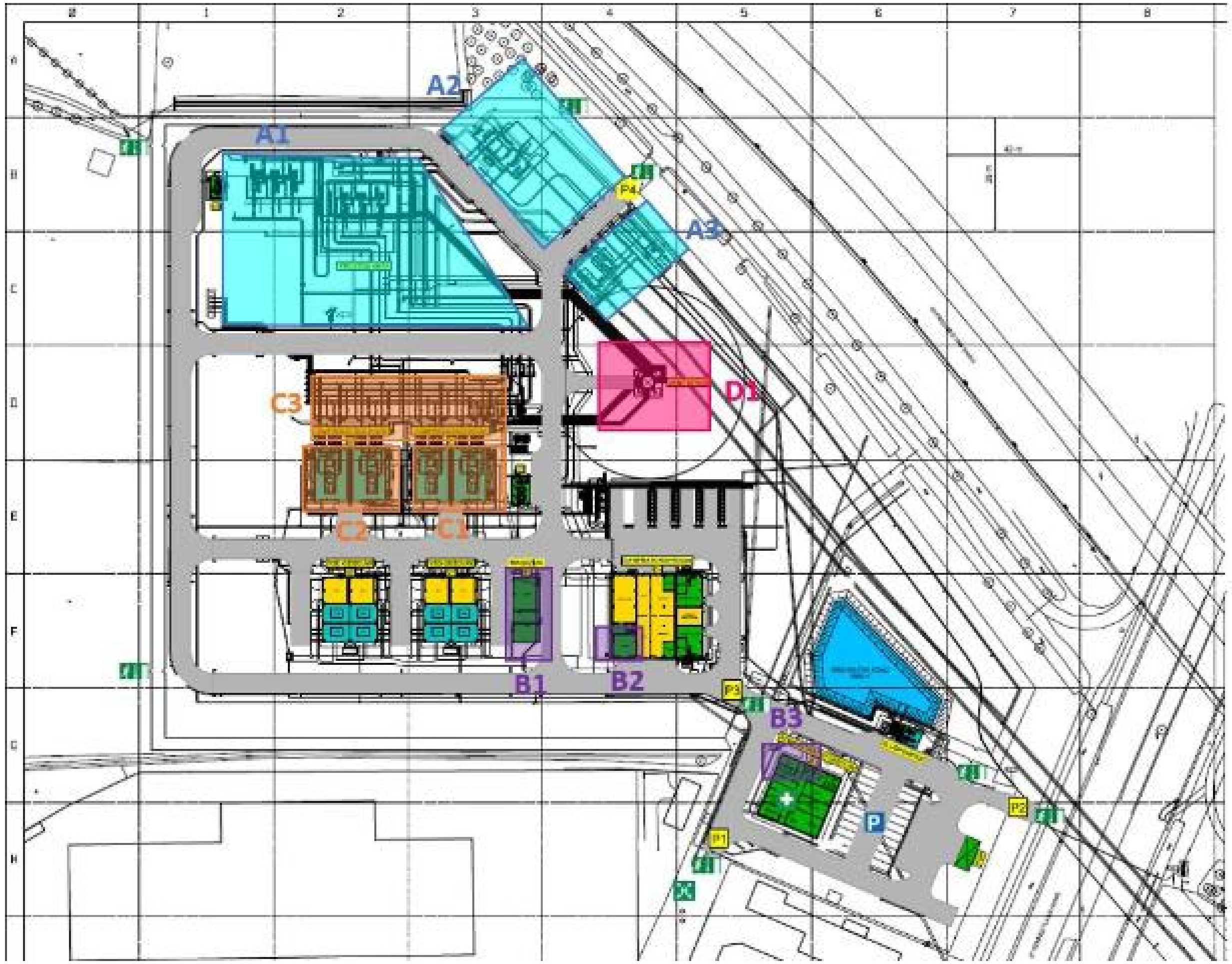
Technique	Provided Uncertainty, %	Actual Relative Error, % (absolute value)	% within 0.5-2x	% within 0.1-10x
LiDAR 1	N/A	29	92	100
LiDAR 2	17	29	100	100
Drone 1	55	140	40	100
Drone 2	29	246	33	100
TRACER	15	19	92	100
FIXED 1	13	175	50	100
FIXED 2	N/A	84	78	100
OGI 1	36	63	36	79
OGI 2	N/A	74	25	69

Indicated uncertainty, mean ARE (%) and percentage of quantified release rates within a particular multiplicative range of the actual leak rate

Liu et al., in prep 2022

Phase II.B. Site and source level reconciliation

Site was partitioned in different areas indicated beforehand to all the providers. All Top Down providers were requested in advance to provide quantification 1) for each area & 2) for the whole site



Areas A
A1, A2, A3: pipelines /connections

Areas B
B1, B2, B3: boilers (methane from incomplete combustion)

Areas C
C1, C2, C3: Compressors
C1 and C2: compressor buildings
C3: equiment in front of compressor buildings

Area D
D1: Vent Stack

Requirements for Snapshot Reconciliation

Requirements to perform *snapshot reconciliation* at a site

Snapshot reconciliation can be considered as an approach to produce a consolidated L5 inventory, as long as the operator has detailed temporal information about emissions in the L4 inventory.

The operator needs to be familiar with the sources of methane emissions and their variability to interpret the data and work on the reconciliation process. For this reason, it's needed:

- detailed information on the equipment (e.g. type of compressors) and the operational mode and status of equipment when the measurements were performed, i.e. operational parameters
- tracking and recording the events related to maintenance, specific operations and incidents
- detailed temporal characterisation from potentially randomly variable sources to develop the L4 emissions inventory.

Practical Recommendations for Snapshot Reconciliation

Recommendations to operators

- **Each pre-identified relevant mode to be verified through snapshot reconciliation**
  - Operational status of a facility during the site level measurement is not known in advance. To avoid logistical challenges and excessive costs for the site level campaign, some flexibility is desirable on this point. Verification of the modes of an asset **can take place at different sites** within the asset and it **can be done in subsequent years**.
  - This way, a consolidated inventory per relevant mode is produced for the asset, and it can be checked that the collected information is consistent with the sampling recommendations included in the guidelines.
  - Preference to prioritise in the first year the reconciliation in those modes emitting the most.

Practical Recommendations for Snapshot Reconciliation

Recommendations to operators

- ***Snapshot reconciliation* is challenging if it is focused on the overlap of uncertainty ranges**. This is mainly due to high and presently unknown uncertainties of site-level methods.
- There is a lack of sufficient academic robust studies on this topic done in real environments replicating midstream EU infrastructures, and most studies are done in simple environments such as open fields or R&D Platforms (e.g. METEC and TADI platforms) that do not replicate realistic geometry and plume dispersion in midstream sites, where high equipment and buildings can interfere in the ideal dispersion. GERG study on controlled releases, available here, addressed this, the analysis showed **there are still challenges to characterise site level uncertainty appropriately in midstream context.**
- In our Reconciliation study, the comparison of estimations gave us no guidance on how to eliminate the disagreement between source and site level approaches. Additional analysis was required, as indicated in the U&R TGD.

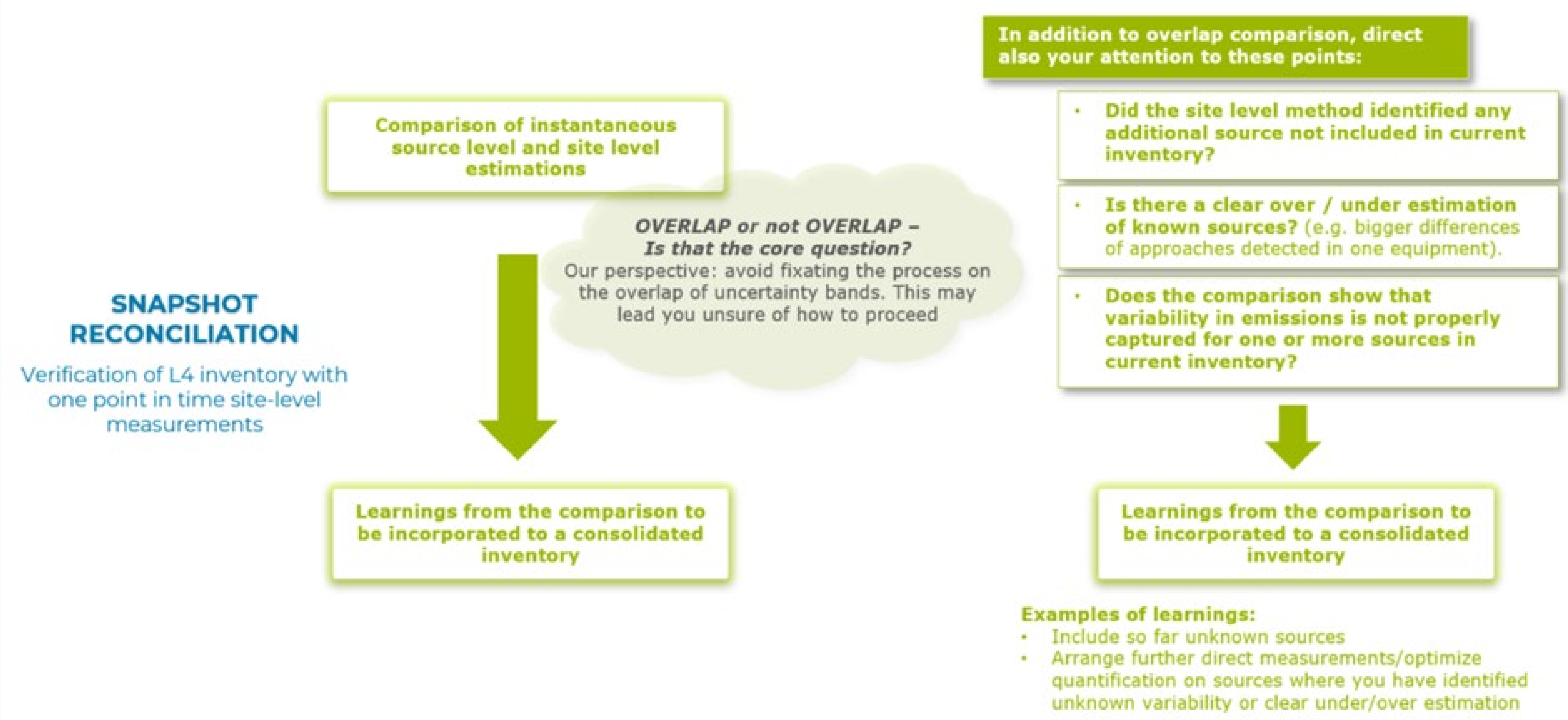
Beyond checking the overlap of uncertainty ranges, the general aim of reconciliation is producing robust inventories that can be improved year after year.

Practical Recommendations for Snapshot Reconciliation

Recommendations to operators

Checking for overlap is just one step in the process.

The aim of the comparison is to identify improvements on quantification to prioritise each year



Practical Recommendations for Snapshot Reconciliation

Recommendations to operators

Ensure source and site level estimations compared are aligned in terms of time and completeness

For this approach, an **instantaneous source level inventory, at the time of the site level measurement,** is needed.

- Source and site level measurements to take place independently from one another and at a short time interval, to ensure no significant variation of operational or environmental conditions (but not exactly simultaneously to avoid interferences).
- Recommended to deploy an OGI camera for identification of main sources during the site level measurement if the site level measurement is not able to locate the origin of the plumes.

Conduct **reconciliation at the area level for all areas (rather than at the the site level) if the TD provider calculates emissions per area to report site-level results**. Otherwise, comparing emissions at the site level may mask errors that offset each other.

- To exclude from the comparison those areas where the TD provider did not detect or quantify emissions. This ensures that disperse emissions not captured by the TD provider are not inadvertently included in the comparison.
- Emissions indoors/below roofs can't be detected by TD methods, they need to be excluded from the comparison too. One possibility for the verification of these indoor emissions would be to use QOGI (to be further investigated).