Jacobs Challenging today. Reinventing tomorrow.

Measuring Life-Cycle Greenhouse Gas Emissions from Water Resource Recovery Facilities Workshop

U.S. DOE Industrial Efficiency & Decarbonization Office

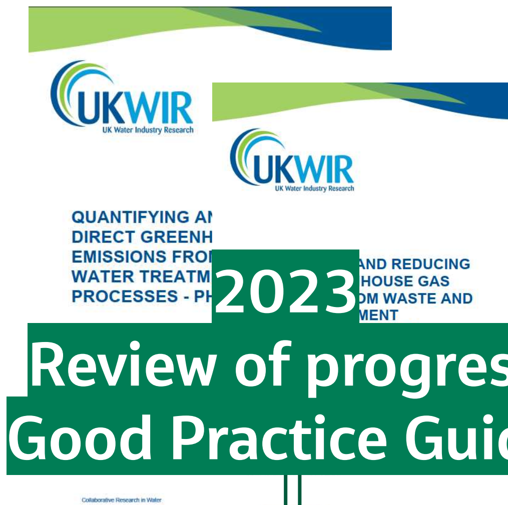
January 2024

My journey measuring GHG emissions in the UK water sector

2019
Desk-top review

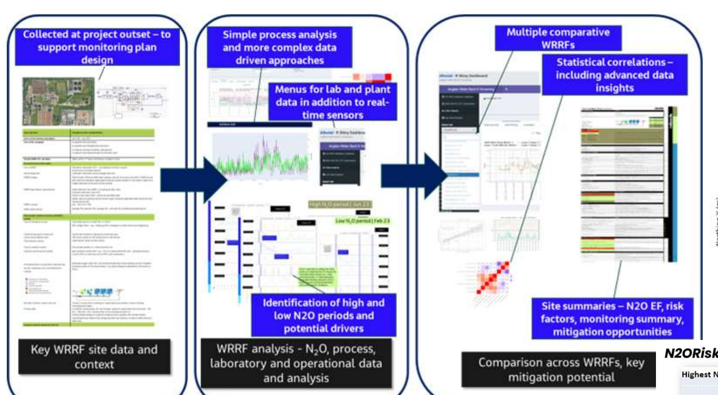
2021
Measurement started

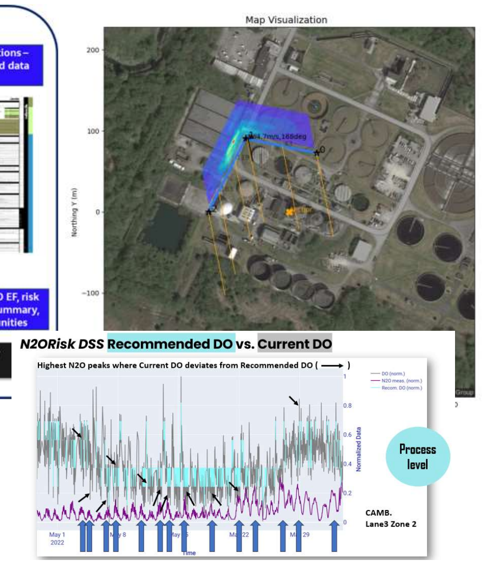
2022
Community of Practice Start-up

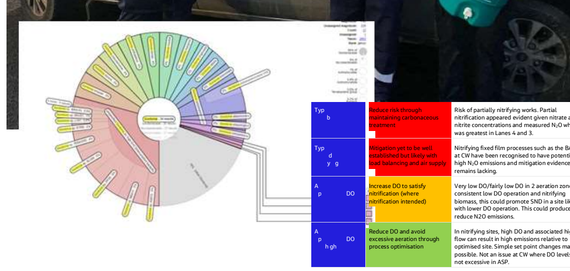


2023
Review of progress
Good Practice Guide

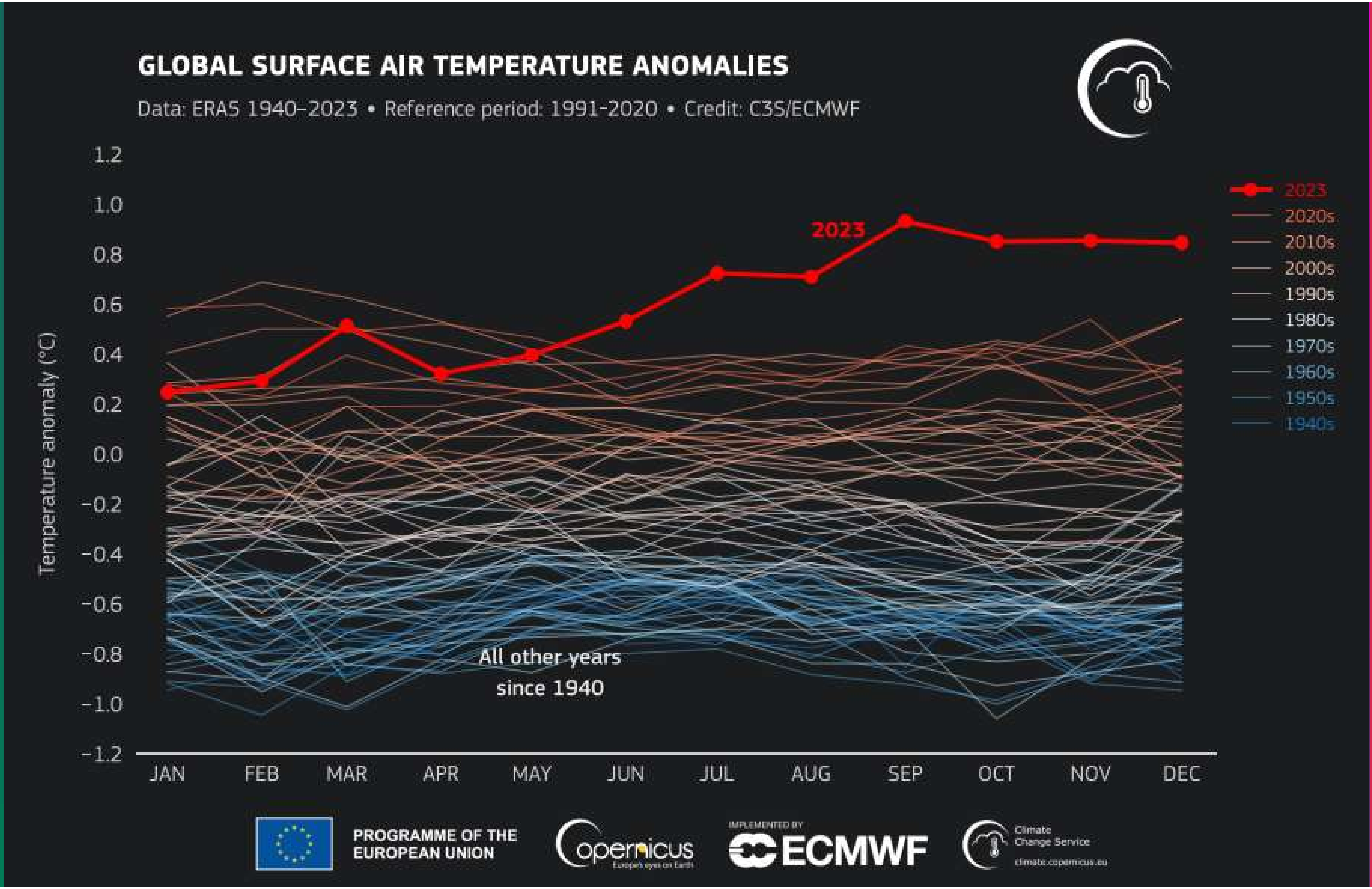
2023
Improving UK GHGI and funding R&I





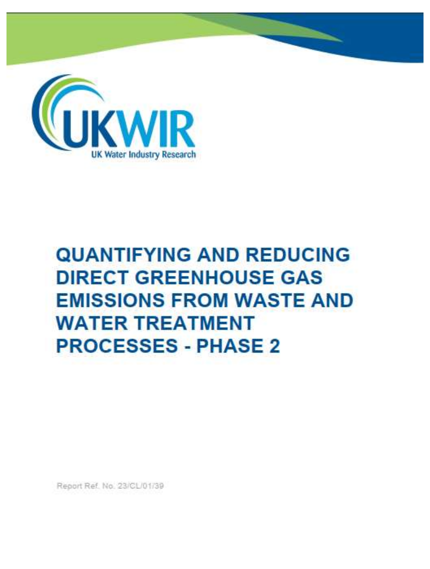


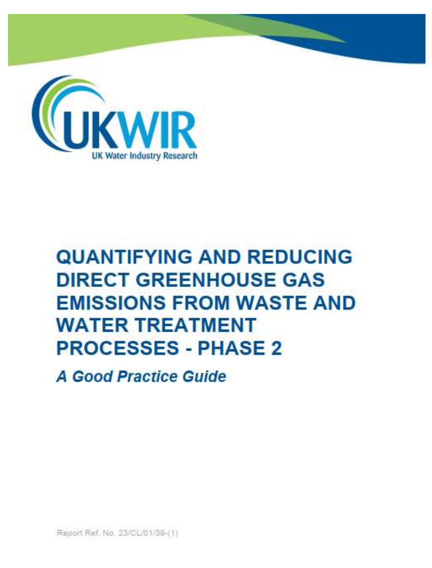
2023
Fate of biosolids and nutrients and GHG – Environment Agency


GLOBAL SURFACE AIR TEMPERATURE ANOMALIES
Data: ERA5 1940–2023 • Reference period: 1991-2020 • Credit: C3S/ECMWF
Temperature anomaly (°C)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
2023
All other years
since 1940
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2023
2020s
2010s
2000s
1990s
1980s
1970s
1960s
1950s
1940s
PROGRAMME OF THE
EUROPEAN UNION
Copernicus
IMPLEMENTED BY
ECMWF
Climate
Change Service
climate.copernicus.eu

(Very) recent R&D and evening viewing on GHG measurement which summarises global practice, best evidence and experience to date

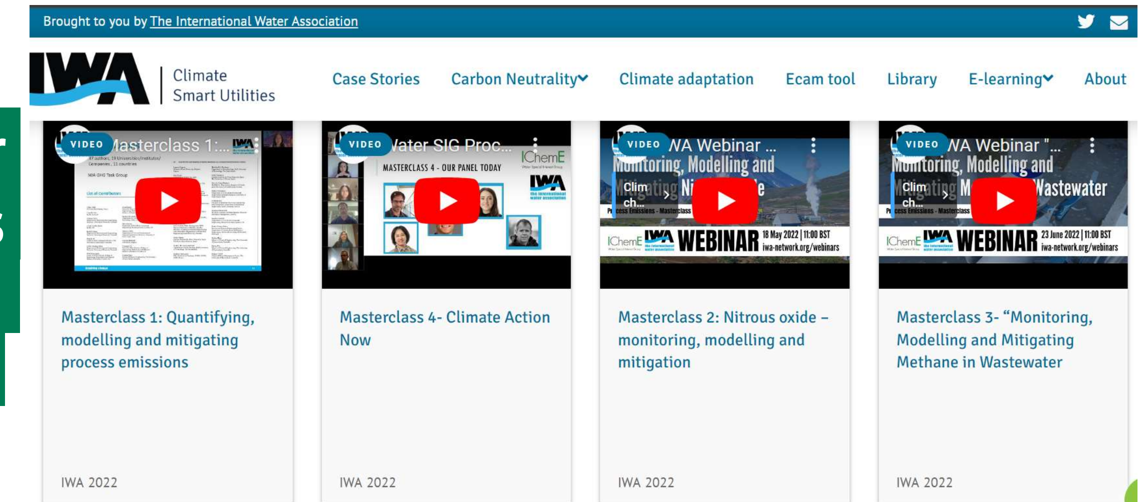
UK Government, 2023
https://randd.defra.gov.uk/ProjectDetails?ProjectId=20451





UK Water Industry Research, 2023
https://ukwir.org/water-industry-research-report?object=940bba8a-048a-4665-b344-11fba7187af3
https://ukwir.org/c0397784-85ad-4ae7-acaf-6c455fd341d5?object=12c38fea-3890-48d8-abb0-a17d7bc6d347

International Water Association Masterclass series on Scope 1 emissions, 2022



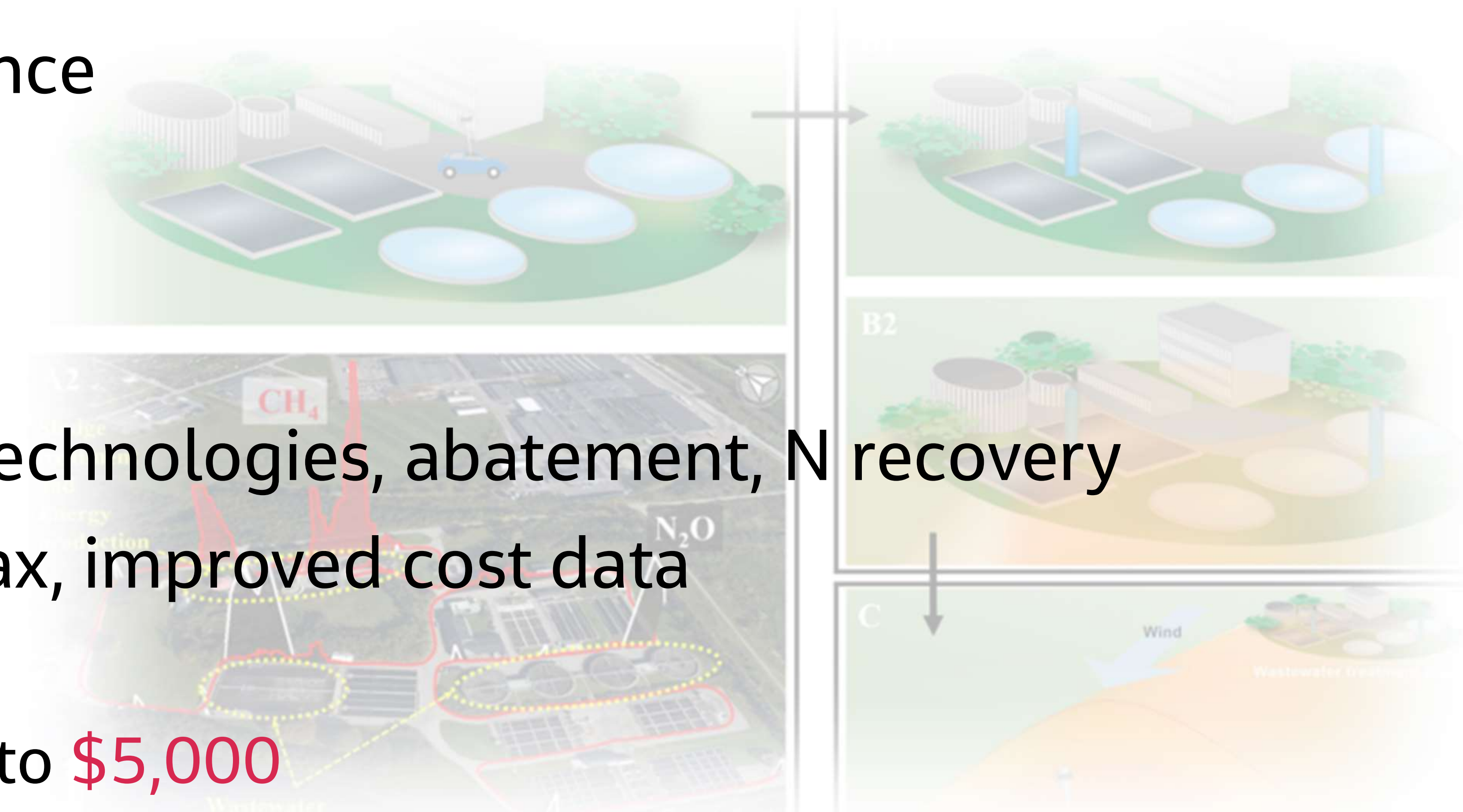
Masterclass 1: https://youtu.be/KW-0MyYnWQU?si=TGjsj66-wtrnNBtN
Masterclass 2: https://youtu.be/VQNeznELmh4?si=8G-G8wEWOyakxKrd
Masterclass 3: https://youtu.be/eLTAxkJkYm0?si=TtVRm7bHIQ652VTV
Masterclass 4: https://youtu.be/VbNc3hYJjSE?si=sTQ-0Xwk-owqiPvc

International Water Association Series, Danish lessons for global practice, 2023

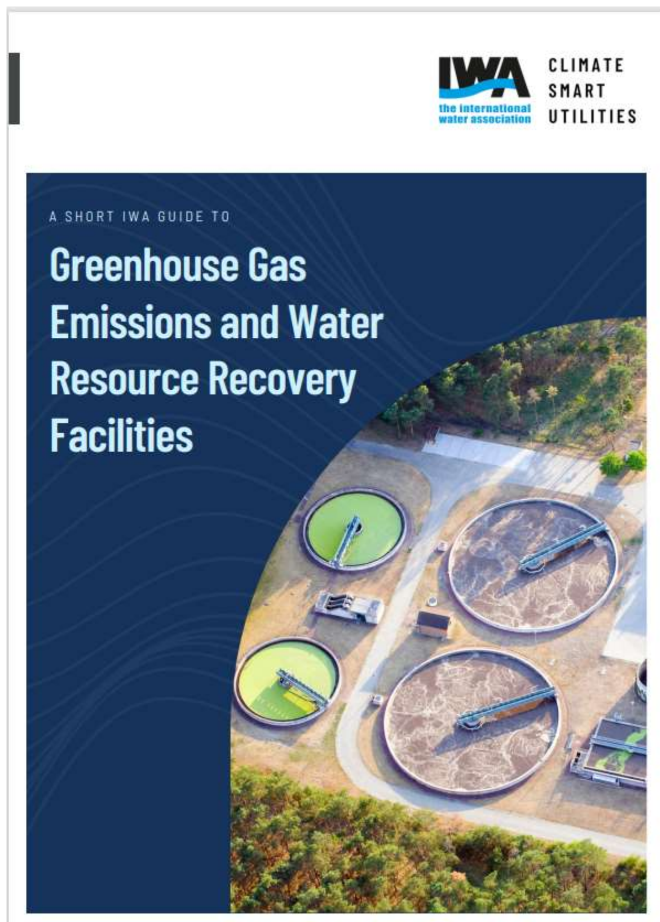
Webinar 1: Towards a Climate Neutral Water Sector: the Nordic experience https://youtu.be/wvplv3tSKpw?si=PB_q1R6oNf2jAq5s
Webinar 2: N_2O https://youtu.be/-szhUdQpYqA?si=OCahjYWa0GSlOvvD
Webinar 3: CH_4 https://youtu.be/FvjdxKpY_jA?si=bl1tvMQ8dHAqTTJS
Webinar 4: Life Cycle Analysis https://youtu.be/fT_SzTuWhJw?si=OCzLtkwAnwdkkEUO

Recommendations from research projects (links in prior slide)

- Start measuring
- Do National Monitoring Programmes (e.g. Danish; approx. $500,000, 9 WRRFs)
- Develop improved sector level guidance
- Mitigate emissions
  - Stop methane leaks at AD facilities
  - Process optimisation for N_2O
- R&D to reduce emissions – low N_2O technologies, abatement, N recovery
- R&D incentives for mitigation – e.g. tax, improved cost data
- Abatement costs limited
  - Methane $350/$tCO_2e$, range -$2,800 to $5,000
  - Nitrous oxide $65-$500 /tCO_2e; campaign costs $60,000-80,000 per WRRF site

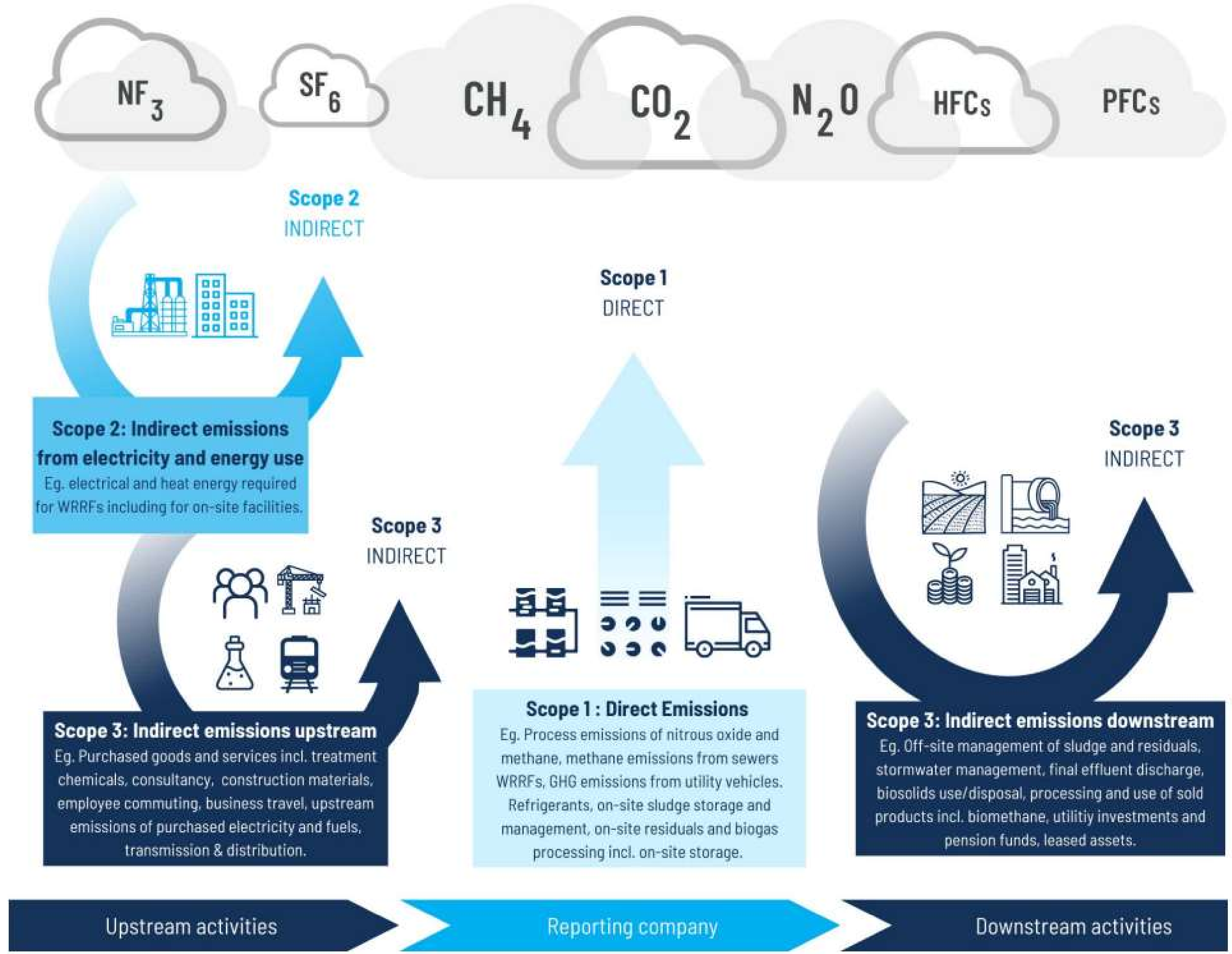


Greenhouse gas emissions from WRRFs

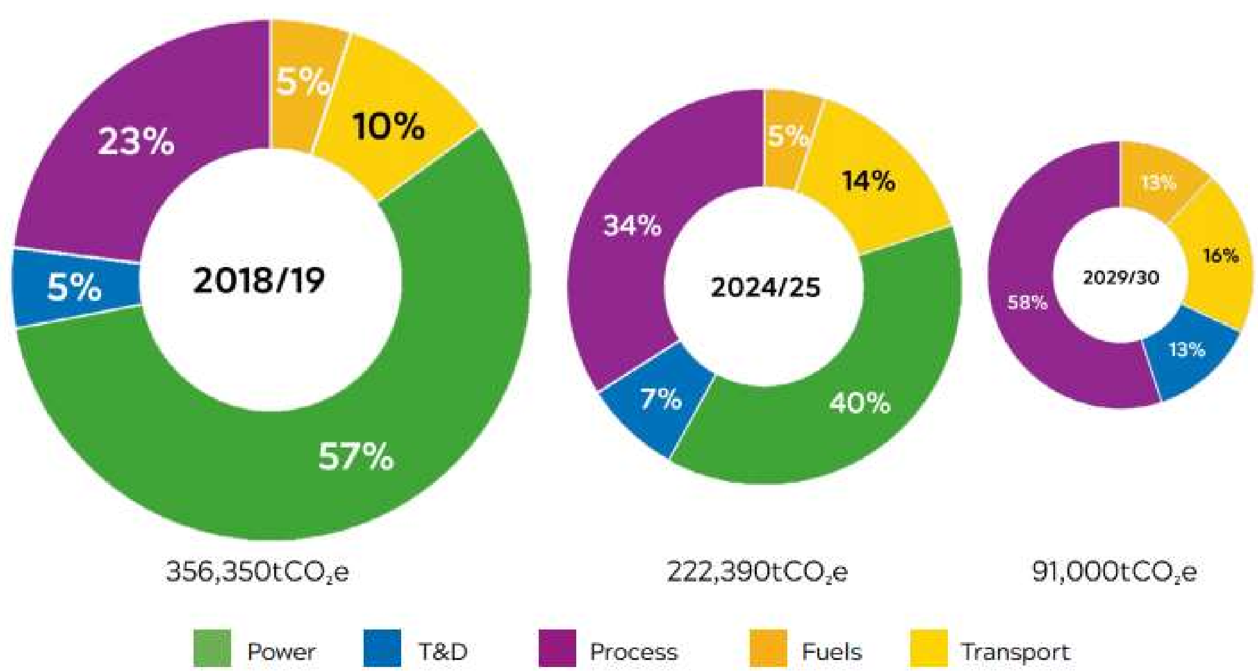


IWA, 2023

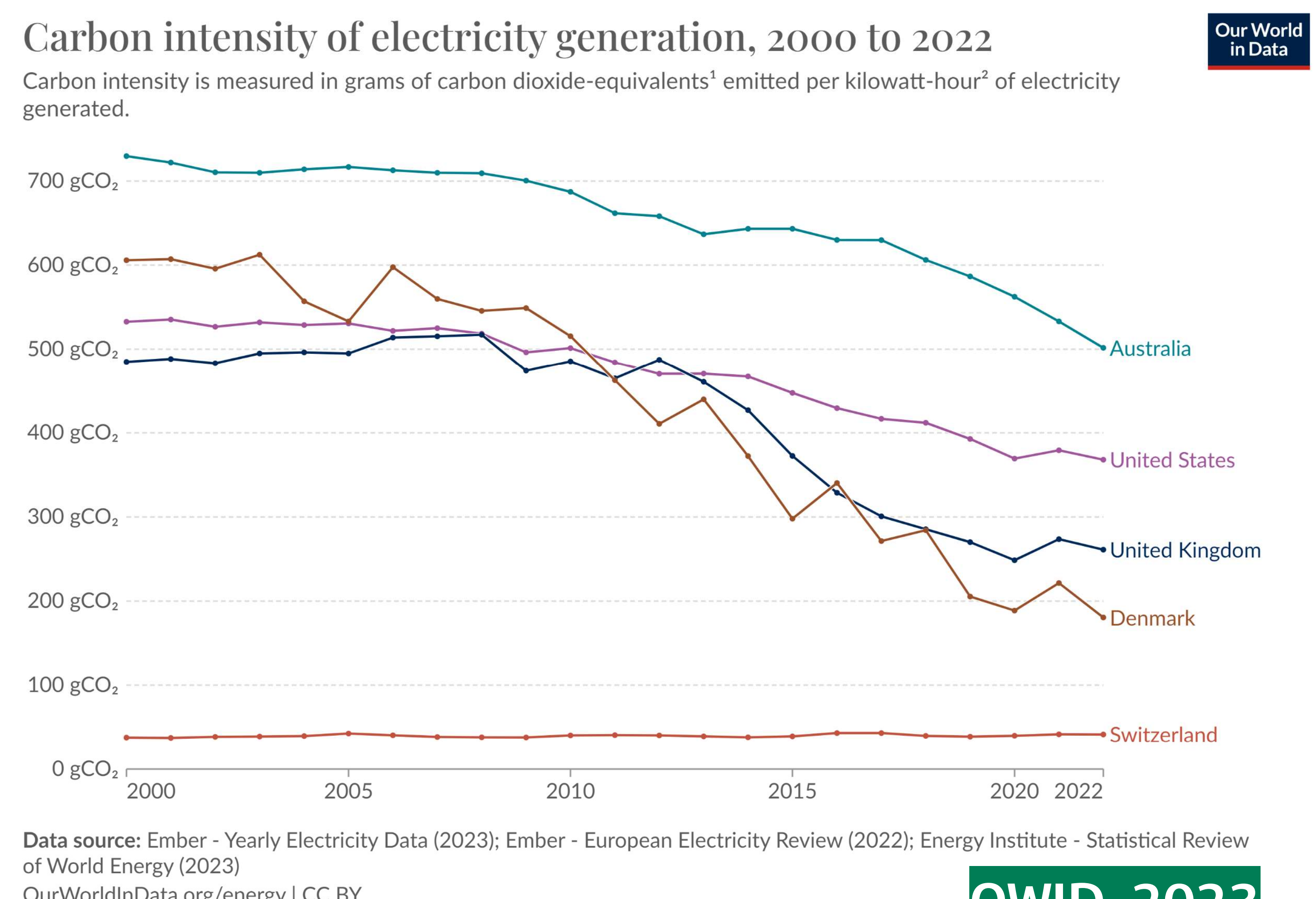
https://iwa-network.org/publications/greenhouse-gas-emissions-and-wwrfs/



As carbon intensity of electricity generation decreases, process emissions of N_2O and CH_4 become key for WRRFs

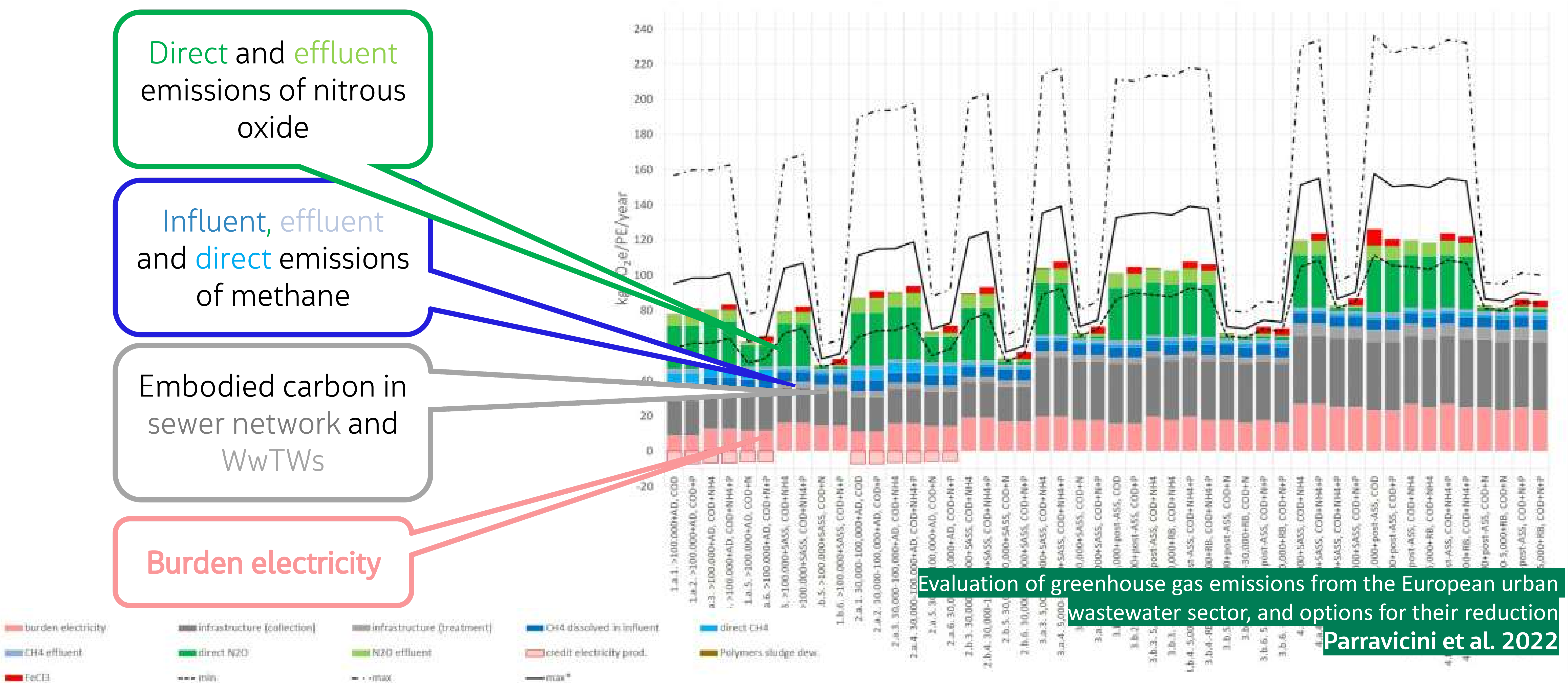


Anglian Water Route Map, 2021



OWID, 2023

Process emissions of CH_4 and N_2O are also key on life cycle carbon basis



Evaluation of greenhouse gas emissions from the European urban wastewater sector, and options for their reduction

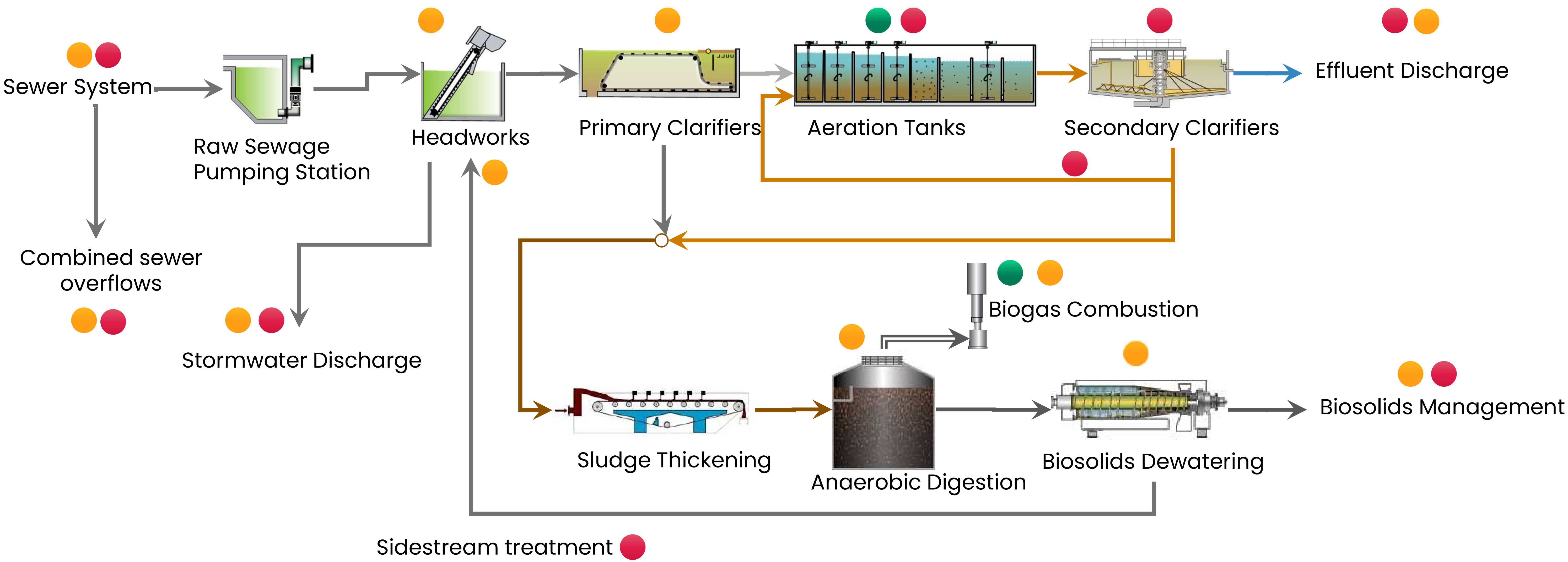
Parravicini et al. 2022

We know where our significant GHG emissions are generated and where we can take action

Carbon dioxide (CO_2)
GWP = 1

Methane (CH_4)
GWP = 28

Nitrous Oxide (N_2O)
GWP = 265



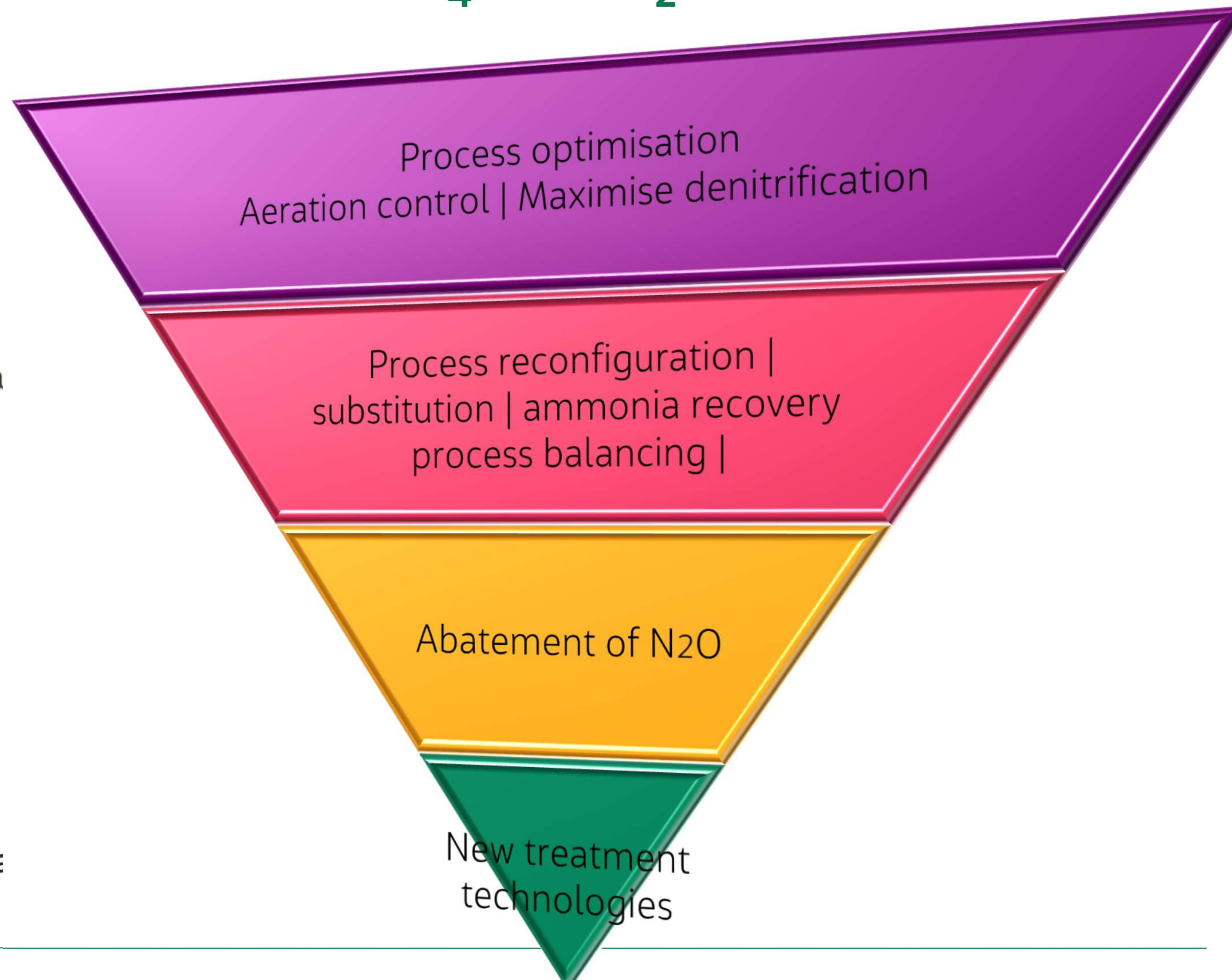
GWP: Global Warming Potential

Adopted from WEF Factsheet "GHG Sources and Sinks for WRRFs" (2021)

We know how to reduce GHG emissions of CH_4 and N_2O

- Stop leaks, cover tanks
- Optimise process
- (all requires measurement)

Huge leaks can be invisible to the human eye – This ta
next to a school



Everything starts with measurement and we know our options

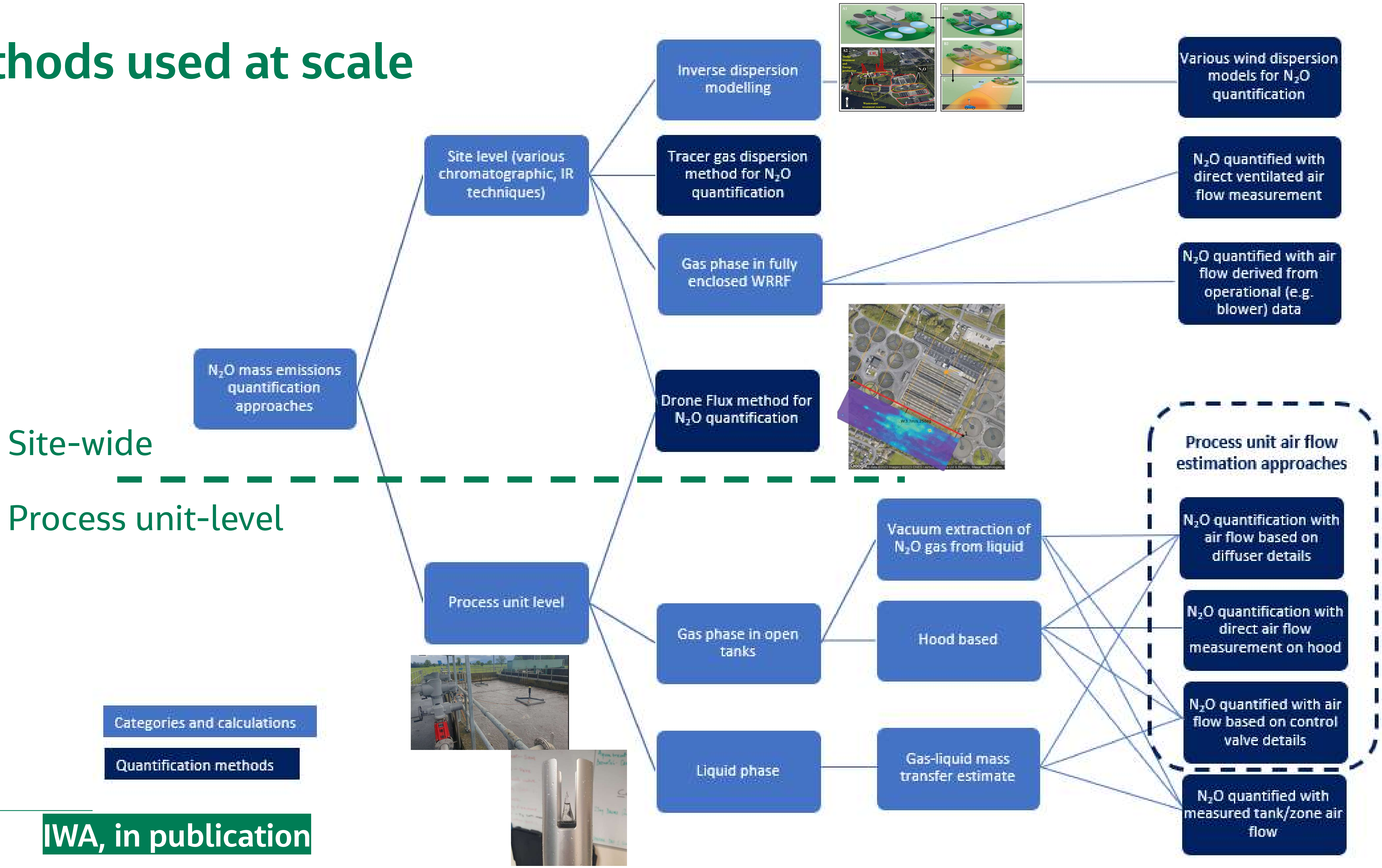
Site-wide

- Captures all emissions (that day/week)
- Campaign based (not continuous)
- Limited granularity
- Compare, prioritise
- Much CH_4 work, some N_2O

Process unit-level

- Discrete (methane leak detection)
- Continuous (liquid/gas N_2O)
- Captures seasonal/operational variation – key
- Supports process understanding, root cause, mitigation

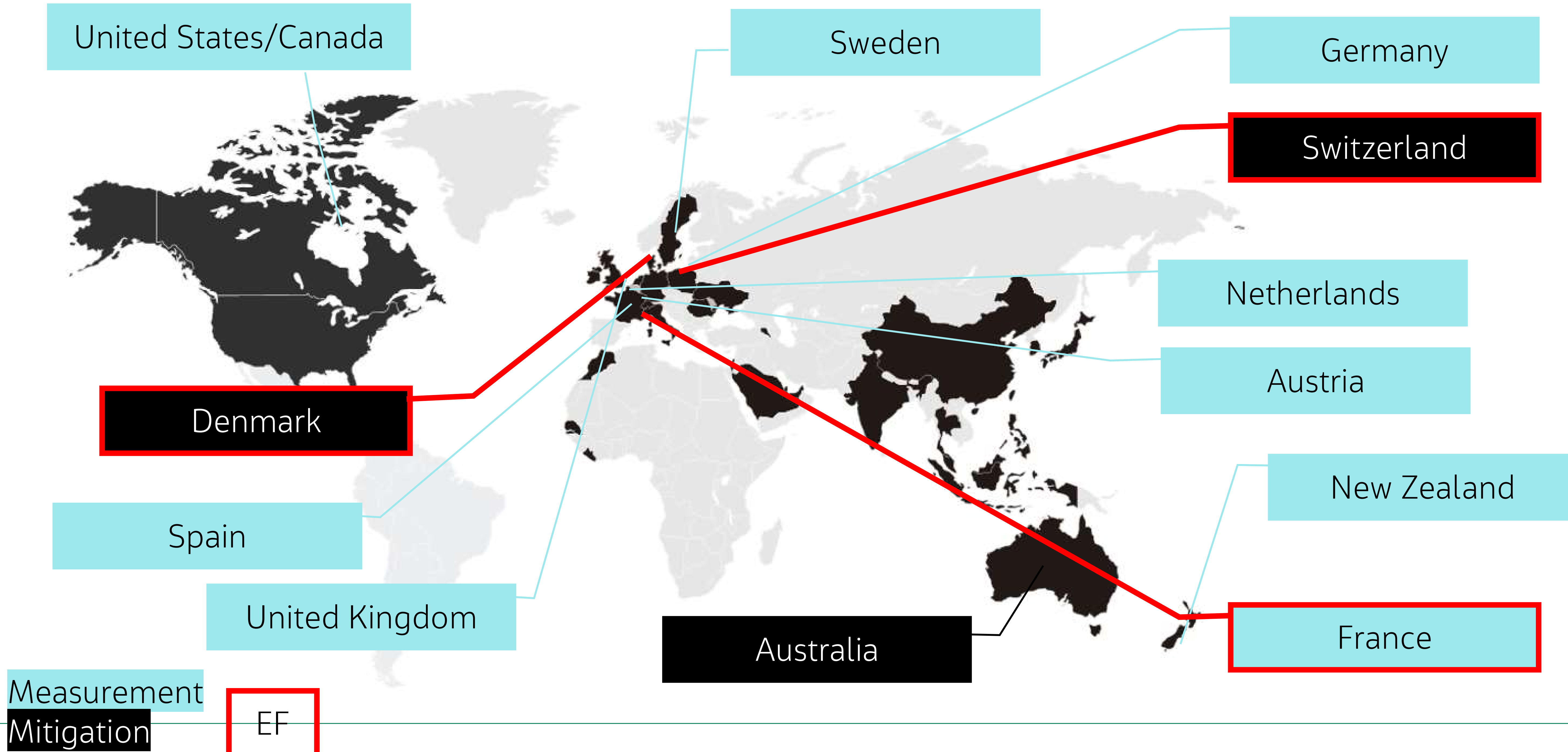
Methods used at scale



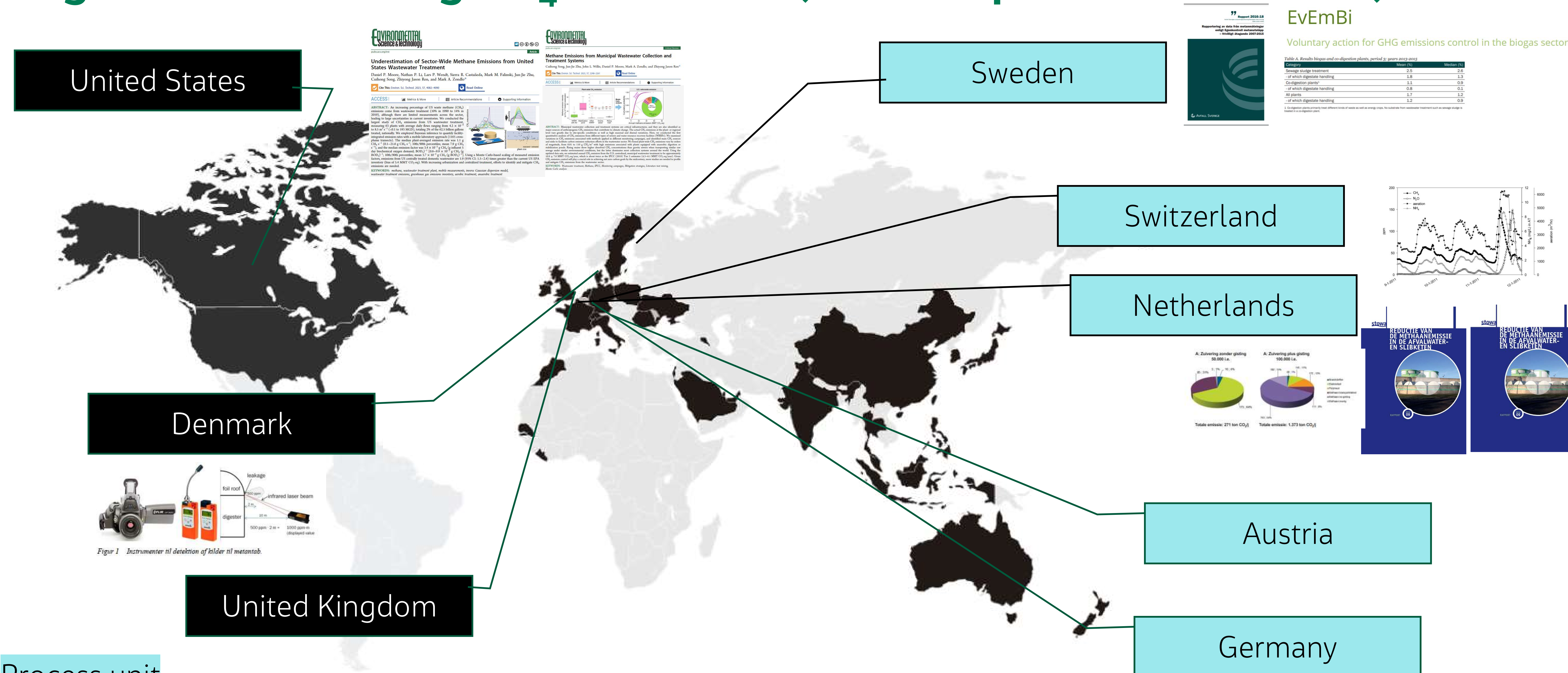
IWA, in publication

acobs 2023

Progress in measuring N_2O emissions (vast majority process unit level)

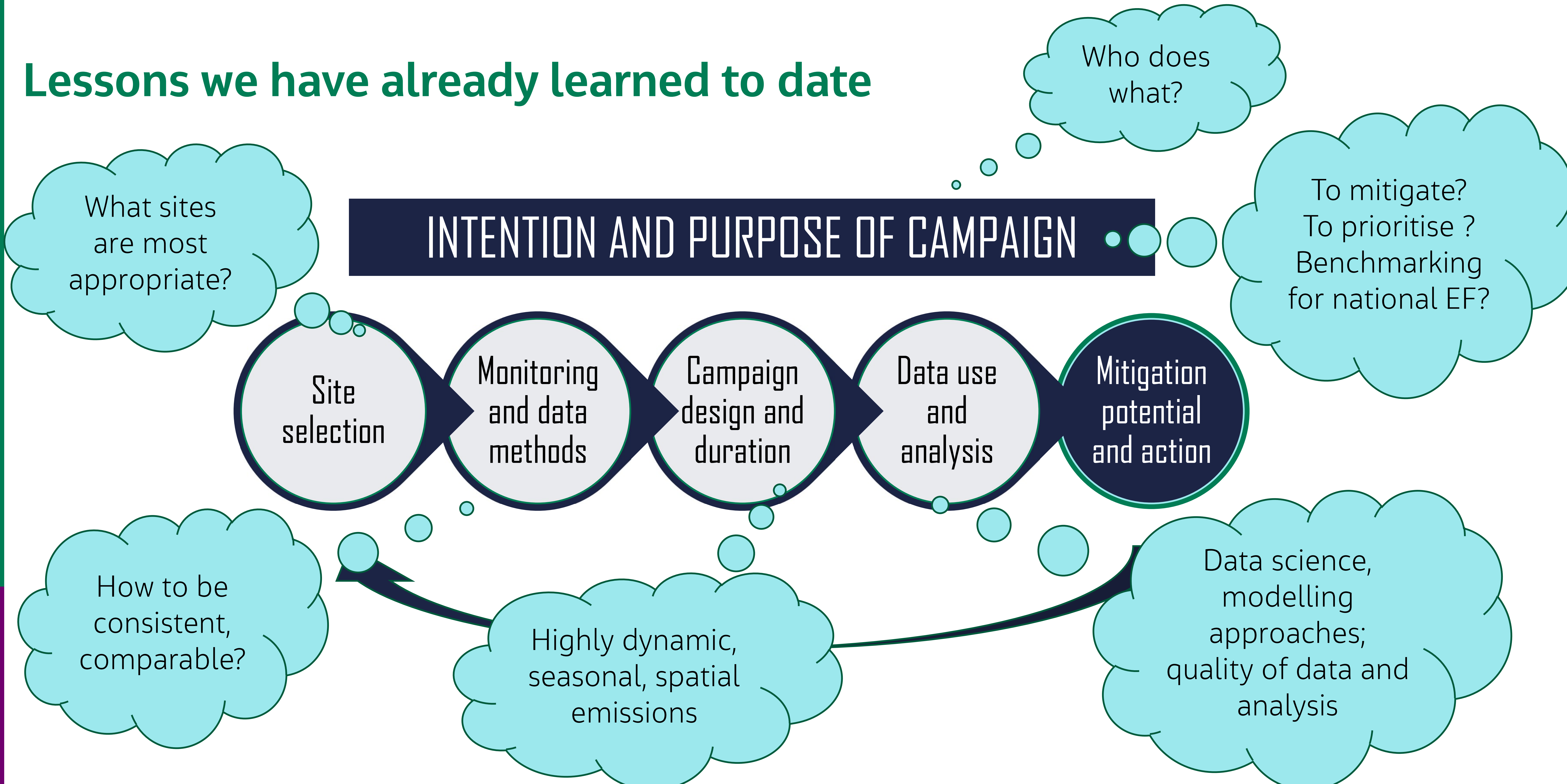


Progress in measuring CH_4 emissions (site and process-unit level)



Process unit
Facility level

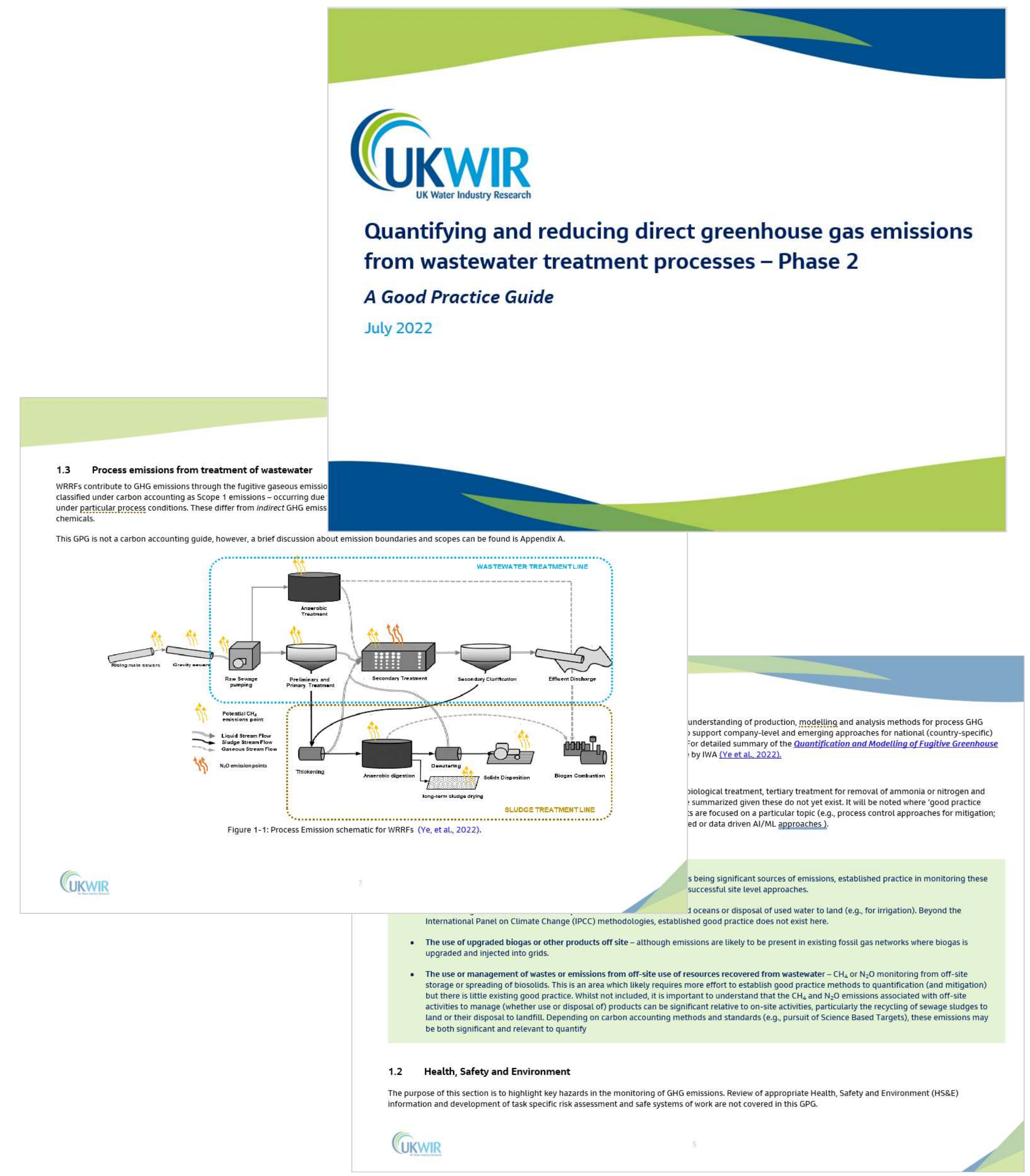
Lessons we have already learned to date



Where can we look for good practice?

1. Introduction and background
2. GHG reporting protocols for process emissions
3. Monitoring Process Emissions
4. Monitoring considerations
5. Mitigating N_2O Emissions
6. Mitigating CH_4 Emissions
7. Bibliography

Linked best practice industry case studies – examples of selection of sites, prioritisation, methods, interpretation



Methods and monitoring techniques – demonstrated at scale

3.2 Process Unit Monitoring

Process unit monitoring techniques are required for identification of key sources of GHG emissions from within a WRRF. Refer to (Ye, et al., 2022) for detailed analysis of flux chambers studies and site-specific considerations for design of a measurement campaign including number and coverage of hoods, size and construction and key data required.

Given the focus on understanding pathways and drivers for N_2O production and emission, most work to date in academic and industry studies has focused on monitoring of N_2O in individual treatment units – largely ASP treatment facilities, undergoing carbonaceous, nitrifying or nitrifying-denitrifying biological treatment, with some work across biofilm processes but a lack of established 'good practice' given lack of literature, published or otherwise.

This section provides an overview of process unit monitoring methods applicable for both N_2O and CH_4, with changes on the analytical detector for quantification. Specific analytical techniques for each of these GHG are describe in sections 3.3 and 3.4.

3.2.1 Monitoring Method: Flux Chambers

How it Works

Flux chambers, also known as floating hoods, are upturned chambers which are placed a few centimetres into the surface of open fluids or onto soils. The enclosed space of the flux chamber collects the exhaust gases and with the known surface area under the chamber, the specific flux (mass per area per time) of the gaseous compounds can be determined.

A detailed methodology can be found in Chandran (2011). This is the only method endorsed by the USEPA for N_2O monitoring at WWRFs. A refined approach has been recently proposed by (Gruber, et al., 2021) to estimate a country wide N_2O EF in Switzerland in long-term monitoring study of 14 full-scale WRRFs.

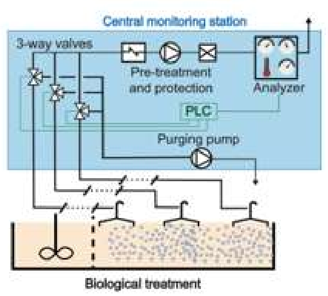


Figure 3-8: Schematic of equipment used in by Gruber et al. (Gruber, et al., 2021)

Strengths

Widely used across research applications, thus operating procedures and techniques are well documented in literature, such as in (Chandran, et al., 2016).

Simple in design and can be made in a variety of sizes and shapes to meet the requirements of the monitoring scheme. The Surface Emission Isolation Flux Chamber (SEIFC) (Schmidt, 1994), in special, have been widely used in WRRFs as endorsed by the United States Environmental Protection Agency (USEPA) as a device for monitoring gaseous emissions from liquid surfaces – thus, there is a standard. Arrangement or repositioning of the chambers can be carried out to understand spatial variations across large areas.

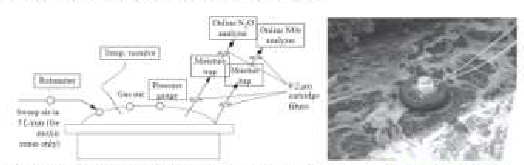


Figure 3-9: Surface emission isolation flux chamber (SEIFC) (Chandran, 2011)

gas analyser where CH_4 and N_2O were detected in separate trials. The gas flow rate was measured at least three times during the measuring campaigns at different points along the pipe. When this is used in conjunction with the internal pipe diameter the flow rate can be determined and when multiplied by the concentration of a compound the total emission can be calculated. (EPA, 2011)

3.4.1 Monitoring Method: Thermal Infrared (IR) Imaging Camera

How it Works

Passive thermal IR spectroscopy uses the difference in heat radiation between the target and the background. When a handheld thermal IR camera is used for inspection around leaked gases, the sensor will pick this up when there is a temperature difference between it and the surroundings.

Figure 3-19: An Infrared Imaging Camera showing the temperature profile on an individual (Teledyne FLIR, 2020).

Strengths

The technology can be used in a variety of setups. Single units can be used as a point source sensor or move to scan a site. Multiple units can be set up for site wide coverage, or can be incorporated as part of a drone to allow for unmanned operation of the sensor.

Provides real time detection and the location of leaks is not needed to be known beforehand.

This unit is cost effective and can be operated quickly without interrupting plant operations (EPA, 2011).

Figure 3-20: Infrared Imaging Camera. (Quantum Design, n.d.)

Limitations

It cannot be used to calculate a quantitative CH_4 concentration or emission.

It cannot separate between different gases that absorbs in this spectral region, it is mainly used to find possible leaks for follow-up measurements using other methods.

Several sensors would be required to achieve site coverage, which would increase the costing to run this.

If the temperature of the leak is similar to the atmosphere, then it will be difficult to detect.

Equipment

The sensor comes in a self-contained unit and will not require any additional equipment. However, the full site coverage and aerial versions will be more costly than an individual unit. For the latter, the heavier and more power intensive the equipment, the more impact it will have on the maximum flight times.

Quantifying and Mitigation Process Emissions, Good Practice Guide, UKWIR, 2023

Methane CH_4 quantification – site level

- Inverse dispersion modelling (IDMM)
- Differential absorption light detecting and ranging (DIAL)
- Mobile tracer gas dispersion modelling (MTDM)
- Drone flux method (DFM)

Concentrations + weather data + inverse dispersion modelling Wind data is key |

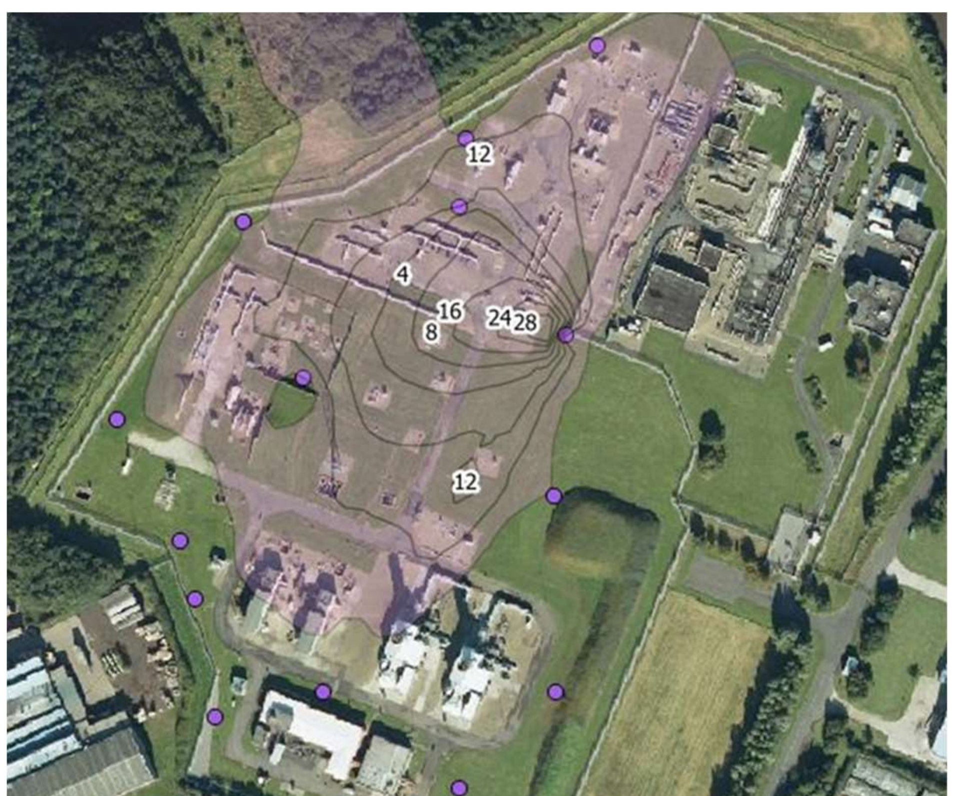


Image courtesy NPL

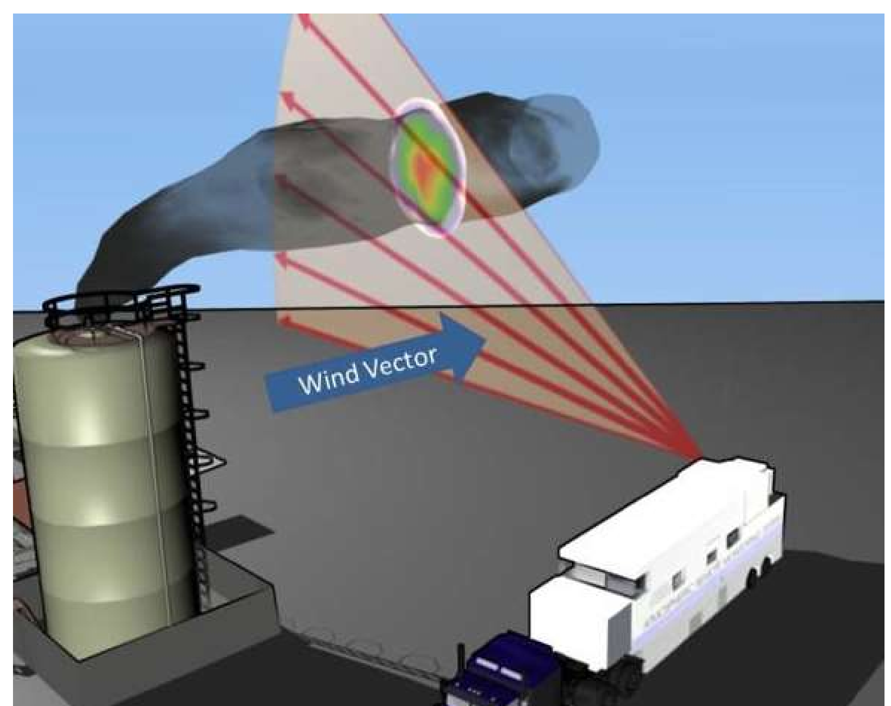


Image courtesy NPL

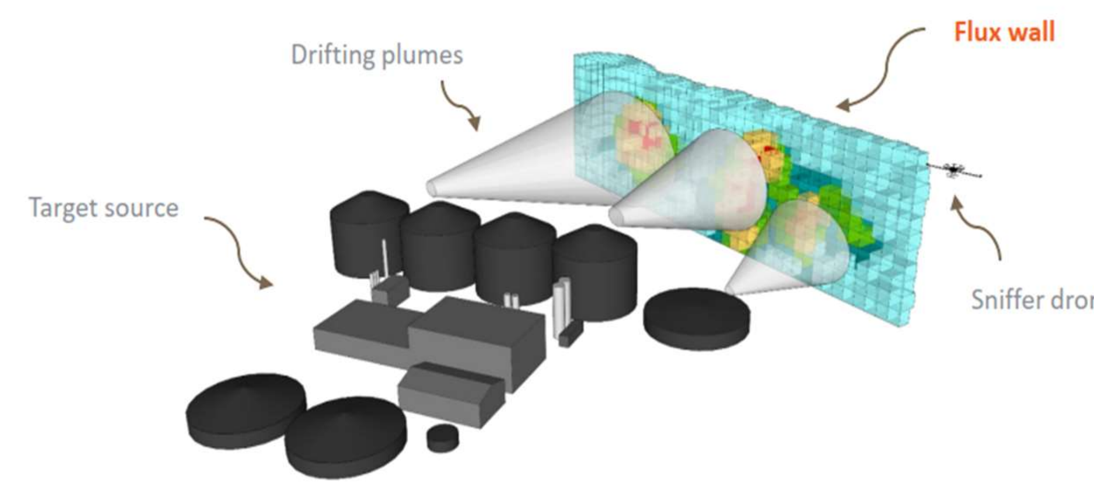


Image courtesy Explicit

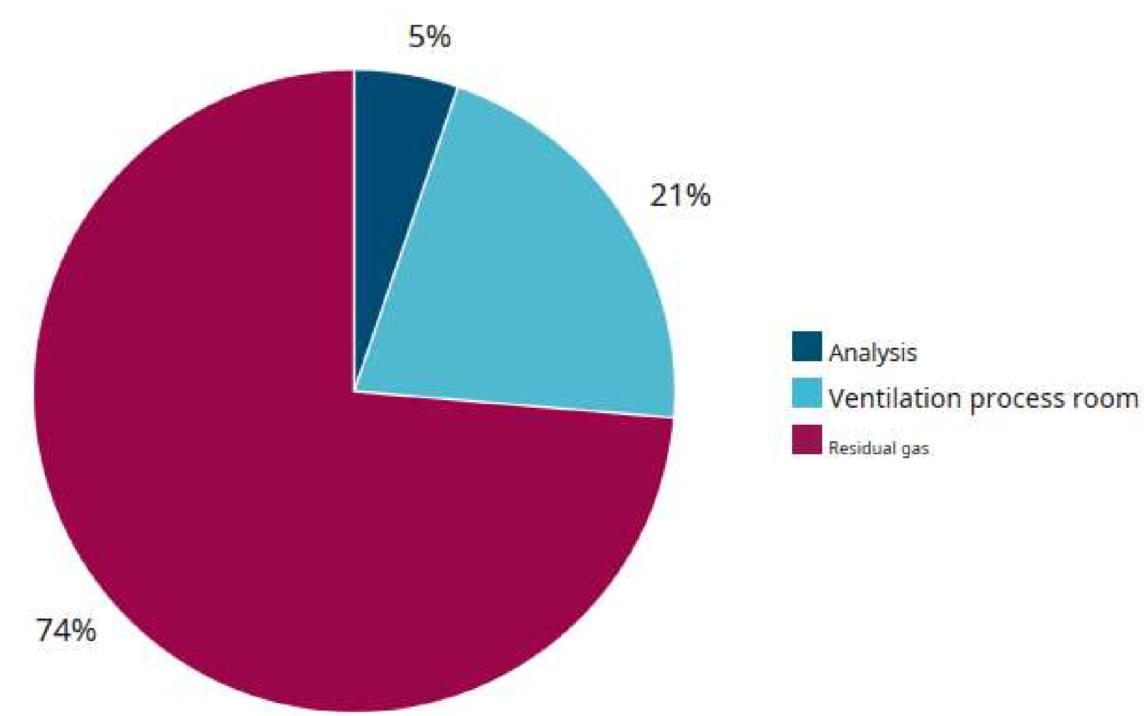
Methane measurement – process unit level

- Sweden programme
  - 25 biogas plants
  - 30 upgrading plants

35% biogas/38% biomethane

Category	Emissions as a share of the amount of methane produced, upper quartile (%)	
	Round 3	Round 4
A) chemical scrubber & facilities with RTO	0.27	0.33
of which residual gas	0.047	0.074
B) water scrubber & PSA	1.8	1.8
of which residual gas	1.7	1.6
All facilities	**1.2**	**1.5**
of which residual gas	**1.1**	**1.2**

[Self-monitoring of methane emissions - Avfall Sverige]

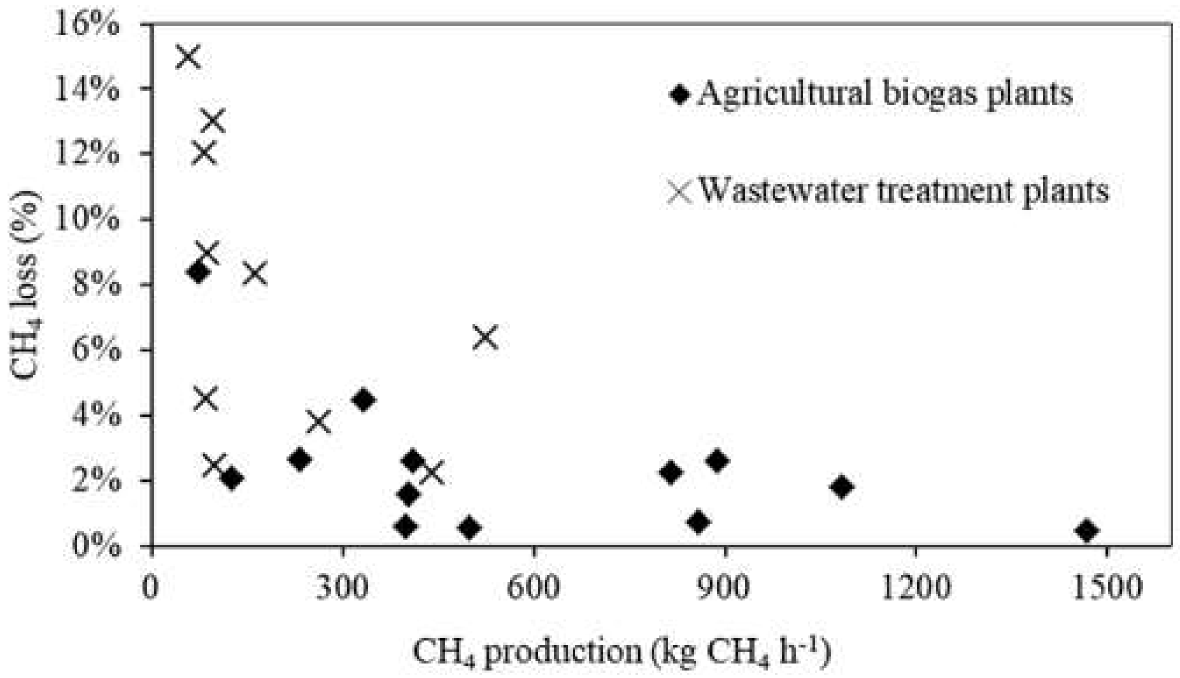


Quantitative at process unit level but expects AD facilities to have proactive LDAR in place

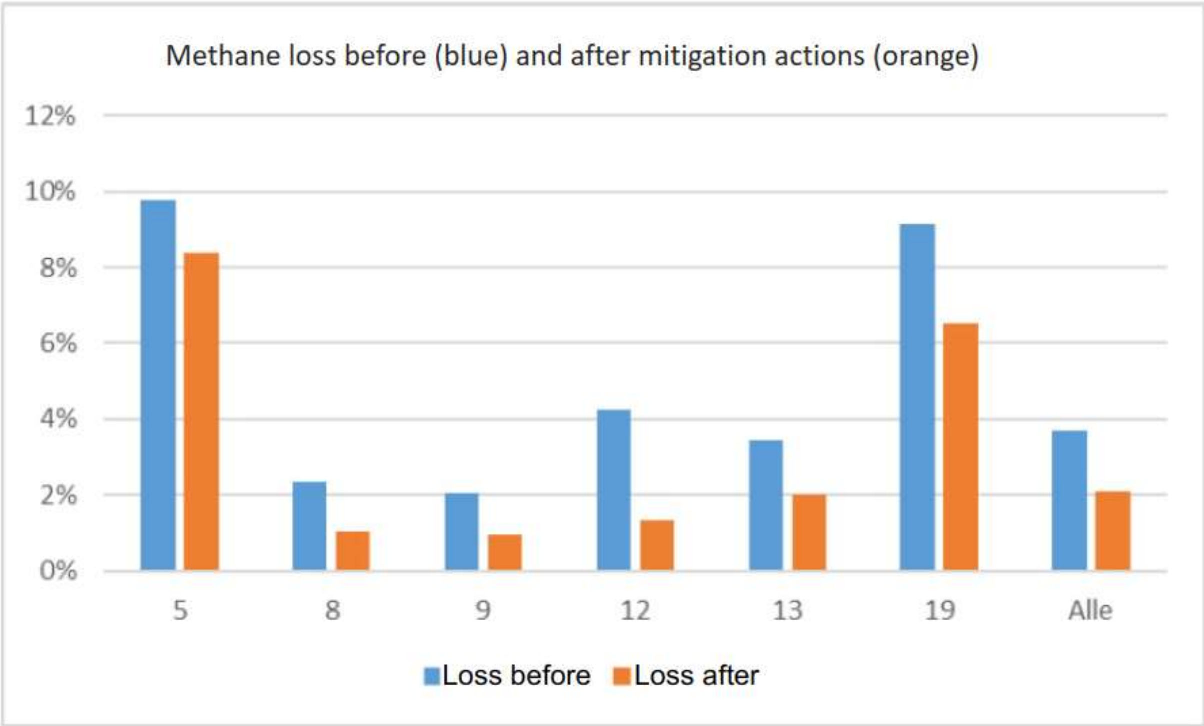
Danish national methane monitoring programme

- Multiple methods | certified laboratory measurements | data collation and reporting | included mitigation
- Has supported Denmark GHGI
- Has informed regulation

Denmark - 69 biogas facilities – 7.5% ave WRRFs
2-15% of biogas produced for WRRFs



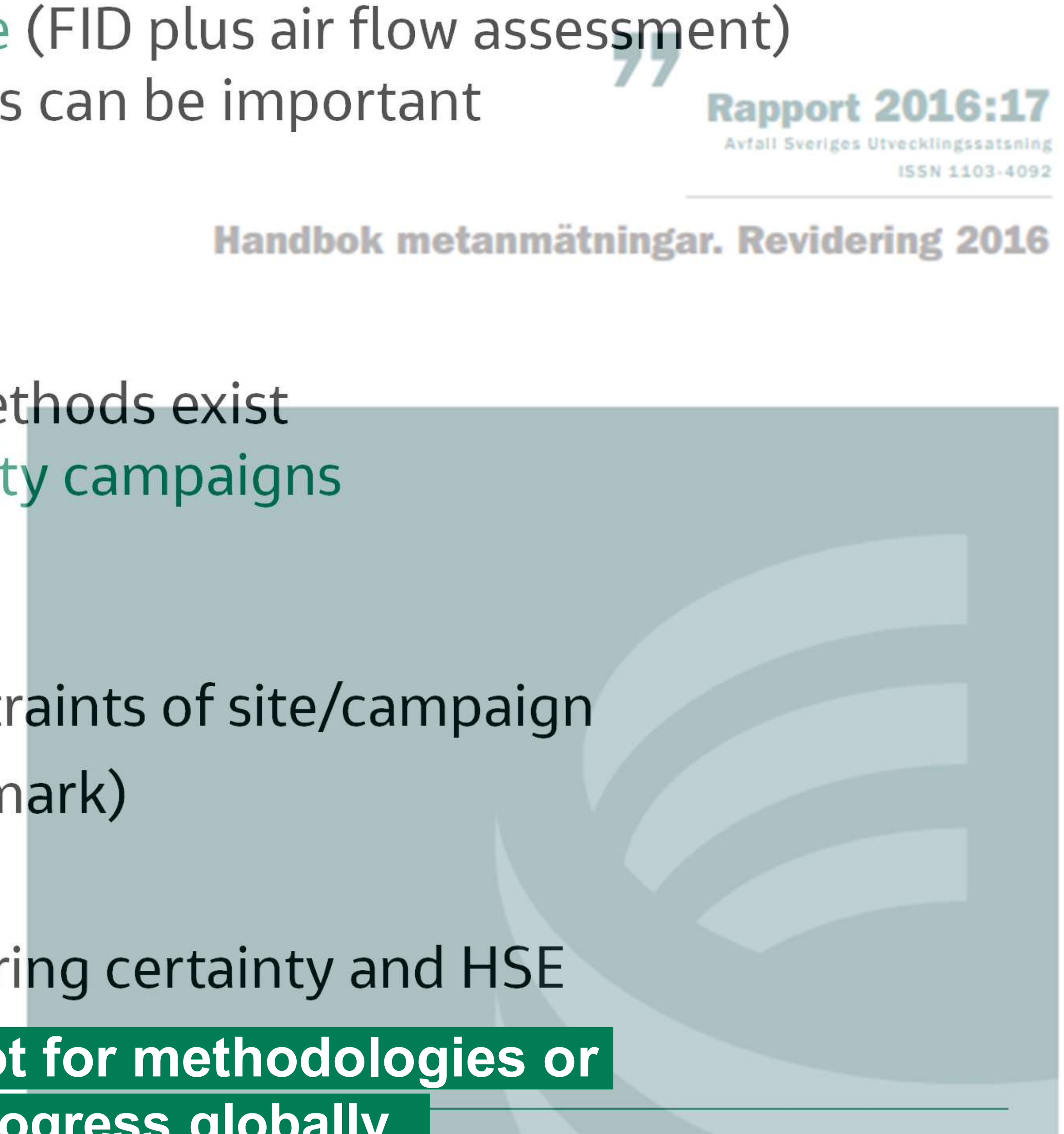
Scheutz & Fredenslund, 2019



Danish Energy Agency, 2021

Summary – good practice for methane measurement campaigns

- **Process unit level** – leak detection and repair, quantification
  - Initial characterisation of leaks and follow up surveys
  - Can be qualitative (e.g. thermal imaging with OGI) or quantitative (FID plus air flow assessment)
  - Suited to leaks from tanks/covers/pipework/valves – PRV settings can be important
  - May not pick up every emission source



- **Site level** – quantification of emissions
  - Tends to be campaign based though can be fixed; continuous methods exist
  - Provides a site baseline at point in time, comparable if high quality campaigns
  - May not allow pinpointing of emissions sources

- Multiple proven and emerging methods exist – depending on constraints of site/campaign
- Monitoring, verification, reporting approaches exist (Sweden, Denmark)
- Has led to demonstrated mitigation (Denmark)
- Required to design mitigation interventions with sufficient engineering certainty and HSE

ISO/BS Standards for gases, components exist but not for methodologies or for N_2O or CH_4 specifically. These are work in progress globally. Good LDAR examples exist already.

National nitrous oxide monitoring campaign – Denmark

-2018
Various projects funded
> 3 M €

2018-2019
Dedicated N_2O funding pool for data generation
~ 0.5 M €

2020
Climate action political agreement for a green waste sector

2021
"Paris-model" for water companies

2023
N_2O Legislation detailed and comes into force Jan. 2025

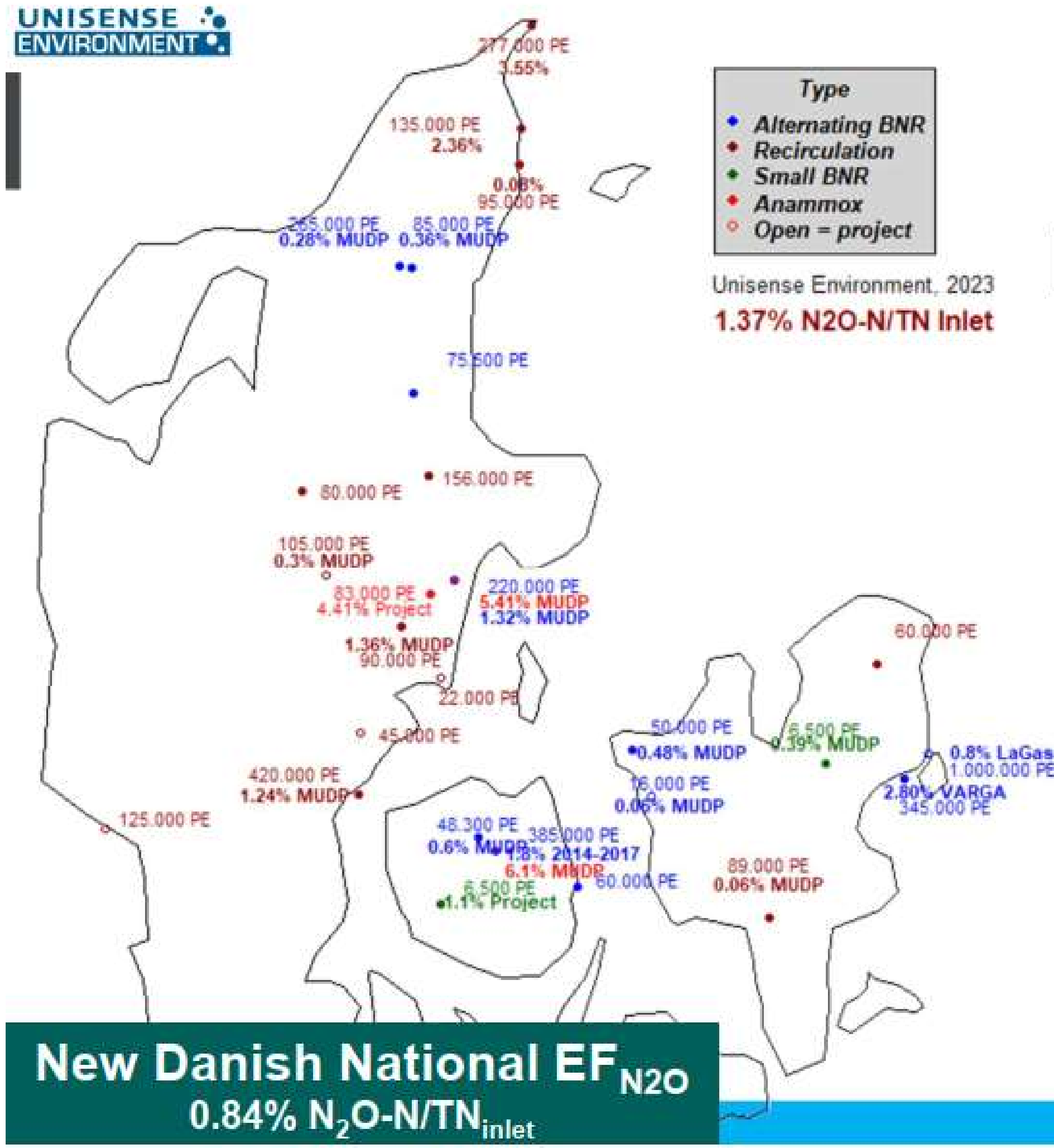
Renseanlæg	kg N_2O-N_{udledt}/år	kg N_2O_{udledt}/år	[illegible]$_{udledt}$/år	% N_2O-N/T-$N_{fjernet}$	St.afv.	% N_2O-N/T-$N_{indløb}$	St.afv.	n målepunkter	mg N_2O-N/PE-N/d
Ejby Mølle*	81.943	128.768	[illegible]8.373	20,9	34,9	17,9	29,5	11	
parallel	16.415	25.795	7.687	5,73	9,78	4,48	7,11	7	
serie	196.320	308.502	91.934	48	49	41	41	4	
Sidestrøms-tank	3.234	5.082	1.514	6,1	4,8	n.a.	-	55	
Fredericia	139	219	65	0,03	0,03	0,02	0,03	20	3,0
Hyllingeriis	82	129	38	0,46	0,78	0,39	0,62	13	46
Kalundborg	506	795	237	0,48	0,19	0,38	0,15	19	45
Marselisborg	7.392	11.615	3.461	1,28	-	1,12	-	-	134
Luftningstanke	5.755	9.044	2.695	1,32	1,36	1,21	1,23	88	
Sidestrøms-tank	1.636	2.572	766	5,65	5,13	5,14	4,69	50	
Næstved*	165	260	77	0,06	0,09	0,06	0,08	37	7
maj-aug. 2019	268	420	125	0,12	0,10	0,11	0,09	19	13
Skanderborg	1.136	1.785	532	1,36	1,03	1,24	0,98	39	149
uden festival	972	1.527	455	1,13	0,88	1,02	0,83	34	
kun festival	113	178	53	2,86	0,59	2,74	0,55	5	
Søholt*	897	1.410	420	0,30	0,28	0,29	0,28	13	35
Aalborg Øst	881	1.385	413	0,28	0,18	0,24	0,15	25	28

*overfladebeluftede renseanlæg

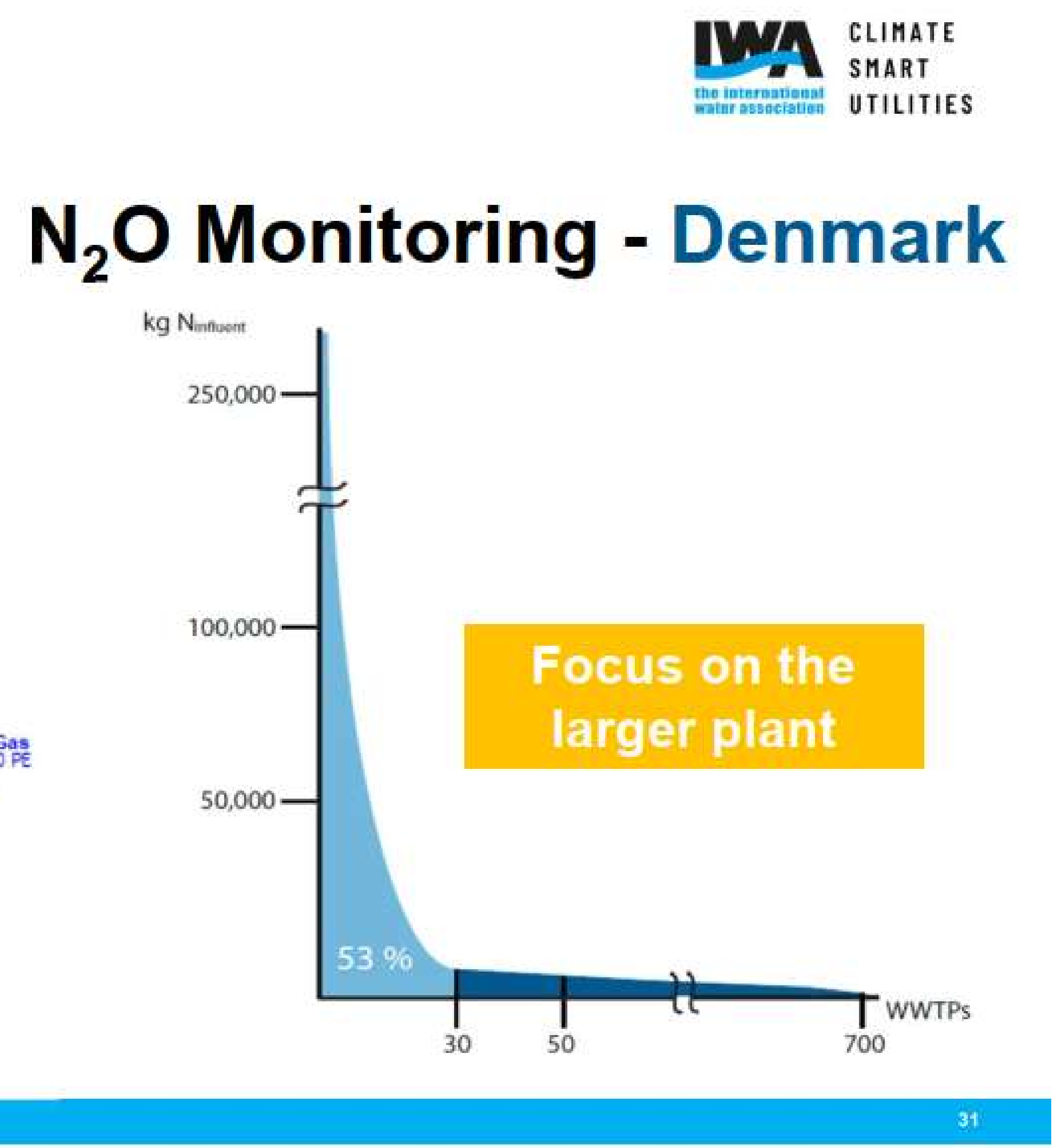
Results from Danish National Monitoring Programme MUDP (2020)

- $500,000(!) co-funded from EPA
- High variation (0.24 – 1.24N_2O_N/TN_{inlet})
- Increased emissions from higher loaded WRRFs
- High emissions from sidestream processes (4-6%N_2O_N/TN_{in})

Danish monitoring programme and ongoing work



New Danish National EF_{N2O}
0.84% N_2O-N/TN_{inlet}



IWA, 2023

Conclusions from Danish national monitoring N_2O work

- Outcome – new EF for N_2O of 0.84%N_2O_N/TN_{inlet}
- Led to mitigation
  - Importance of measurement (critical to mitigation)
  - Opportunities for mitigation (load balancing, control interventions)
  - Cost of abatement 2-15 euros for measurement + optimisation
- Continued measurement and mitigation
- Ongoing technology trials and development

National nitrous oxide monitoring campaign – France

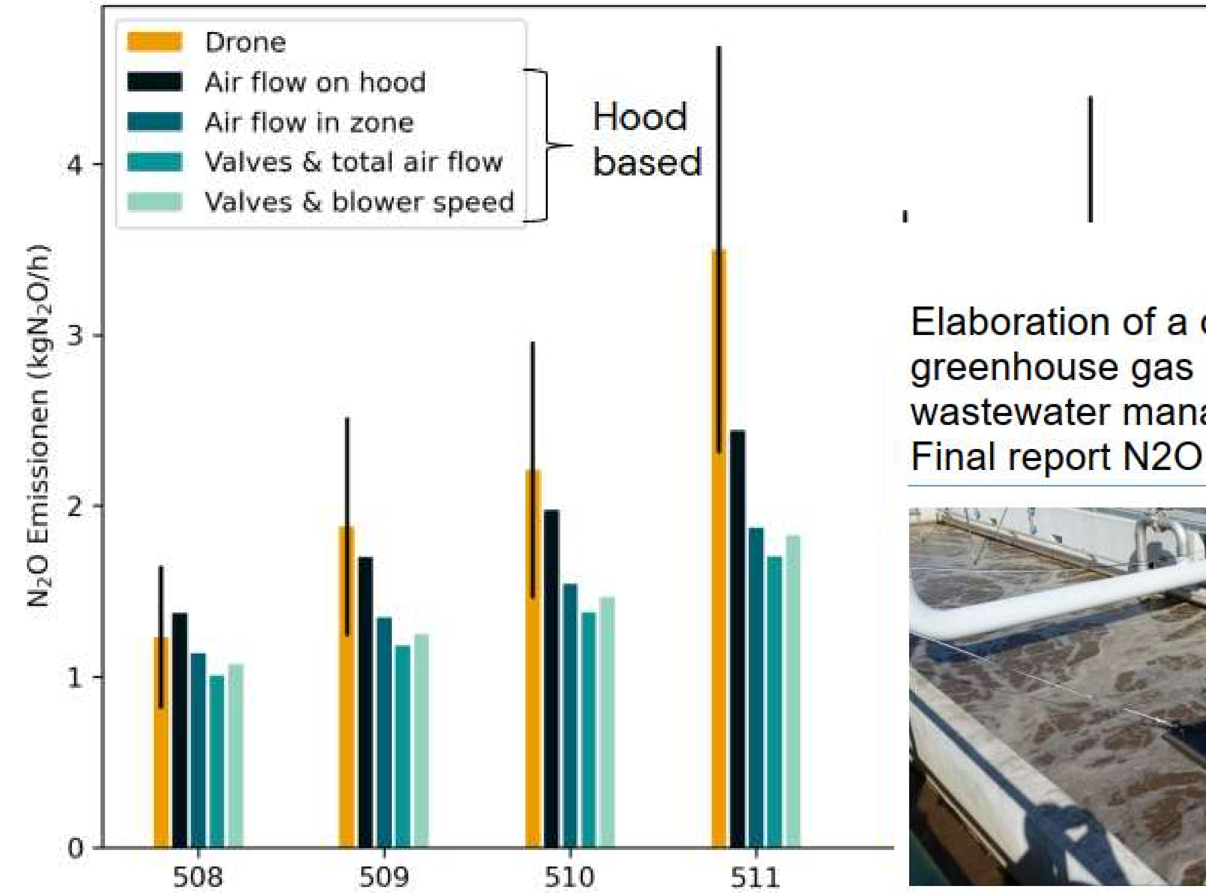
- Led to recommended EFs for 3 typologies
- Coordinated approach
- Consistent methods
- Med-long term campaigns
- Robust research institute oversight

Cas	Process	Foreign literature min-max (number) [ref]	Recommendation Astee 2022
1. Free culture methods	BA designed to treat carbon pollution alone	0,99 – 8 (3) [5, 12]	None
	BA designed to nitrify	0,005 – 2,8 (37) [13, 14] **0,012 – 7,4** (10) [15, 16]	0,06
	Membrane filtration process (MBR)	0,004 – 0,5 (2) [18, 19]	0,06
2. Fixed or mixed culture processes	Biofilters designed to nitrify	1,4 (1) [5]	1,65
	Granular slurry process (GSBR)	0,33 (1) [23] **0,35** (1) [23]	None
	Fluidized bed process combining free and fixed culture (IFAS)	1,4 (1) [5]	None
3. Secondary stream processing methods	Partial nitration process (E.G)	1,7 – 3,8 (3) [20, 21] **3,1 – 7** (3) [20, 22]	None
	Anammox Partial Nitritation Process (NPA)	0,14 – 2 (2) [17]	None
4. Extensive processing methods	Horizontal flow planted filter	0,04 – 3,0 (8) [17]	None
	Vertical flow planted filter	0,001 – 0,096 (22) [17]	None
	Lagoon	- 0,05 – 0,43 (24) [17]	None

Filali et al. (2022)

National monitoring work - Switzerland

- 14 monitoring campaigns (N_2O)
- Led to recommended EFs for 3 typologies
- Long term off-gas method
- EAWAG oversight ETH Zurich
- Has led to commercial off-gas in-country spinoff
- Has supported N_2O and CH_4 abatement programme



Upwater, 2023

Elaboration of a data basis on greenhouse gas emissions from wastewater management - Final report N2OklimARA

Authors: Wenzel Gruber[1], Adriano Joss[1], Manuel Luck[1], Thomas Kupper[2], Marcel Bühler[2], Tobias Bührer[1]

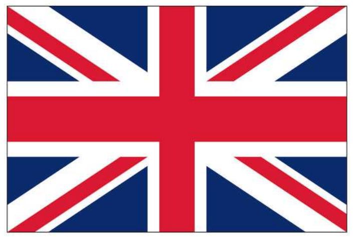
Affiliations:

[1]Eawag, Swiss Federal Institute for Aquatic Science and Technology, 8600 Duebendorf, Switzerland

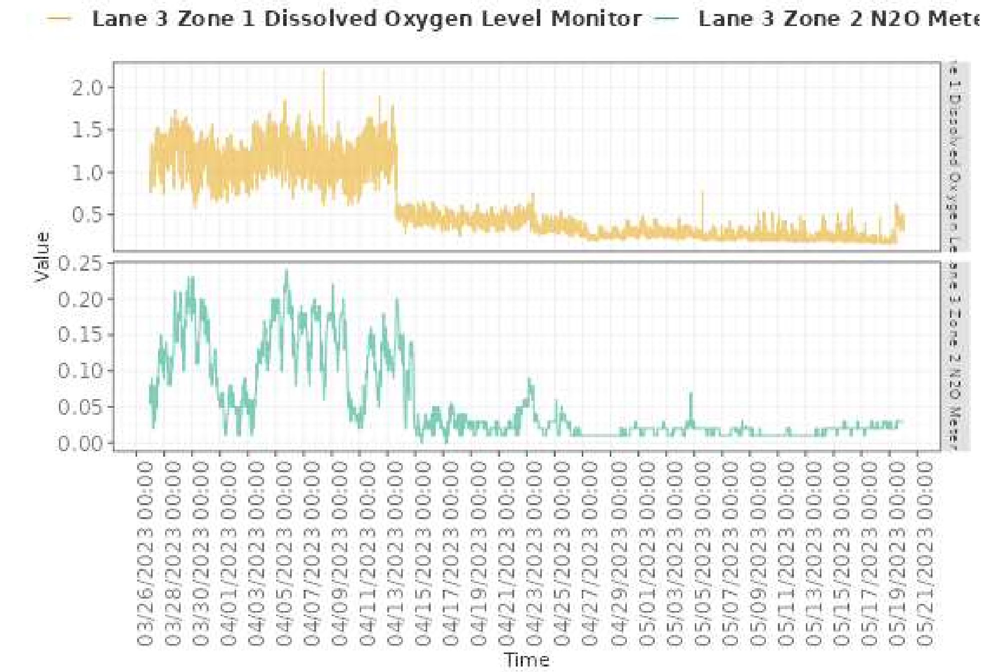
[2]Bern University of Applied Sciences School of Agricultural, Forest and Food Sciences, 3052 Zollikofen, Switzerland

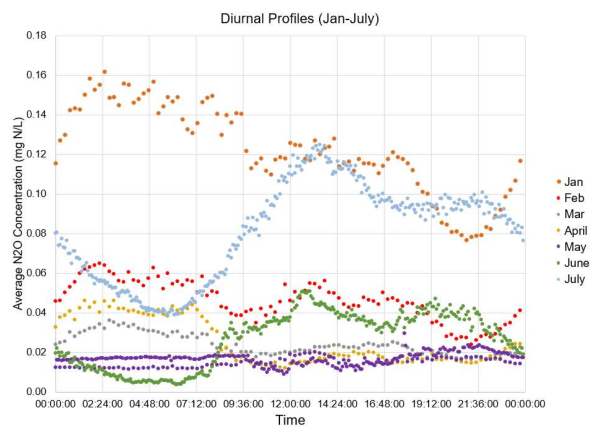
Swiss FOEN, 2021

UK sector work on GHG emissions

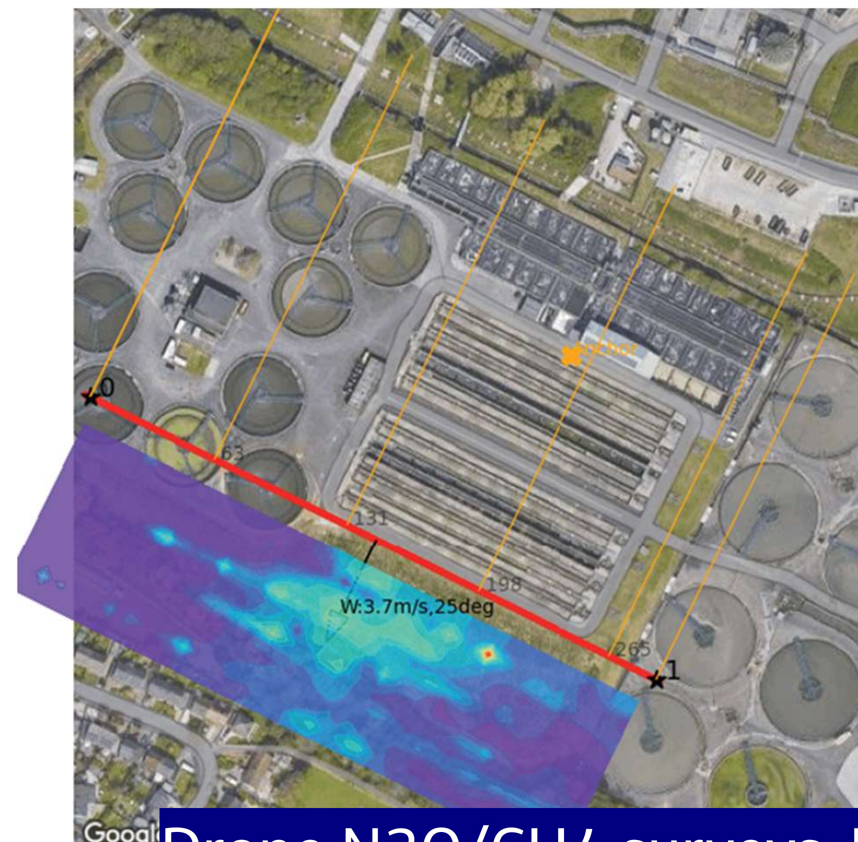


N2O drivers and mitigating process conditions, AWS

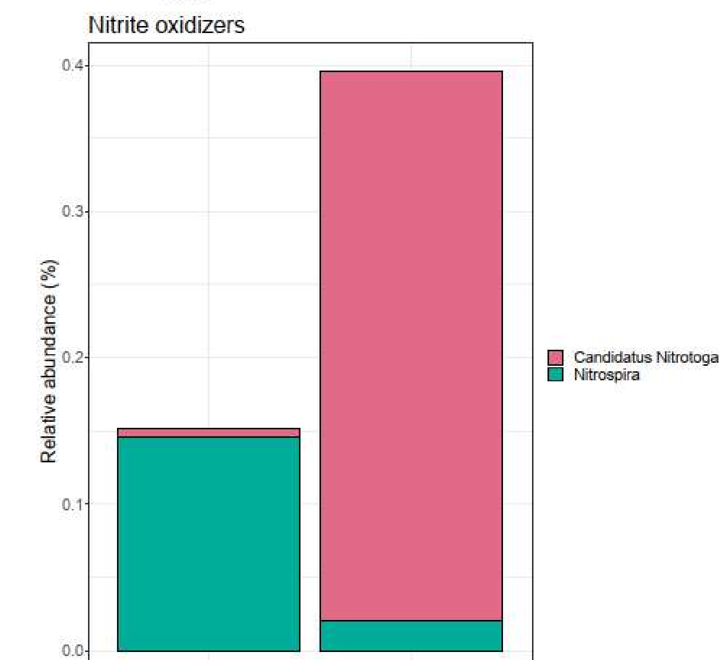




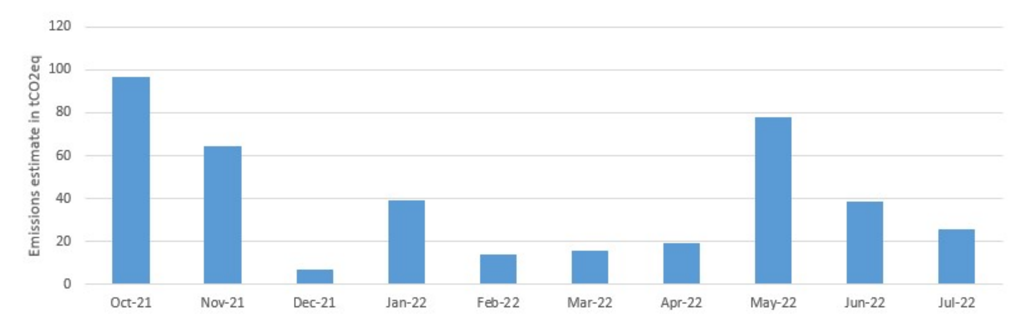
TWL, ASP aerobic zone liquid N_2O



Drone N2O/CH4 surveys, UU

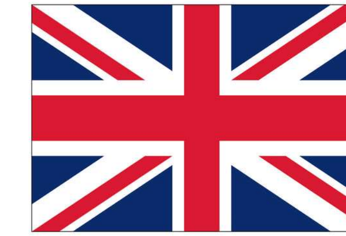


Metagenomics, UU

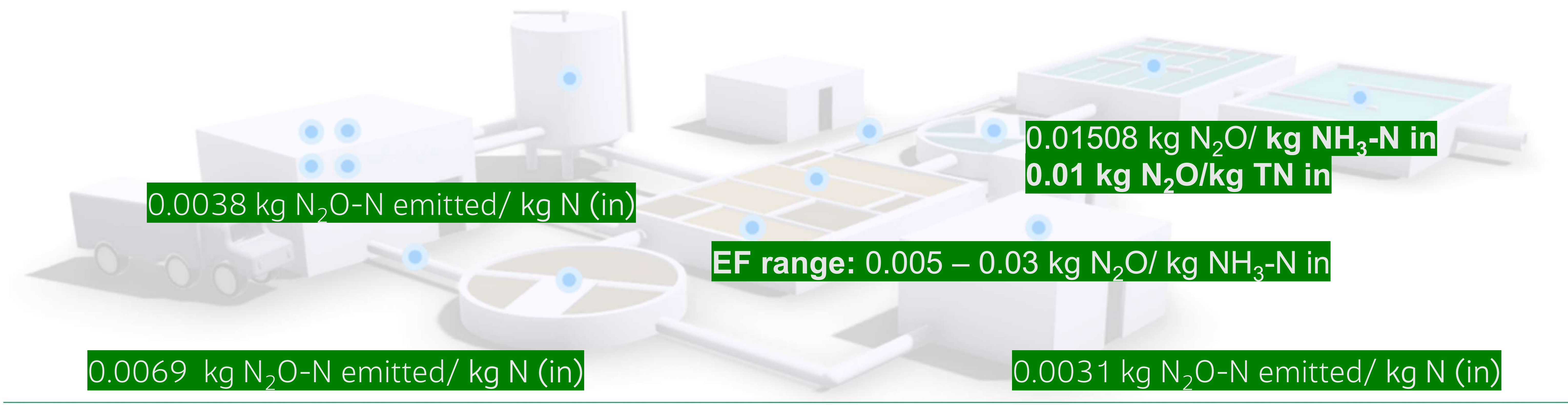


STW, Cakepad monitoring, CH_4

Results from UK measurement work to date

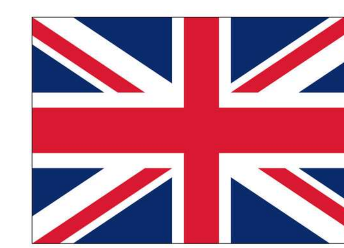


- Variable and not very coordinated – but now over 20 sites
- Range of methods, mostly established, some experimental
- Supported by UK and Irish Community of Practice
- Good Practice Guide and Recommendations for National Monitoring Programme



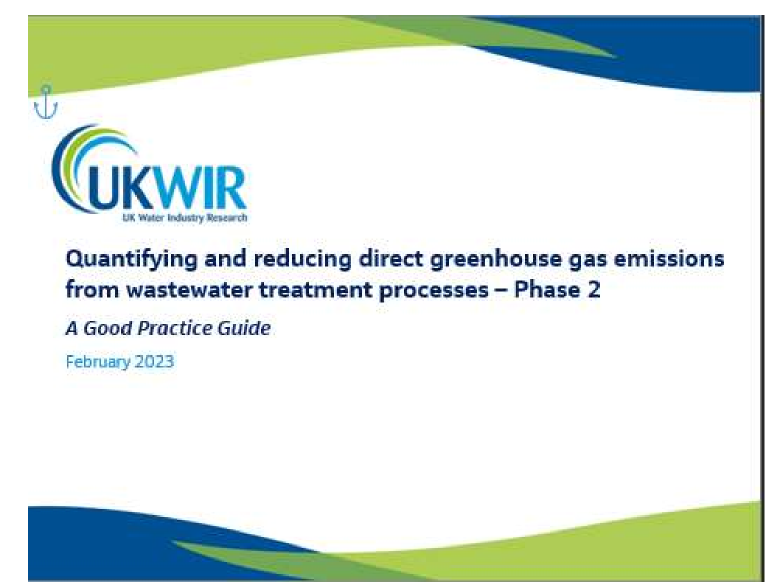
UK Good practice guide – standardising campaign and EF reporting

WRRF Campaign attribute	
Loading/capacity and consent	PE, average:peak Q COD/BOD:TN:NH4:TP
Catchment and plant type	E.g. combined catchment, plug flow nitrifying ASP, anaerobic digestion
Sludge imports	tDS/day
MLSS	Kg/m3
F:M	BOD/COD:MLSS
SRT	Aerobic/anoxic
SS/VSS	ratio
Average temperature	deg C
Average in coming N load(s)	N, NH4, including liquors if relevant
% removal	TN reduction, NH4 reduction
Sludge management	Including any sidestream, liquors balancing, sludge storage, AD
Measurement methods	Technology type Site wide or process unit level



Good practice exists and national monitoring programmes have happened or are happening

- UK and Irish Water Industry Research (UKWIR)
  - ➢ Quantifying and reducing direct GHG emissions (2019)
  - ➢ Quantifying and reducing (Phase 2) (2023)
  - ➢ Good practice guidance and sector monitoring summary
  - ➢ Recommendations for National Monitoring Programme
- Netherlands - STOWA, 2023
- France - INRAE, 2022
- Switzerland – Eawag, 2021
- Germany – DWA, 2022



Advice on design of national monitoring programme (NMP)

Framework

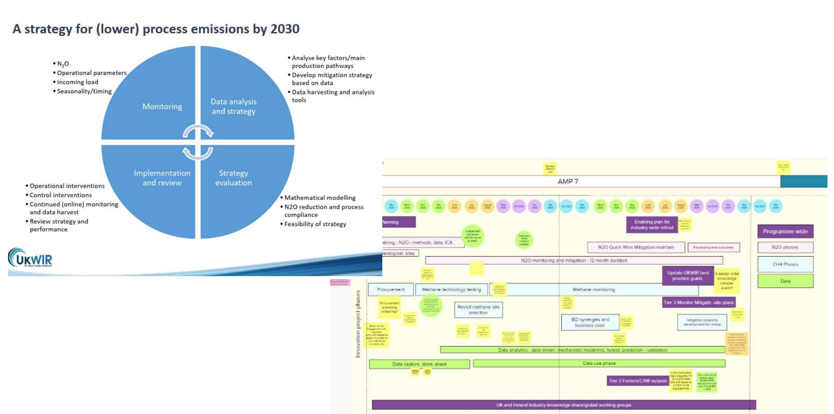
- ✓ Health and safety
- ✓ Roles and responsibilities
- ✓ Coordination and communication
- ✓ Opportunities aligned with IED
- ✓ Data management

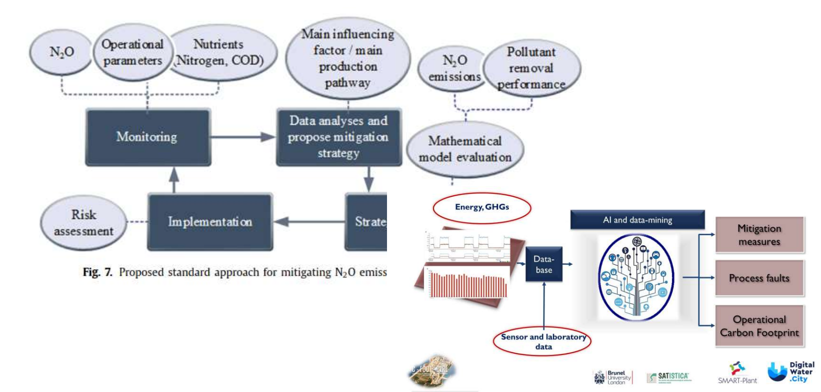
Processes

- ✓ Standardisation
- ✓ Data quality, quantity and sharing
- ✓ Lessons learned from ongoing work
- ✓ Funding, procurement and commercial
- ✓ Leveraging local knowledge and teams
- ✓ Knowledge sharing

Technical

- ✓ Site selection
- ✓ Site and process choices
- ✓ Specification and procurement
- ✓ Installation and commissioning
- ✓ Calibration, maintenance and replacement
- ✓ Considerations of site control and mitigation potential





Advice on design of a National Monitoring programme – UKWIR, 2023

Central organisation and funding including <u>expert advisory group</u> – utilities, academia and supply community

Clear objectives: to understand emissions to support and prioritise action, to support improvement of National EF

Builds on existing starting point for sector

Data and monitoring requirements clear

Nitrous oxide monitoring and analysis

Methane monitoring and analysis

Data, results collation and interpretation

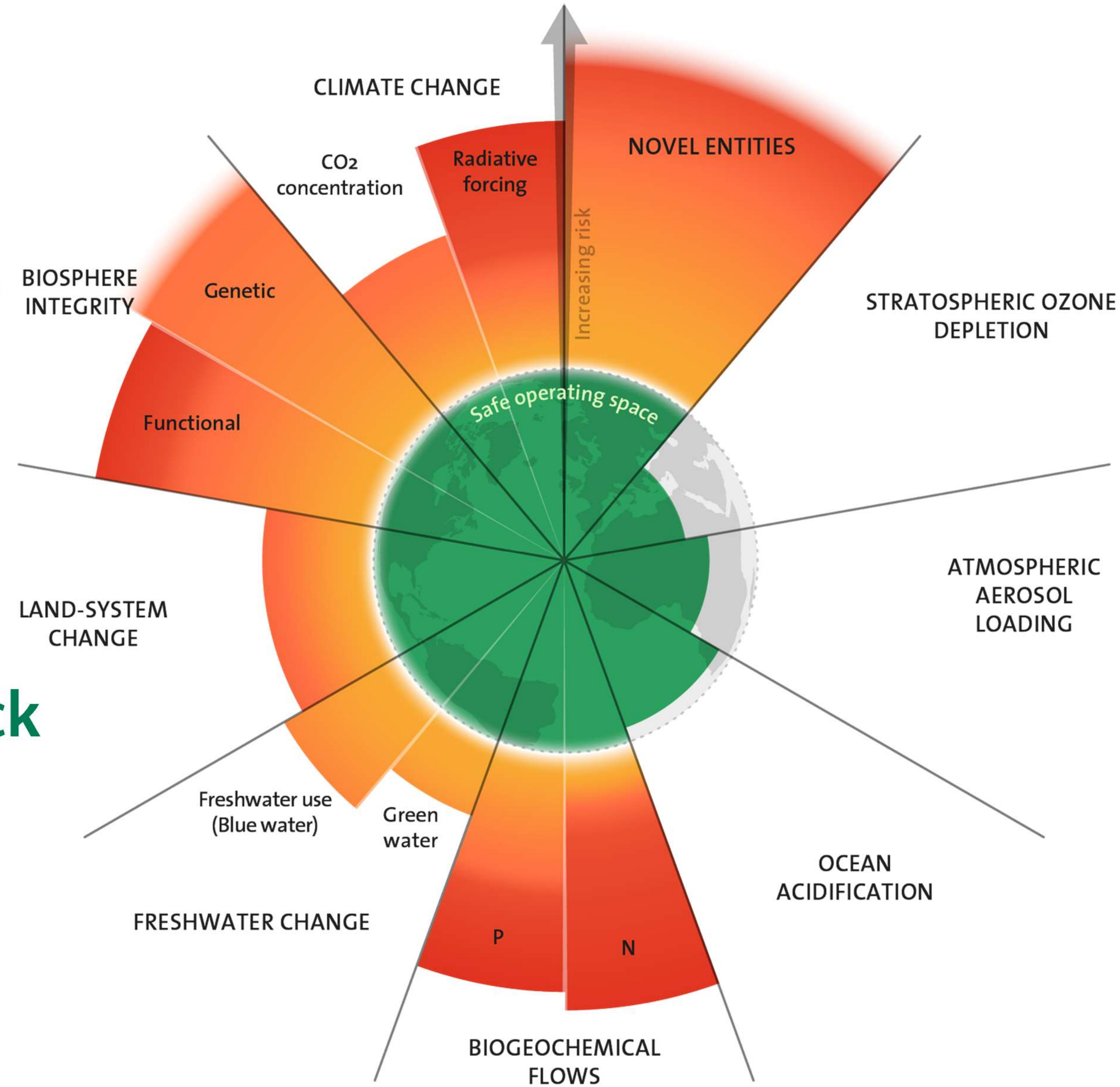
Outcomes: revised GPG, industry protocols

In the meantime… let's start!

Understanding GHGs at WwTWs is critical

to help **resource recovery** and systemic solutions

become *a reality* that bring us back within **planetary boundaries**



Thank you

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