Monitoring and mitigating nitrous oxide: Danish lessons for global action

04/09/2023

inspiring change

IWA the international water association

CLIMATE SMART UTILITIES

WEBINAR INFORMATION

the international water association CLIMATE SMART UTILITIES

- This webinar will be **recorded and made available "on-demand"** on the IWA Connect Plus platform, with presentation slides, and other information.
- The **speakers** are responsible for **securing copyright permissions** for any work that they will present of which they are not the legal copyright holder.
- The opinions, hypothesis, conclusions or recommendations contained in the presentations and other materials are the **sole responsibility of the speaker(s)** and do not necessarily reflect IWA opinion.

WEBINAR INFORMATION

- **'Chat' box**: please use this for general requests and for interactive activities.
- **'Q&A' box**: please use this to send questions to the panelists.

(We will answer these during the discussions and in post-webinar materials.)

Please Note: *Attendees' microphones are muted. We cannot respond to 'Raise Hand'.*

AGENDA

- Welcome and introductions

  Anna Katrine Vangsgaard, Envidan, (Moderator)
- Introduction to funding, results and legislation (Danish context)

  Jacob Kragh Andersen, Envidan

  Q&A
- Measure to kN_2OW

  Mikkel Holmen Andersen, Unisense

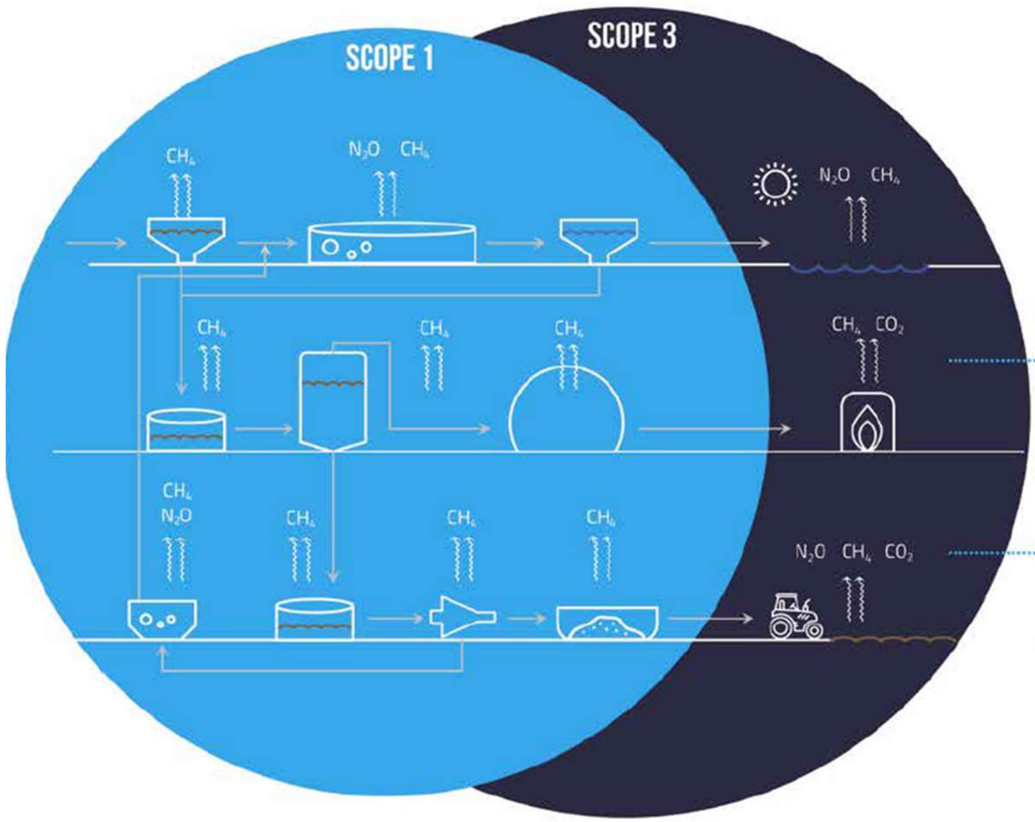
  Q&A
- Case study – Mitigating N_2O emissions

  Morten Rebsdorf, Aarhus Vand

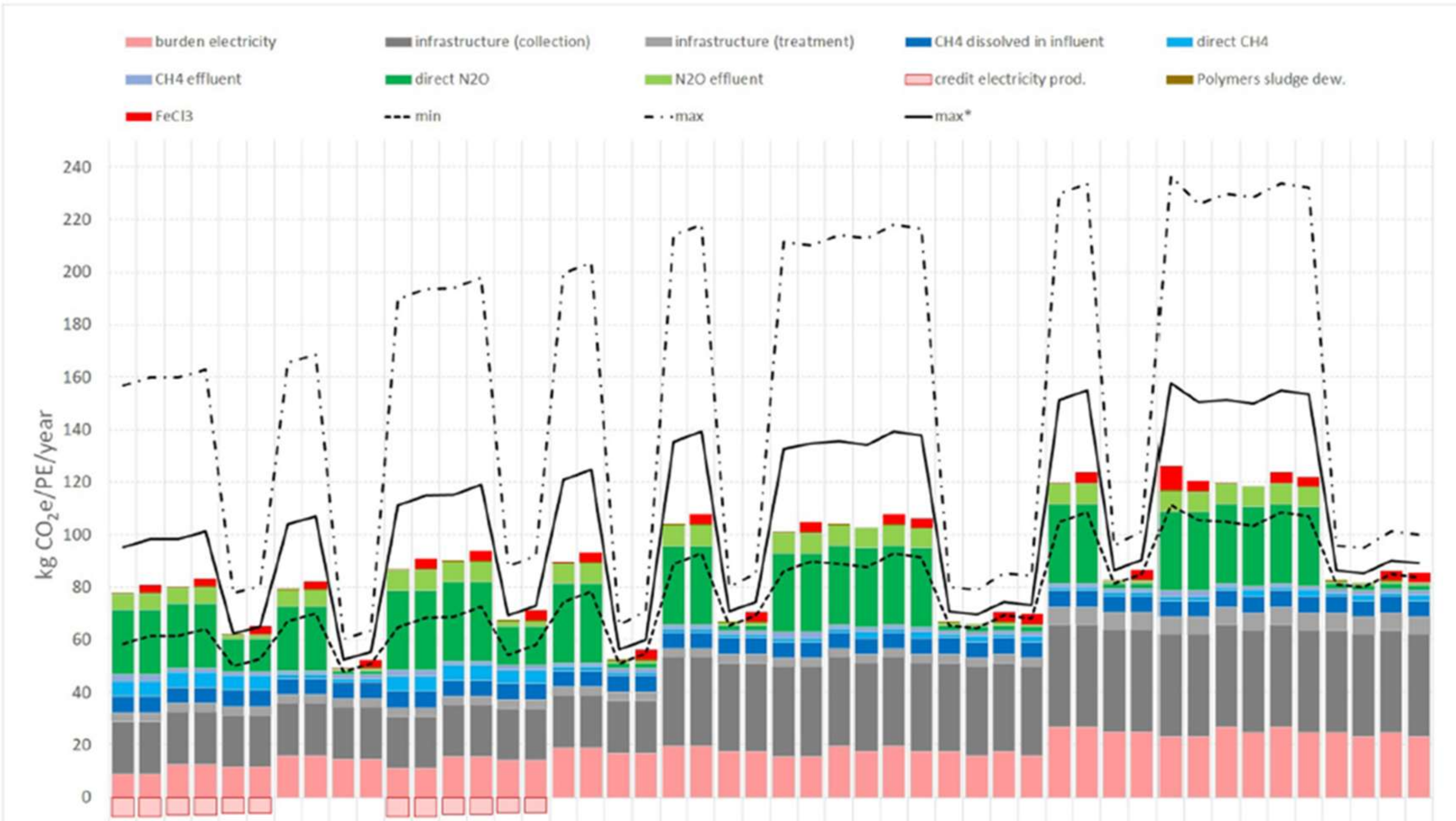
  Q&A
- New developments, catalytic elimination

  Anna Katrine Vangsgaard, Envidan and Amanda Lake, Jacobs
- Q&A Discussion
- Final remarks and conclusion

N_2O IN WASTEWATER TREATMENT



N_2O IN WASTEWATER TREATMENT



Parravicini et al., 2022

MODERATORS & PANELISTS

Anna Katrine Vangsgaard
Envidan
Denmark

Jacob Kragh Andersen
Envidan
Denmark

Mikkel Holmen Andersen
Unisense Environment
Denmark

Morten Rebsdorf
Aarhus Vand
Denmark

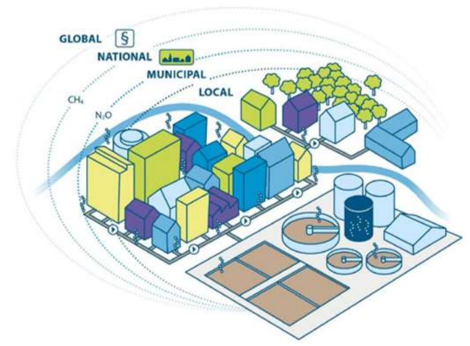
Amanda Lake
Jacobs
United Kingdom

the international water association

CLIMATE SMART UTILITIES

Introduction to funding, results, and legislation (Danish context)

JACOB KRAGH ANDERSEN, ENVIDAN WITH INPUT FROM THE DANISH EPA



inspiring change

AGENDA

- Funding and political agreements
- Early funding projects
- National funding pool results
- Links to other initiatives
- Next steps
- Legislative actions
- Outlook to other countries

CLIMATE ACTION:
POLITICAL AGREEMENT FOR A GREEN WASTE SECTOR

IWA the international water association CLIMATE SMART UTILITIES

6 topics in the water sector:

- **N_2O limits**
- P recovery
- Softening of drinking water
- Self-sufficiency
- **”Parismodel” for an energy and climate neutral water sector**
- Consolidation in the water sector

FUNDING AND POLITICAL AGREEMENTS

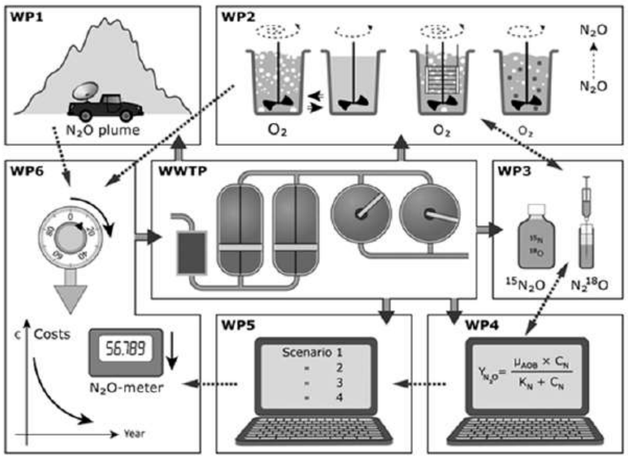
IWA the international water association CLIMATE SMART UTILITIES

-2018	2018-2019	2020	2021	2023
Various projects funded > 3 M €	Dedicated N_2O funding pool for data generation ~ 0.5 M €	Climate action political agreement for a green waste sector	"Paris-model" for water companies	N_2O Legislation detailed and comes into force Jan. 2025

Ministry of Environment of Denmark
Environmental Protection Agency

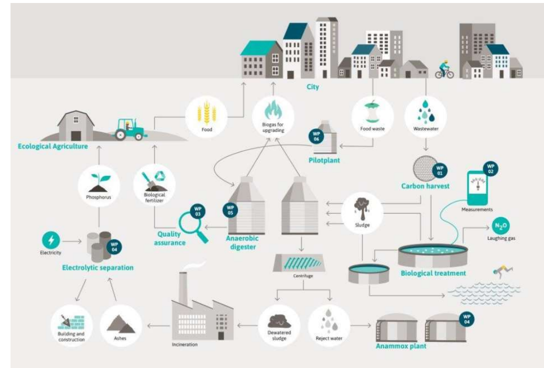
the international water association
CLIMATE SMART UTILITIES

EARLY PROJECTS

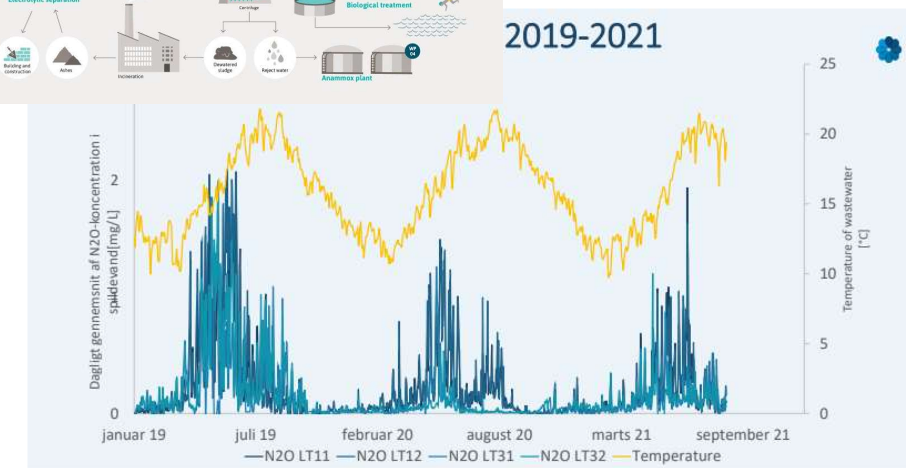


2014-2018

LaGas



2017-2023



HEPWAT
Smart spildevand

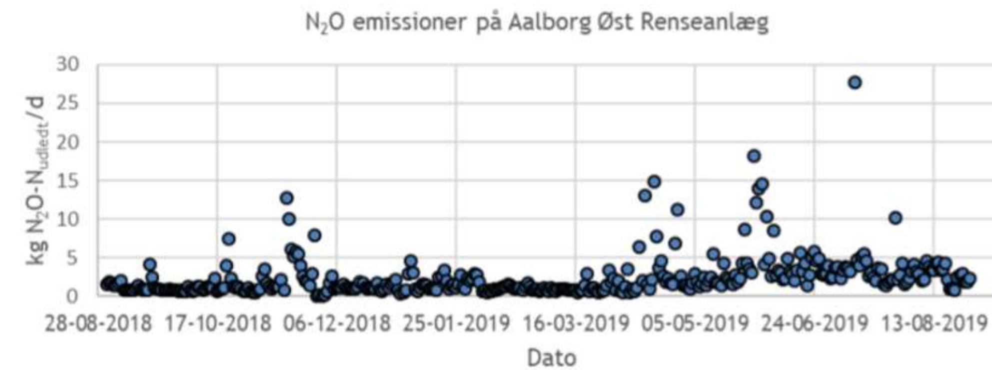
2016-2019

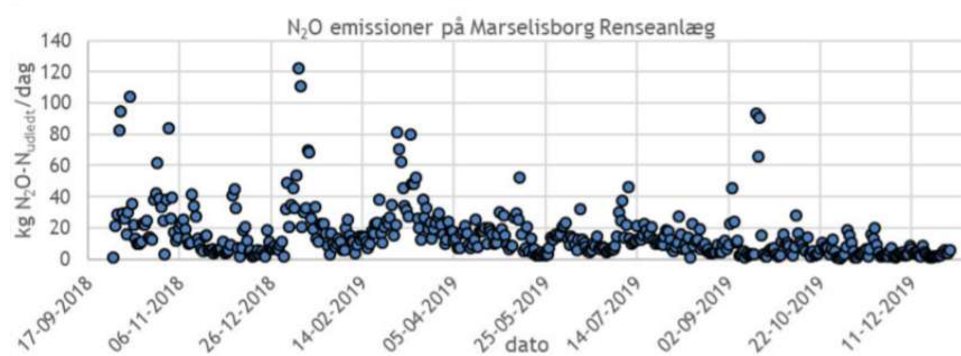
RESULTS - DEDICATED N_2O FUNDING

- Budget: 5 mio. DKK
- Aim:
  - Increase knowledge on N_2O emissions
  - Improve the national inventories
  - Reduce N_2O emissions from WWTP
- Analyses and reporting conducted by Envidan
- Published in December 2020

RESULTS: GENERAL OBSERVATIONS

- Very dynamic emission profiles
- Changes from day to day (and during the day)





RESULTS: OBSERVATIONS WITH HIGH EMISSIONS

CLIMATE SMART UTILITIES

- Load to WWTP app. doubled during festival

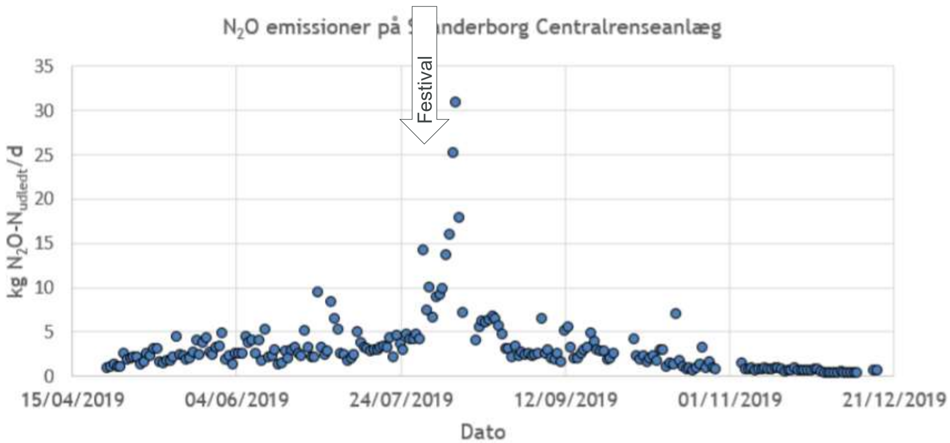
⇒Bacteria are working overtime

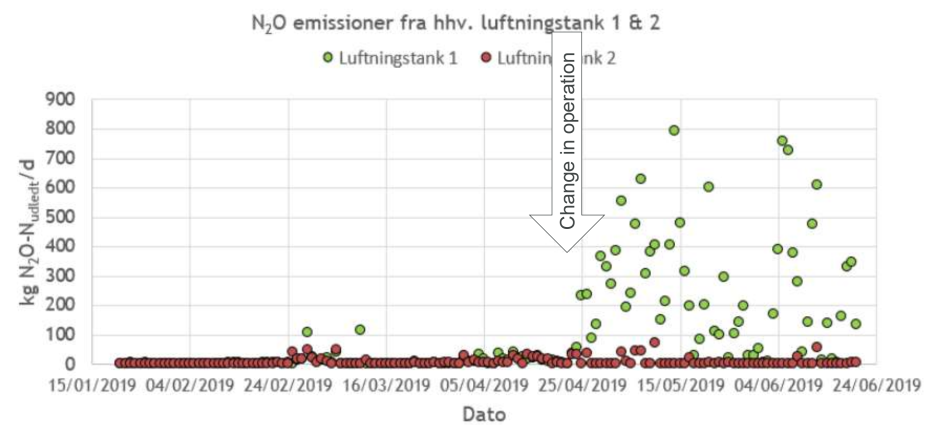
⇒More TN ends up as N_2O

- Change in operation from parallel to operation in series

⇒Bacteria in the first tank are working overtime

⇒More TN ends up as N_2O





N_2O EMISSION FACTOR (EF)

IWA the international water association — CLIMATE SMART UTILITIES

Timeline

Reference		EF	St. dev.
		(% N_2O-N/$TN_{indløb}$)	
IPCC 2006	IPCC Guideline for National Greenhouse Gas Inventories	0,05	0,03-0,12
IPCC 2019	Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories	1,60	0,016-4,50
Denmark 2019 (country-specific)	Denmark's national inventory report 2019	0,32	-
Miljøstyrelsen 2020 (country-specific)	MUDP Lattergaspulje: Dataopsamling på måling og reduktion af N_2O emissioner fra renseanlæg (EnviDan report)	0,84	0,24-1,24

→ IPCC 2019: Based on 30 datasets from different parts of the world

→ Denmark 2019: Average value from 2 studies

→ Miljøstyrelsen 2020: Based on measurements from 9 (5) Danish WWTPs in the period 2018-2020 (current study)

There is a large demand for measurements and emissions estimates from individual wastewater treatment plants.

CONCLUSIONS

the international water association CLIMATE SMART UTILITIES

Overall conclusions:

- Emission factor: 0,84 % N2O-N/T-Ninlet
- High variation: 0,24-1,24 % N2O-N/T-Ninlet
- Increased emissions from high loaded biological processes
- High emissions from sidestream processes: 5-6 % N2O-N/T-Ninlet

Miljøministeriet
Miljøstyrelsen

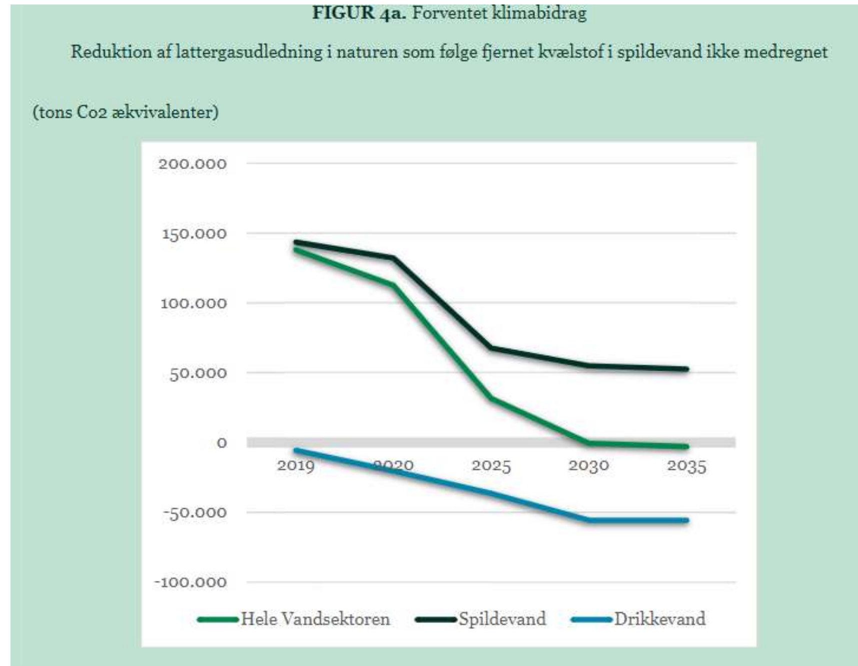
MUDP Lattergaspulje Dataopsamling på måling og reduktion af lattergasemissioner fra renseanlæg

What can be done for the specific WWTP:

- Measure! Preferably over a longer period of time and at different operational conditions
- Reduce the specific ammonium load
- Expand existing online control to take N2O emissions into account

“PARIS-MODEL”

- Simple CO_2 accounting model containing the biggest contributors to utilities’ operation
- Voluntary reporting in 2021
- Current status and projections for 2025, 2030, and 2035
- Result: Goal of climate neutrality in 2030
- Model being updated in 2023
- New reporting round in 2024



NEXT STEPS

Pre-study and preparatory work for legislation

Work have just commenced and will be delivered by late 2023/early 2024:

- Updated N_2O baseline
- Screening and evaluation of measurement methods
- Development of regulation models coming into force early 2025
- Recommendations for revision of national reporting and compliance checks

OUTLOOK TO OTHER COUNTRIES

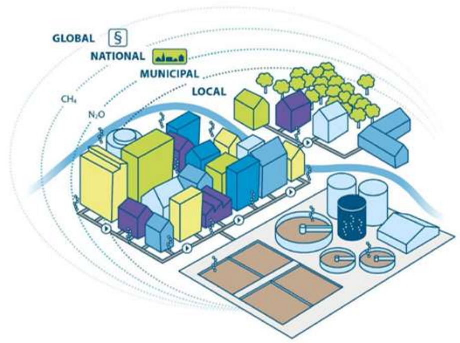
- EU
  - Urban Wastewater Treatment Directive
- Switzerland
  - CO_2 offsetting – compensation
- Sweden
  - National study by IVL Swedish Environmental Research Institute
- Netherlands
  - Screening tool for accessing risk of N_2O emissions
- UK
  - Possible national monitoring campaign

OUTLOOK – ONGOING RESEARCH PROJECTS

IWA the international water association — CLIMATE SMART UTILITIES

- ARES (MUDP): Active reduction of emissions from WWTPs

ARES
Aktiv Reduktion af Emissioner fra Spildevandsanlæg



VandCenterSyd, BIOFOS, aarhusvand, Envidan, DTU, AARHUS UNIVERSITET

- NACAT (MUDP): N_2O Abatement by CAtalytic Treatment

TÅRNBYFORSYNING, Hillerød Forsyning, Envidan, VandCenterSyd, DTU, HALDOR TOPSØE

THANKS FOR LISTENING

For more information or questions do not hesitate to get in contact:

Jacob Kragh Andersen, jka@envidan.dk

Anna Katrine Vangsgaard, akv@envidan.dk

-2018	2018-2019	2020	2021	2023
Various projects funded > 3 M €	Dedicated N_2O funding pool for data generation ~ 0.5 M €	Climate action political agreement for a green waste sector	"Paris-model" for water companies	N_2O Legislation detailed and comes into force Jan. 2025

CLIMATE SMART UTILITIES

Measure to kN_2Ow

+20 years of collected kN_2Owhow

Mikkel Holmen Andersen, Unisense Environment, Denmark

Born @ 294ppb N2O, Today @ 334ppb

inspiring change

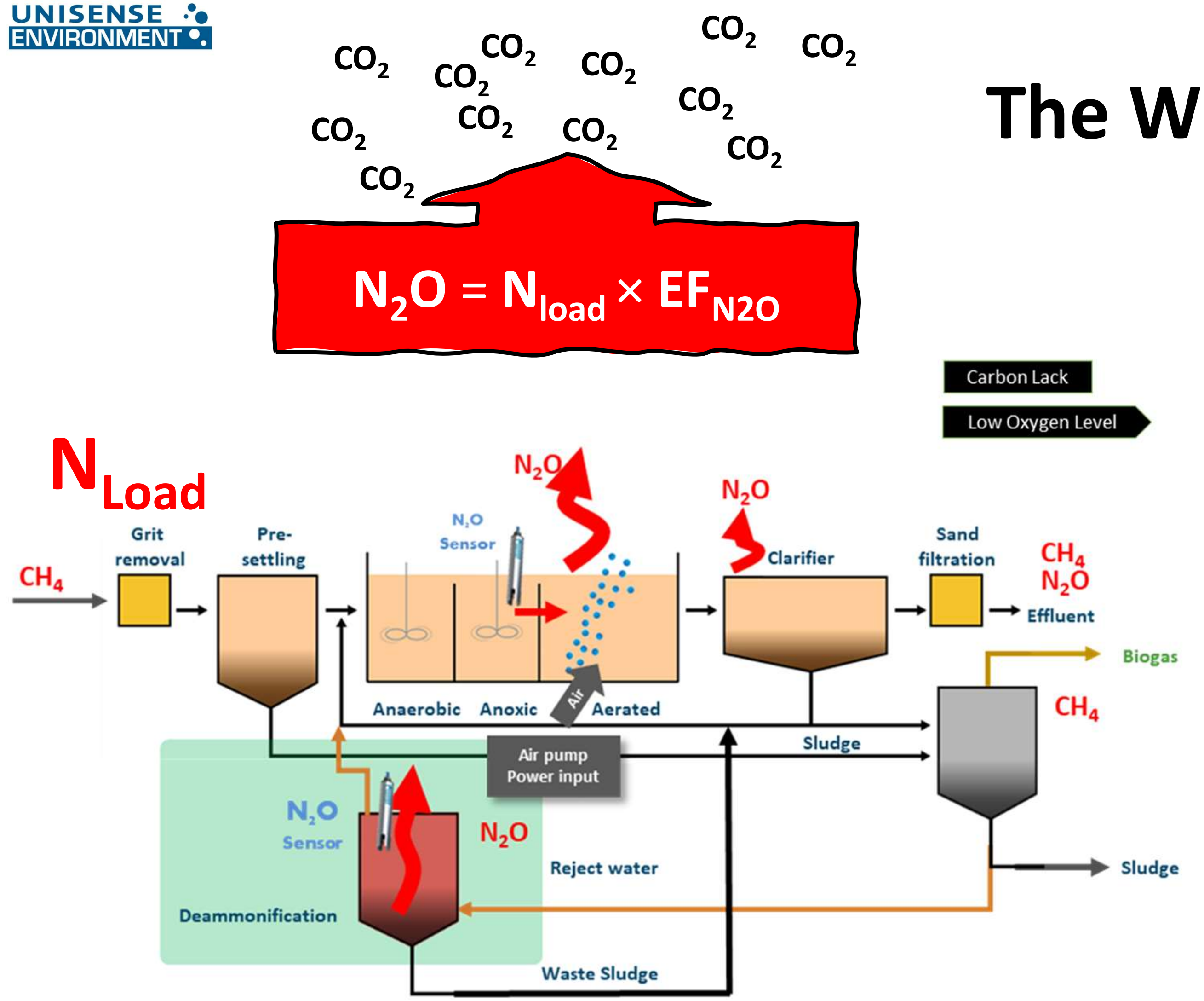
UNISENSE ENVIRONMENT

AGENDA

IWA the international water association CLIMATE SMART UTILITIES

- Utilities and the CO_2 footprint
- N_2O monitoring evolution
- N_2O mitigation status
- Regulations as a driver for GHG reductions

The WWTP Challenge



The wastewater treatment process used throughout the world has a major defect:

- **Uncontrolled N_2O emission - adding to global warming**
- **Unwise energy savings lead to increased emissions of N_2O**
- **Urbanisation**

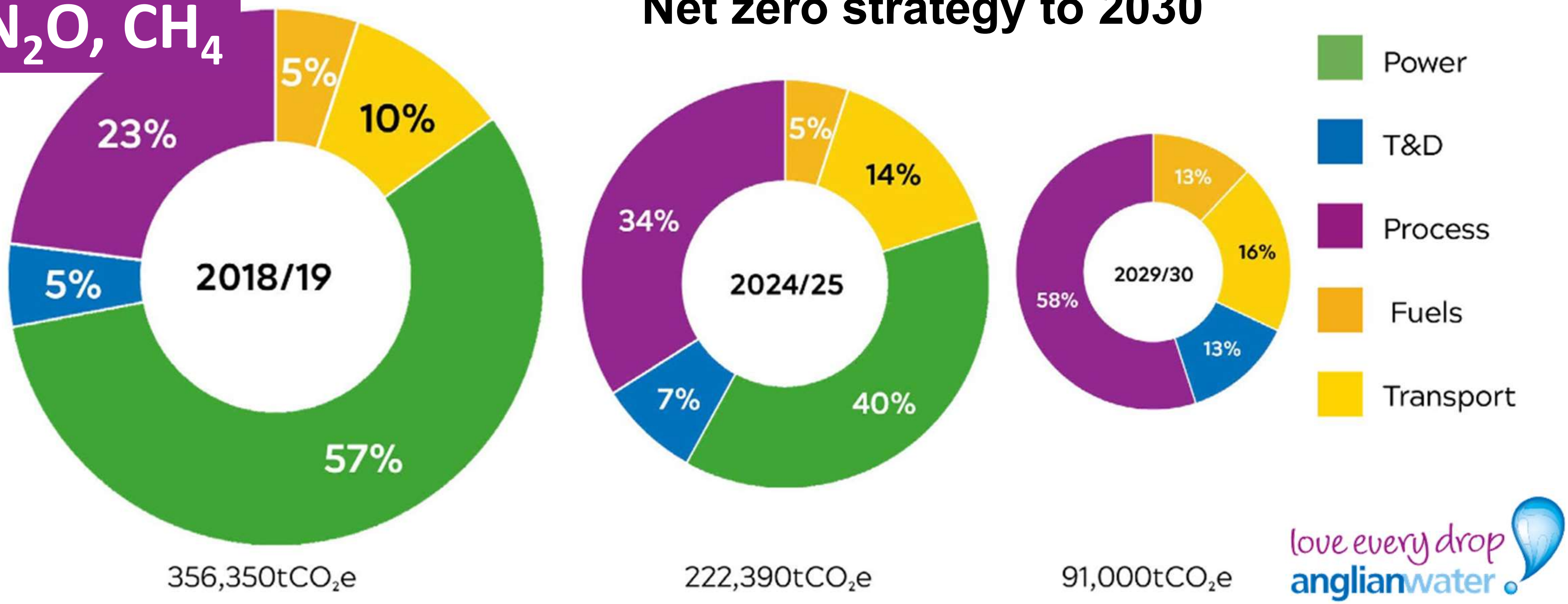
UNISENSE ENVIRONMENT

IWA the international water association CLIMATE SMART UTILITIES

SUPPLY WATER AND WATER RECYCLING SERVICES TO ALMOST 7 MILLION PEOPLE IN THE EAST OF ENGLAND

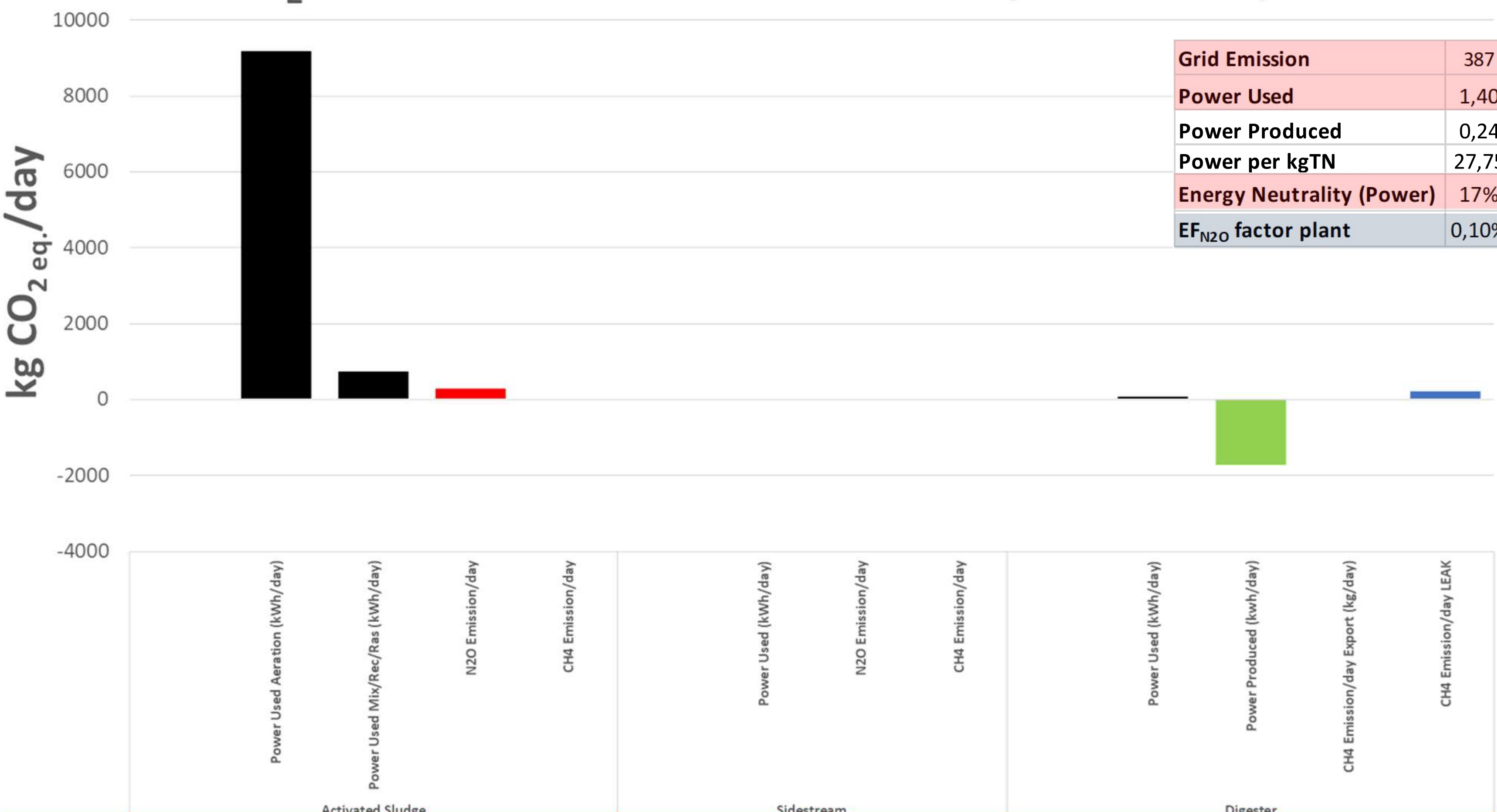
N_2O, CH_4

Net zero strategy to 2030



UTILITIES AND CO_2 FOOTPRINT - 2011

CO_2 Emission from standard WWTP (200.000 PE)



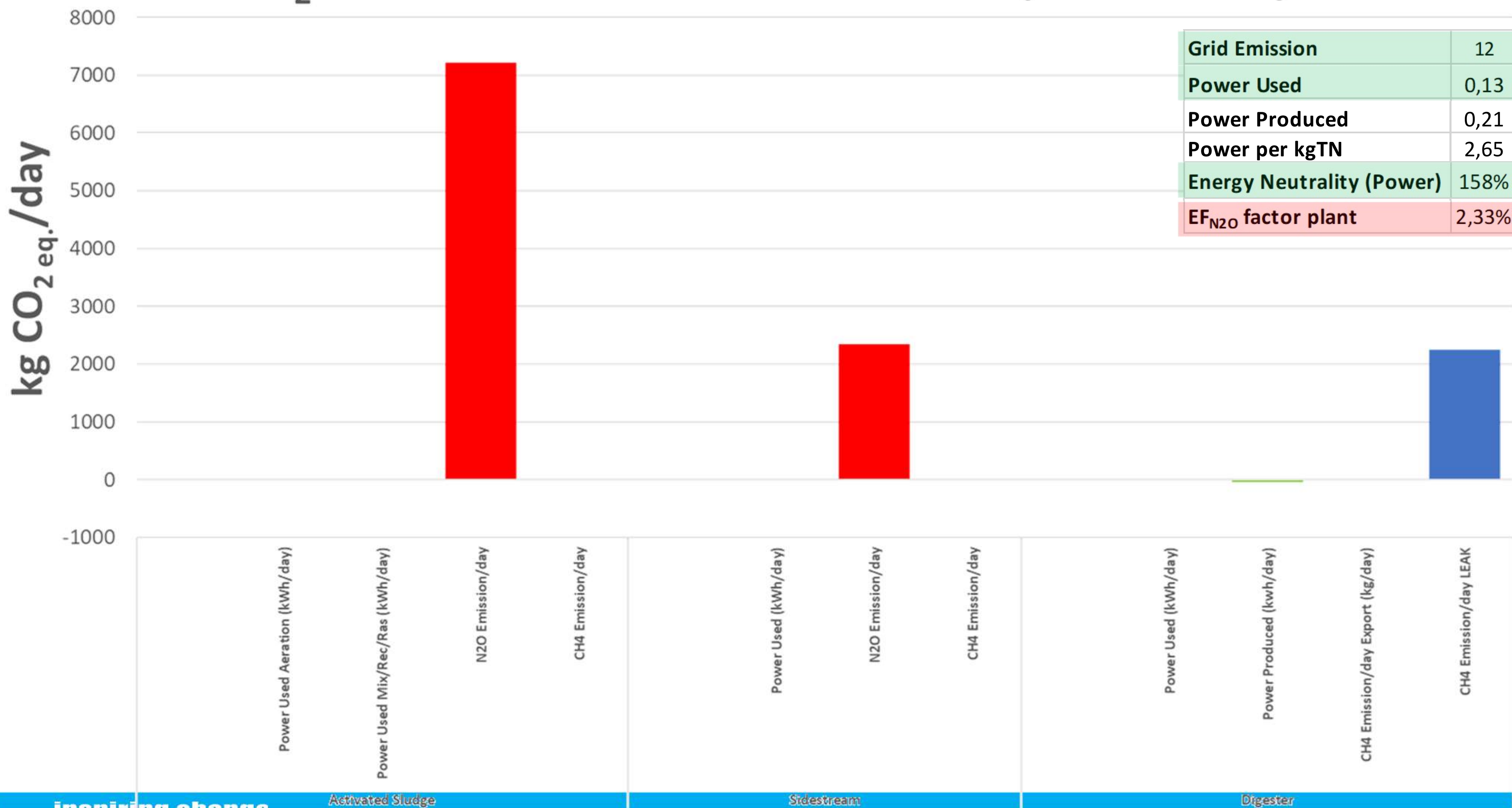
Grid Emission	387	gCO_2/kWh
Power Used	1,40	kWh/m^3
Power Produced	0,24	kWh/m^3
Power per kgTN	27,75	kWh/kgTN
Energy Neutrality (Power)	17%	$kWh_{used}/kWh_{produced}$
EF_{N2O} factor plant	0,10%	$kgN_{N2O}/kg\ TN_{inlet}$

UNISENSE ENVIRONMENT

UTILITIES AND CO_2 FOOTPRINT - 2030

IWA the international water association — CLIMATE SMART UTILITIES

CO_2 Emission from standard WWTP (200.000 PE)



Grid Emission	12	gCO_2/kWh
Power Used	0,13	kWh/m^3
Power Produced	0,21	kWh/m^3
Power per kgTN	2,65	kWh/kgTN
Energy Neutrality (Power)	158%	$kWh_{used}/kWh_{produced}$
EF_{N2O} factor plant	2,33%	$kgN_{N2O}/kg\ TN_{inlet}$

UNISENSE ENVIRONMENT

N_2O MONITORING - TIMELINE

IWA the international water association — CLIMATE SMART UTILITIES

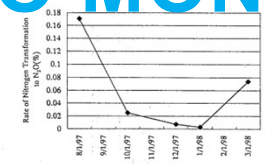


Figure-1 Change of the Rate of Nitrogen Transformation

1997
Full-scale EF_{N2O}

118 N_2O WW papers

1.570 N_2O WW papers

Denitrification pathways

Range of JP emission studies

5.390 N_2O WW papers

Nitrous oxide emission during wastewater treatment

M.J. Kampschreur, B.G. Temmink, R. Kleerebezem, M.S.M. Jetten, M.C.M. Loosdrecht

Environmental Technology, WIMEK

Intergovernmental Panel on Climate Change

WMO UNEP

2006 IPCC Guidelines for National Greenhouse Gas Inventor

EF_{N2O} range 0.05-25%

9.700 N_2O WW papers
86 with N_2O sensor

6.3.1.2 CHOICE OF EMISSION FACTORS

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.005 (0.0005 - 0.25) kg N_2O-N/kg N. This emission factor is based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries. The first assumption is that

1970s	1980s	1990s	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009

First papers on N_2O and denitrification

585 N_2O WW papers

Environ. Sci. Technol. 1995, 29, 2352–2356

Nitrous Oxide Emissions from Municipal Wastewater Treatment

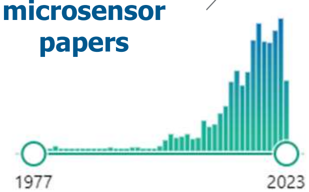
PETER CZEPIEL,* PATRICK CRILL, AND ROBERT HARRISS

Complex Systems Research Center, Morse Hall, University of New Hampshire, Durham, New Hampshire 03824-3525

as bacterially mediate
occurs under anaerob

$IPCC_{2006}$ EF_{N2O}
0.05% or 3.2g/PE/y

N_2O microsensor papers



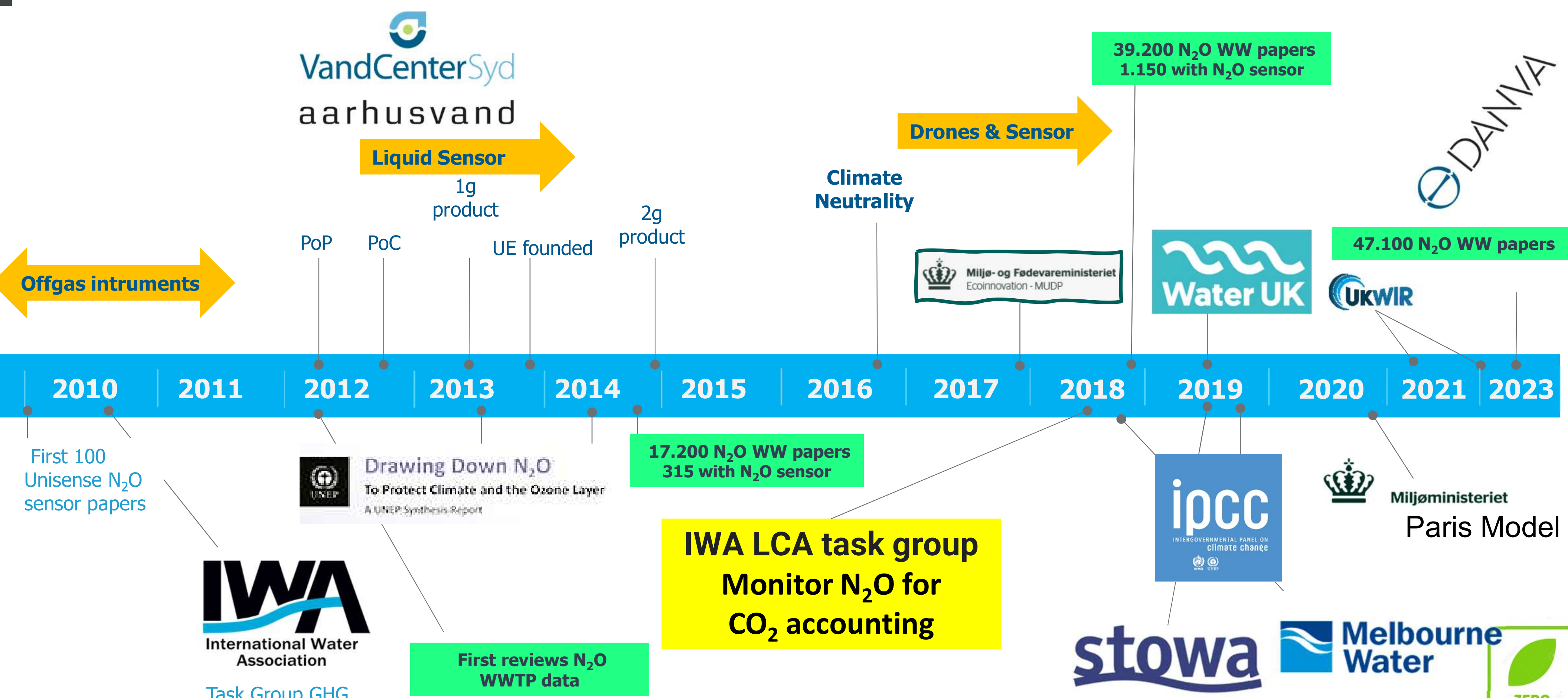
Short measurement-campaign N_2O Grabsamples CH_4

stowa

UNISENSE ENVIRONMENT

N_2O MONITORING - TIMELINE

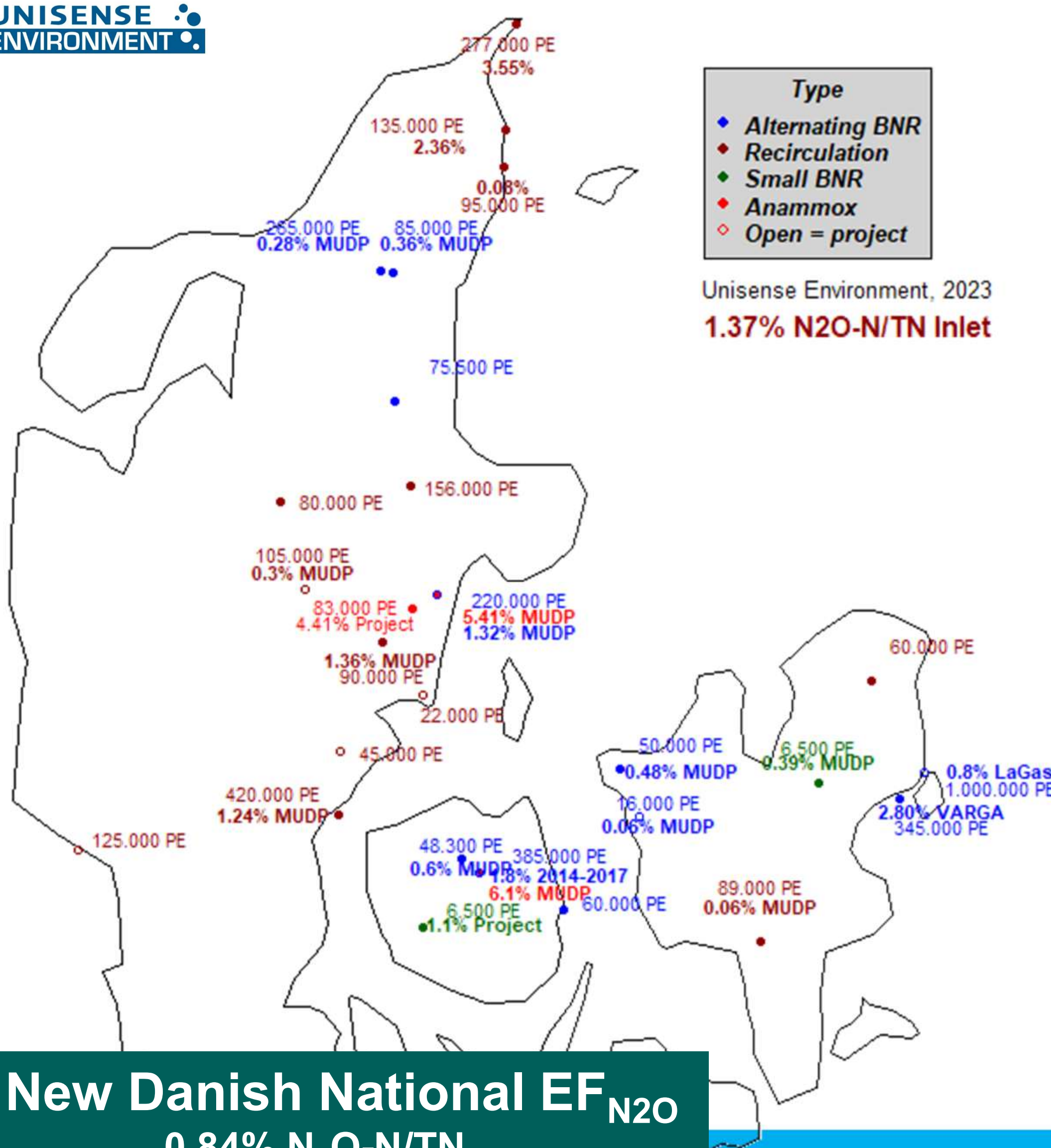
IWA the international water association CLIMATE SMART UTILITIES

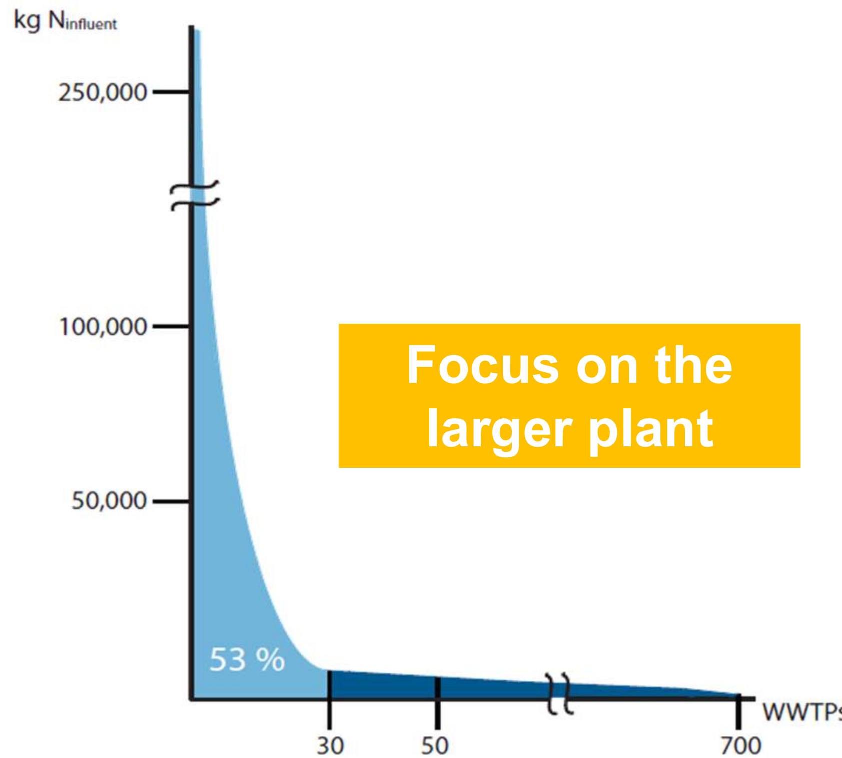


UNISENSE ENVIRONMENT

IWA the international water association — CLIMATE SMART UTILITIES

N_2O Monitoring - Denmark



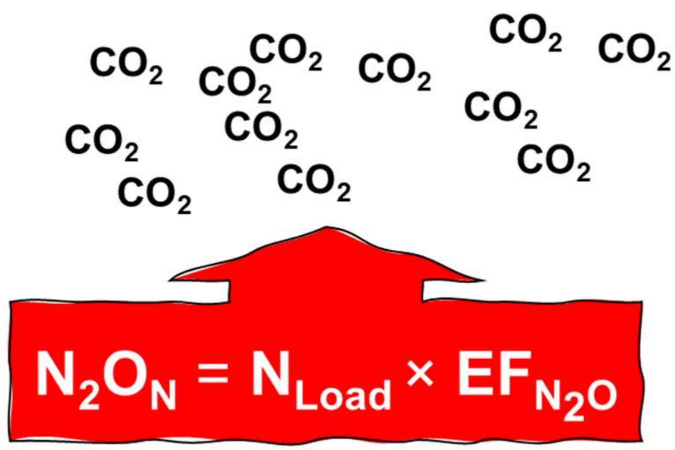


Focus on the larger plant

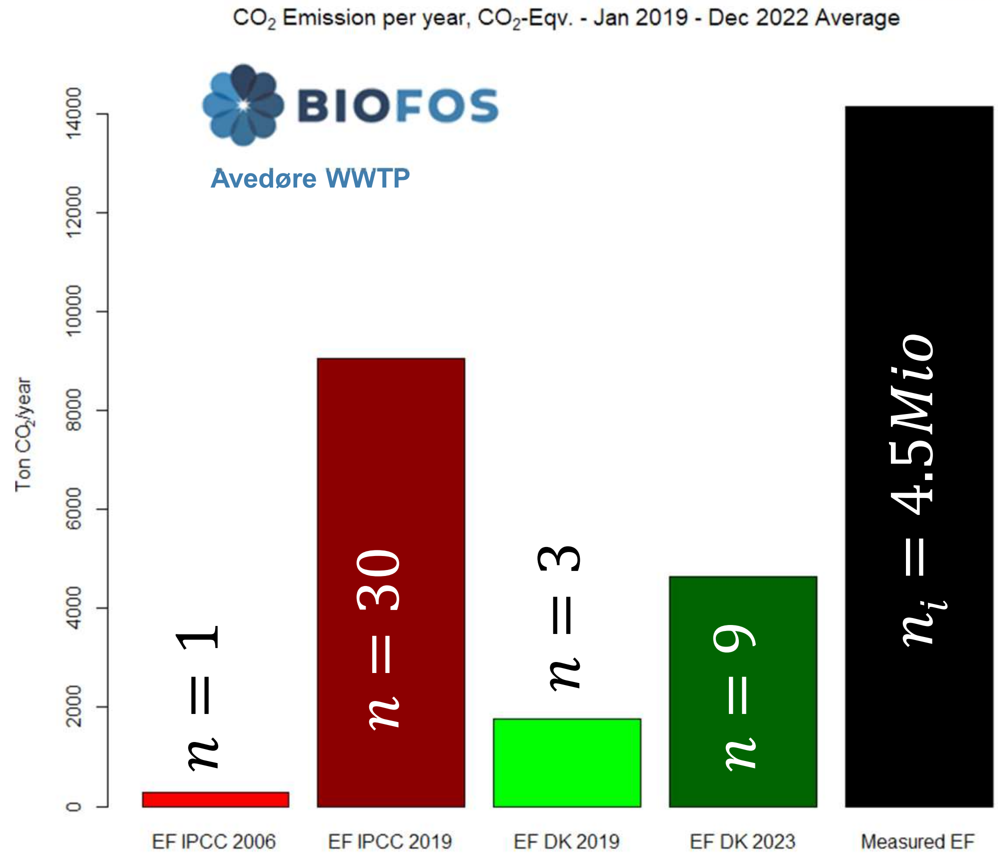
New Danish National EF_{N2O}
0.84% N_2O-N/TN_{inlet}

UNISENSE ENVIRONMENT

CO_2 Neutrality without Monitoring?



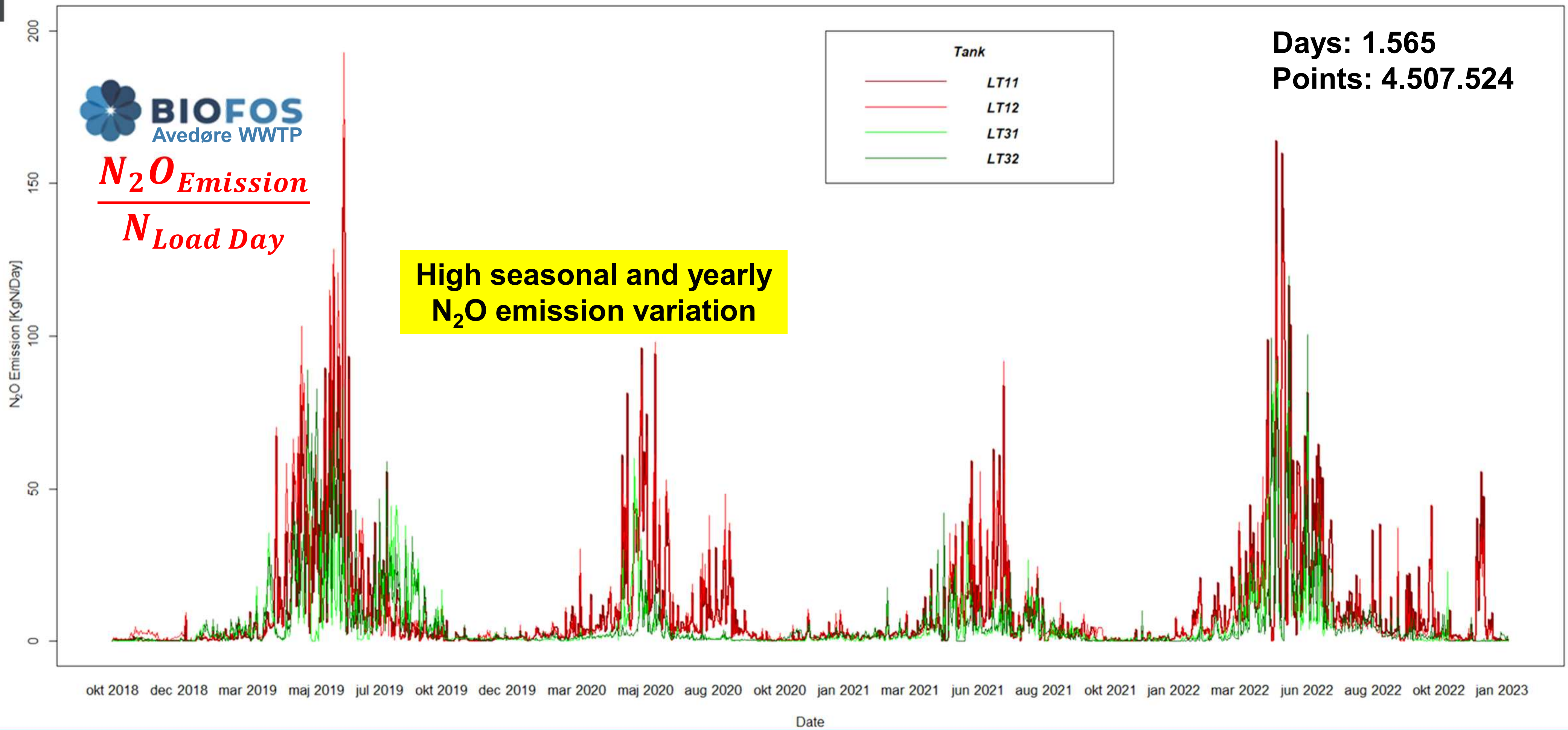
EF_{N2O} IPCC 2006	0.05% of kg TN_{inlet}
EF_{N2O} IPCC 2019	1.64% of kg TN_{inlet}
EF_{N2O} Denmark 2019	0.32% of kg TN_{inlet}
EF_{N2O} Denmark 2023	0.84% of kg TN_{inlet}
EF_{N2O} Avedøre 2019-2022	2.80% of kg TN_{inlet}



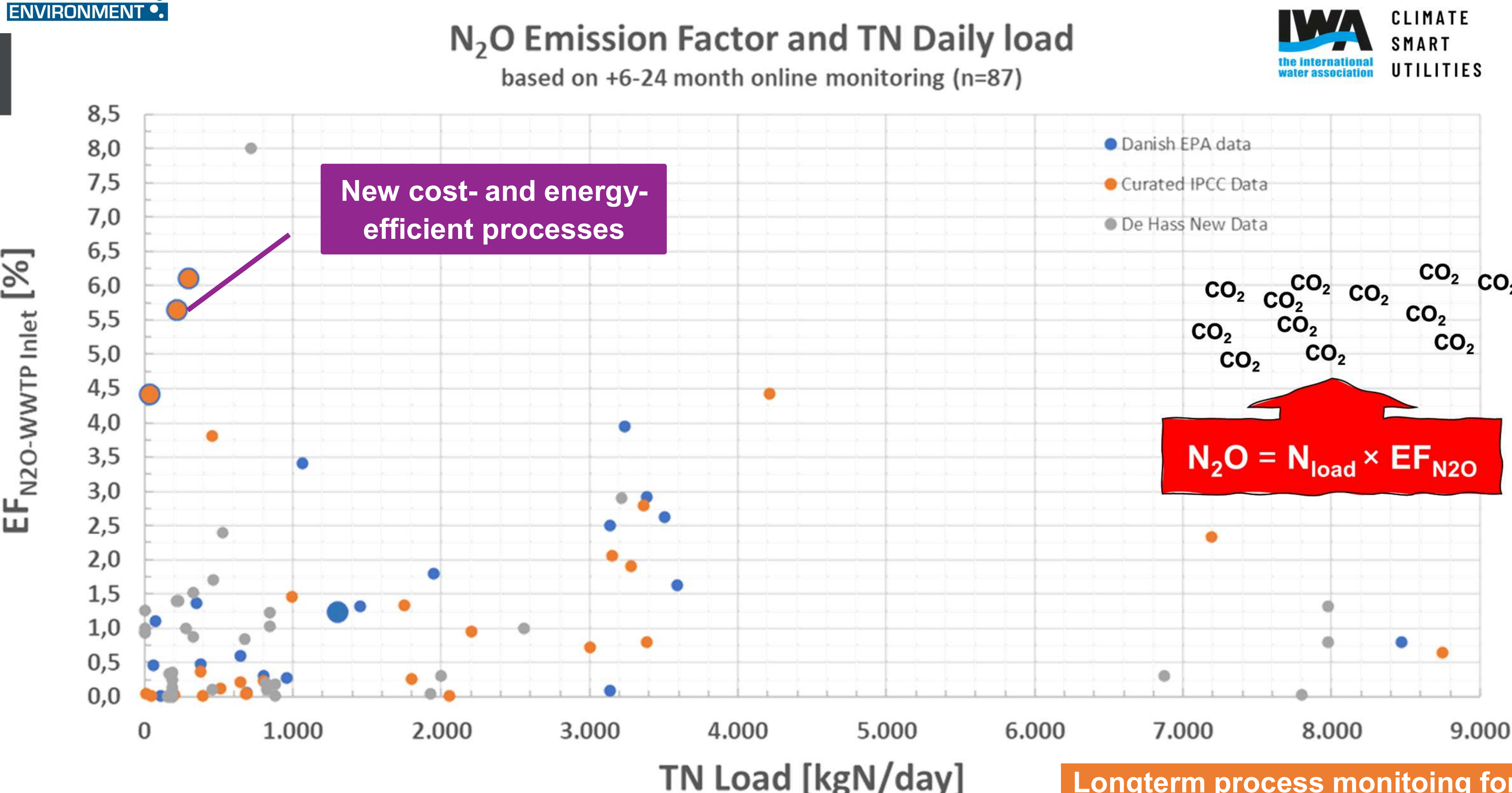
UNISENSE ENVIRONMENT

N_2O MONITORING – SHORT-TERM OR SPOT?

IWA the international water association CLIMATE SMART UTILITIES



UNISENSE ENVIRONMENT



IWA the international water association CLIMATE SMART UTILITIES

New cost- and energy-efficient processes

$$N_2O = N_{load} \times EF_{N2O}$$

Longterm process monitoing for understanding and mitigation

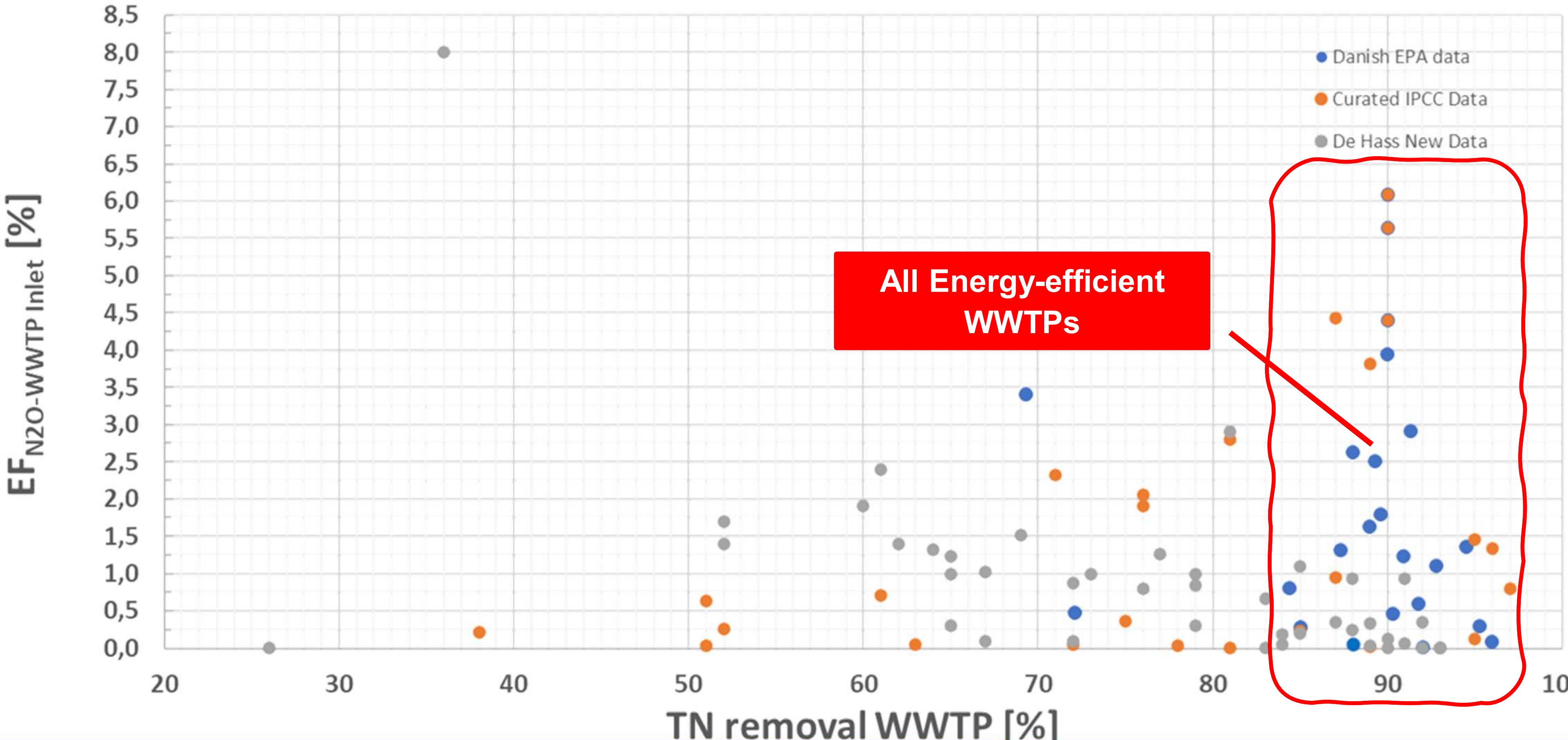
inspiring change

UNISENSE ENVIRONMENT

IWA the international water association CLIMATE SMART UTILITIES

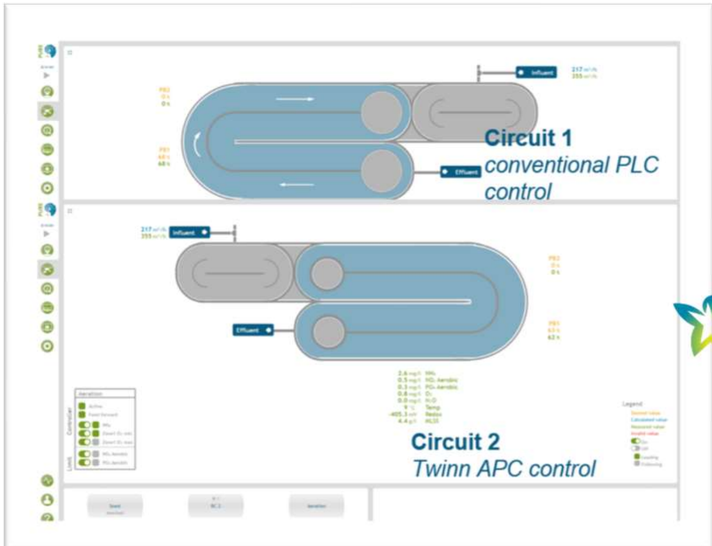
N_2O Emission Factor and TN Removal Efficiency

based on + 6-24 month online monitoring (n=89)



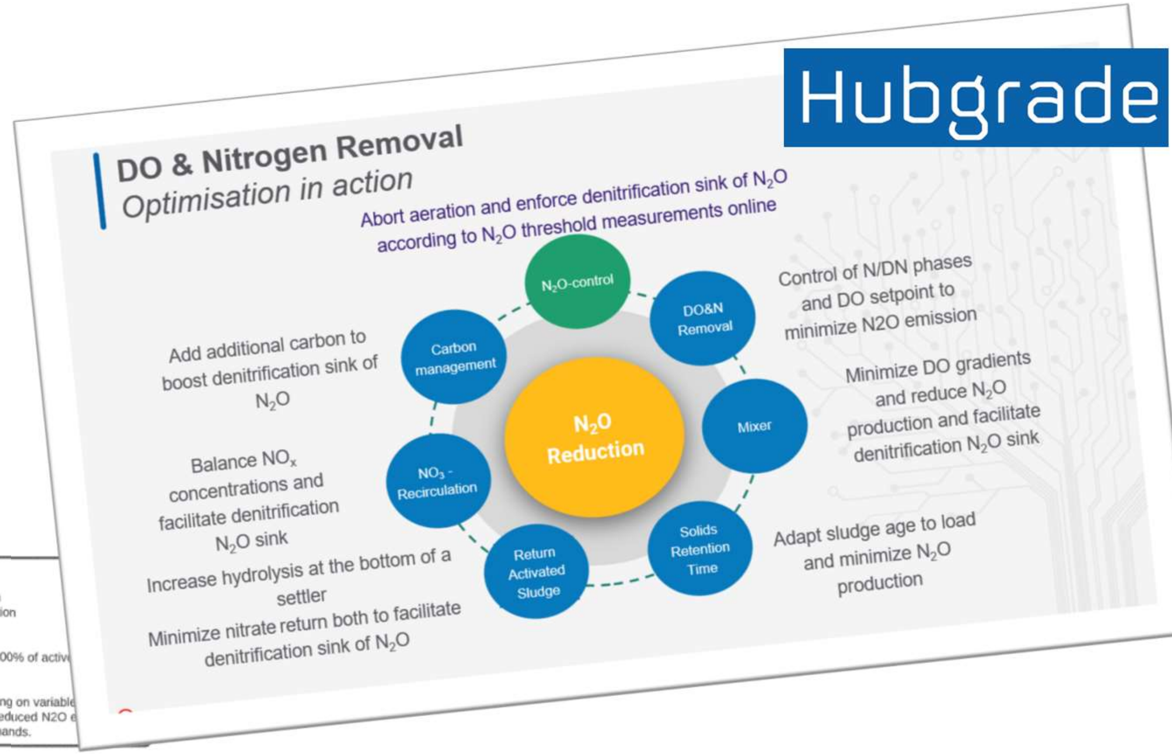
ADVANCED PROCESS CONTROLS - MITIGATION

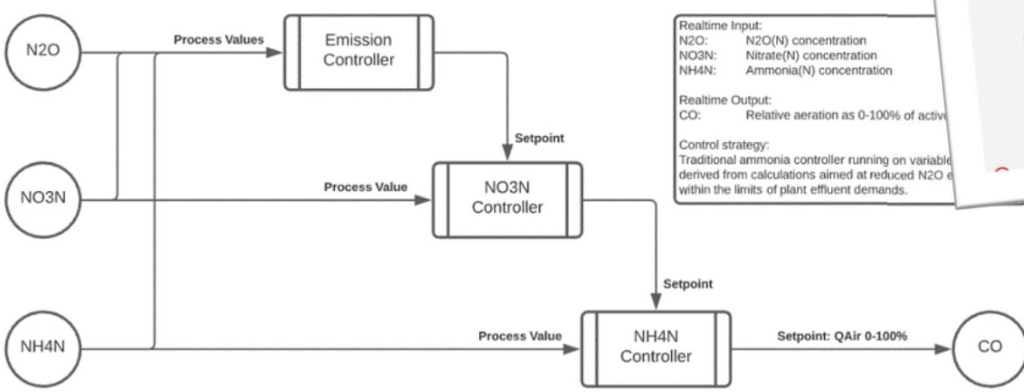
IWA the international water association CLIMATE SMART UTILITIES



Twinn by Royal HaskoningDHV

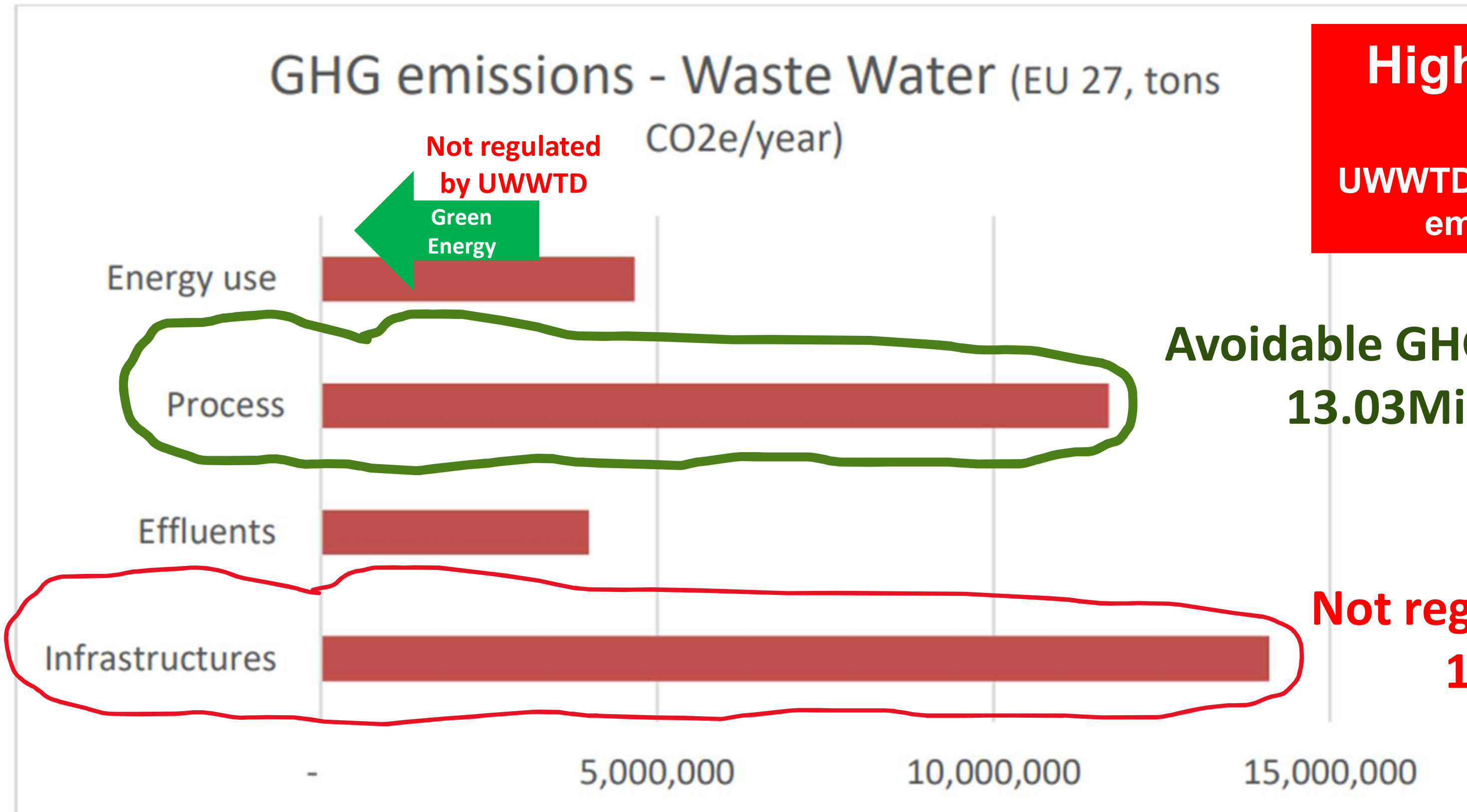
Hubgrade





Envidan

REVISION OF THE URBAN WASTEWATER TREATMENT DIRECTIVE (UWWTD)



Higher ambitions needed!
UWWTD only looks at energy emission by 2040!!

Avoidable GHG emissions 13.03Mio tons

Not regulated by UWWTD 14.1 Mio tons

Wastewater treatment responsible for 34.5Mio tons CO_{2e}/year in EU

UNISENSE
ENVIRONMENT

STEPPING STONES CLIMATE NEUTRALITY

IWA
the international water association

CLIMATE
SMART
UTILITIES

Reduce energy consumption
Install energy efficient equipment

N_2O

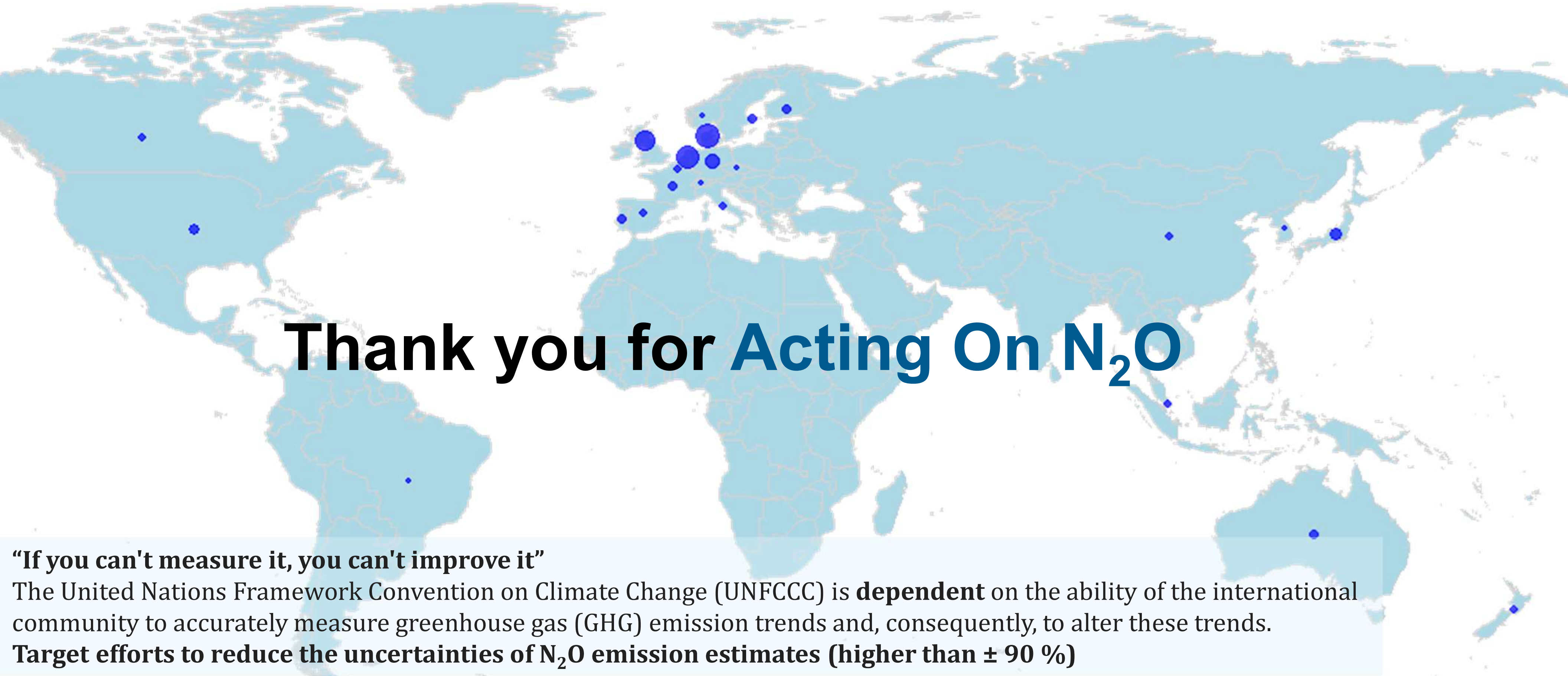
Mitigate process emissions

Sustainable energy production

UNISENSE ENVIRONMENT

MEASURE TO kN_2Ow

the international water association CLIMATE SMART UTILITIES



Thank you for Acting On N_2O

“If you can't measure it, you can't improve it”

The United Nations Framework Convention on Climate Change (UNFCCC) is **dependent** on the ability of the international community to accurately measure greenhouse gas (GHG) emission trends and, consequently, to alter these trends.

Target efforts to reduce the uncertainties of N_2O emission estimates (higher than ± 90 %)

Case study – Mitigating N2O emissions

MORTEN REBSDORF, AARHUS VAND

inspiring change

CONTENT

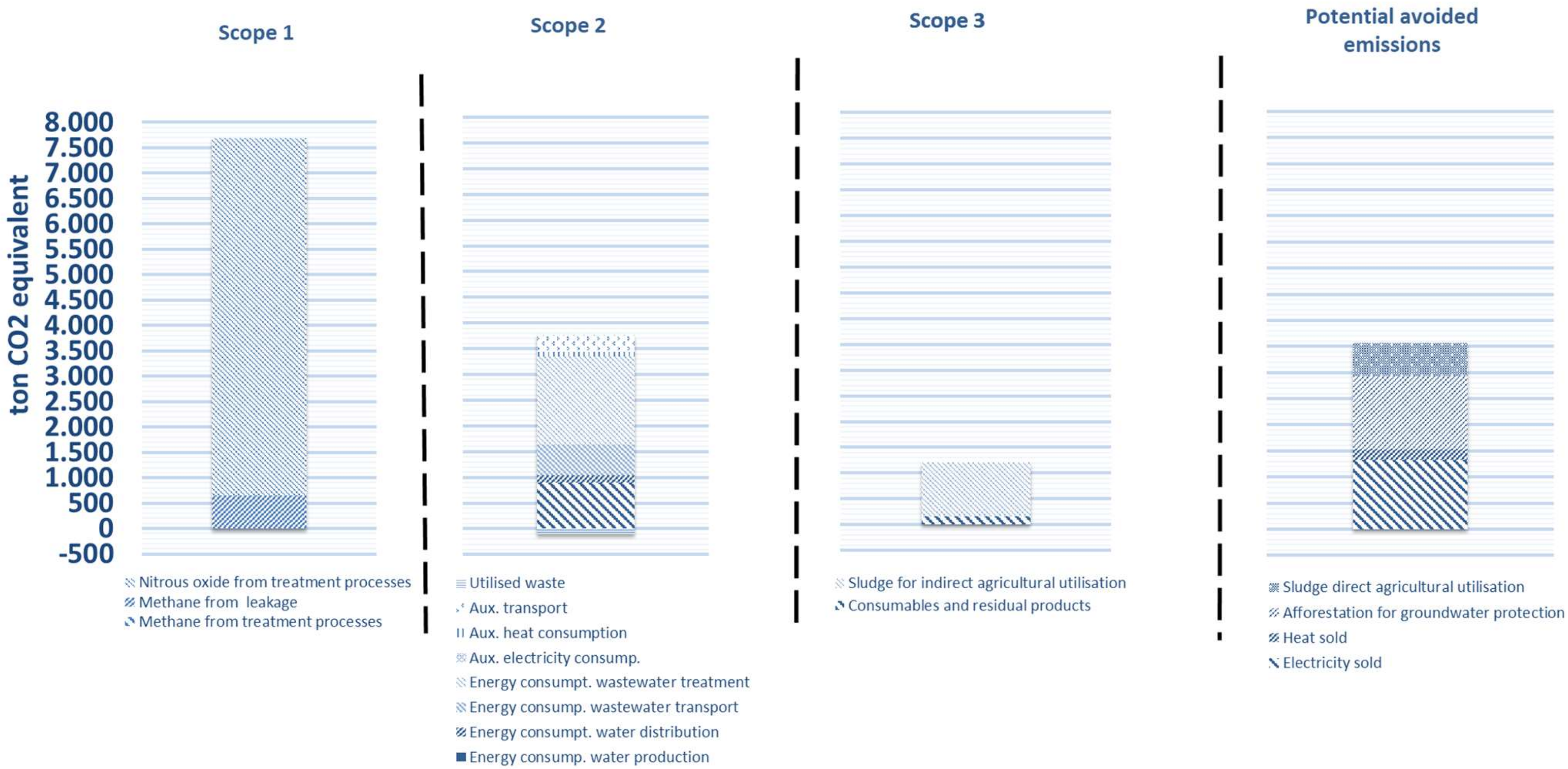
- Ambition
- Problem
- Trials
- Collaboration
- Results
- Wrap-up

AMBITION

- Aarhus Municipality CO_2-neutral in 2030 (Goal set in 2008), which applies also for Aarhus Vand.
- Corporate Sustainabilty Reporting Directive (CSRD) will enforce new GHG accounting in 2025, by using GHG Protocol (Scope 1, 2, 3..)
- Will this shift the focus for the industry, as in
- You will act and become as you are measured?
- Standardisation and transparent accounting and calculation principles are needed

THE NEW CARBON FOOTPRINT; AARHUS VAND 2021; ACCORDING TO THE GREENHOUSE GAS PROTOCOL

IWA the international water association CLIMATE SMART UTILITIES

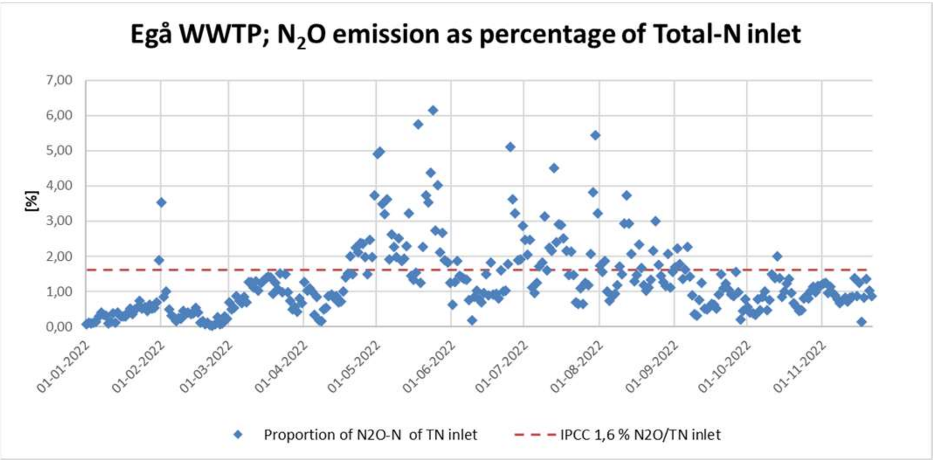


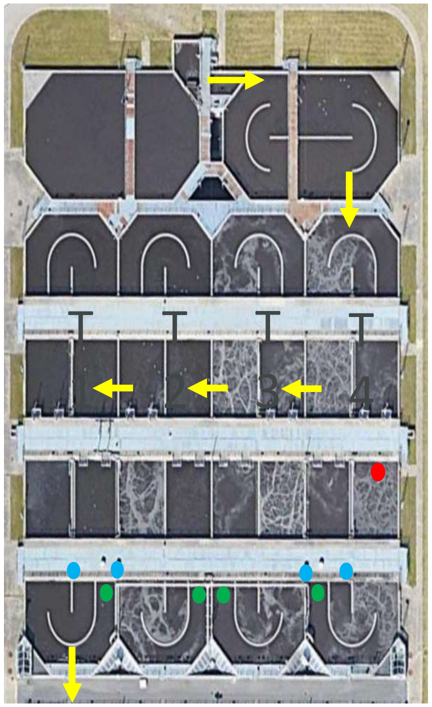
THE PROBLEM

- How to ensure reliable measurements?
- Finding the “true” values
- Liquid phase sensors
- Off gas analysis
- Calculation methods
- New control levers needed?
- Reporting principles

EGÅ WWTP

- 120,000(Capacity)/85.000(Load) PE
- Liquid phase sensors
- Off-gas hood
- Intense calibrations efforts reg. airflow.





Lynggaard-Jensen, A; Aarhus Vand

OFFGAS FLOW CALIBRATION EGAA

THE COLLABORATION – NET ZERO PARTNERSHIP

- Severn Trent (UK)
- Melbourne Water (AUS)
- Aarhus Vand

- IPCC 1,6 % N_2O/T-N inlet
- 0.4% N_2O/T-N removed (UK)
- 0.5 % N_2O/T-N removed (AUS)
- 0.84 % N_2O/T-N inlet (DK)

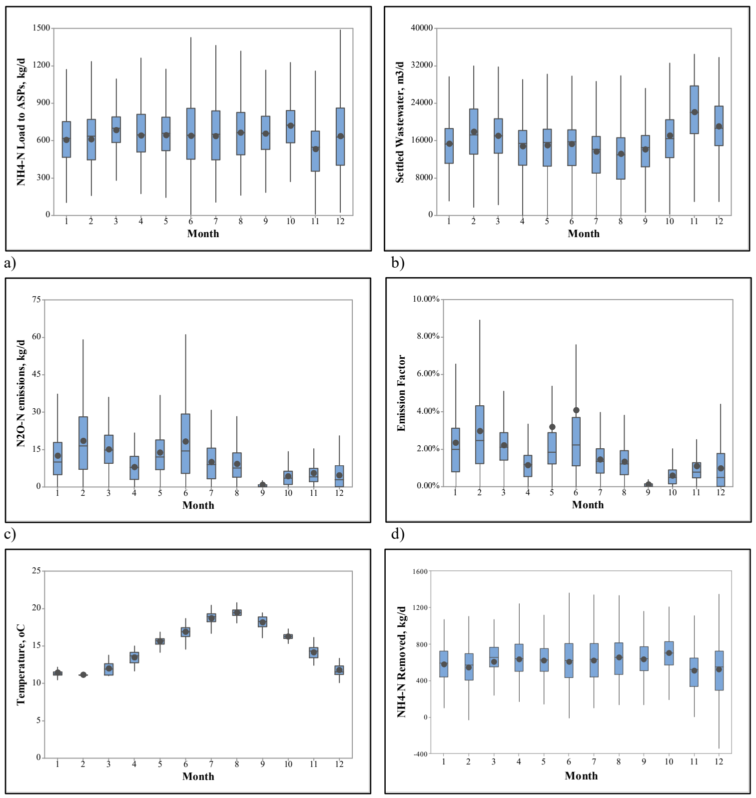
Parameter/Site	Spernal (ST)	Werribee (MW)	Egå (AAV)
Loading/Capacity [PE]	115,000	2,500,000/NA	85,000/120,000
Plant type	Plug flow nitrifying ASP (with small anoxic selector zone)	Step fed continuous flow ASP	Plug flow ASP SND (with small anoxic selector zone)
MLSS (kg/m³)	3.0	4.5	3.9
F/M BOD/COD/MLSS	0.094 (BOD)	0.03 (COD)	0.14 (COD)
F/M NH3/MLSS	0.04	0.01	0.01
SS/VSS	1.25	1.33	1.3
HRT Avg. retention time (hrs)	10	19.4	28
Avg. temp (°C)	14,9	21.6	14,6
Aerobic sludge age (days)	10	17.4	22.4
Daily Avg. EF (% N2O/NH4-N or % N2O/TN)	1.8(NH4-N)	1.4(TN)	1.2(TN)
Avg Ammonia removal (%)	94,1	99.0	99.1
Avg Total-N removal (%)	38	95.7	93.5
Liquid phase nitrous oxide sensor	Clark-type electrode (Unisense)	Clark-type electrode (Unisense)	Clark-type electrode (Unisense)
Nitrous oxide gas analyser	Spot samples - Li-Cor LI7820 N2O optical feedback cavity enhanced absorption spectrometer	Horiba Sample Conditioning and Gas Analysers units (VS 3000/5000)	Thermo-Fischer 46i-HL High level Nitrous Oxide Analyzer

THE RESULTS; SEASONAL VARIANCE

CLIMATE SMART UTILITIES

SPERNAL WWTP

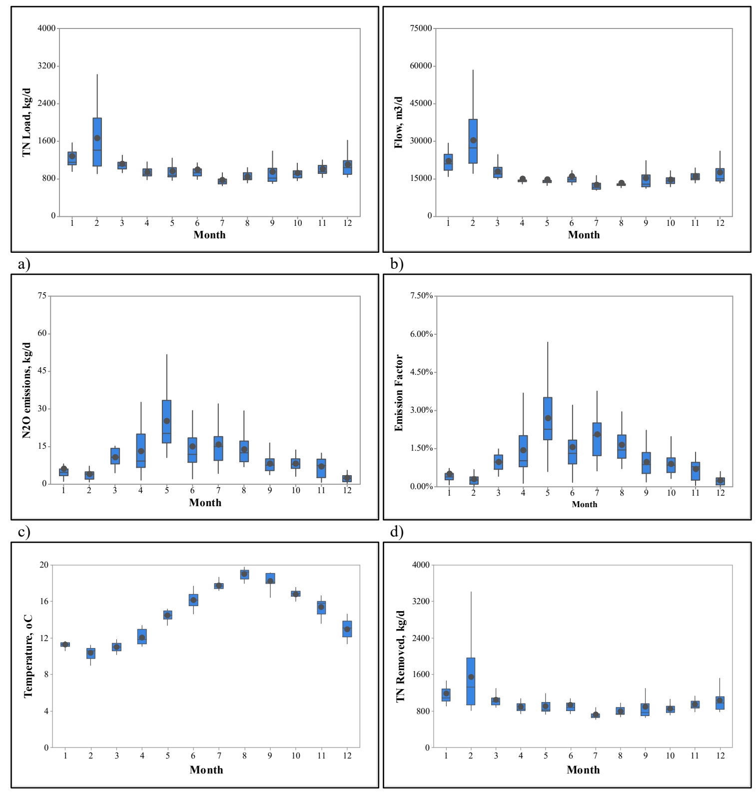
a) NH4-N load to ASP; b) Flow to ASP; c) N2O-N emission;
d) Emission factor; e) temperature in ASP; f) NH4-N removed



a) b) c) d) e) f)

EGÅ WWTP

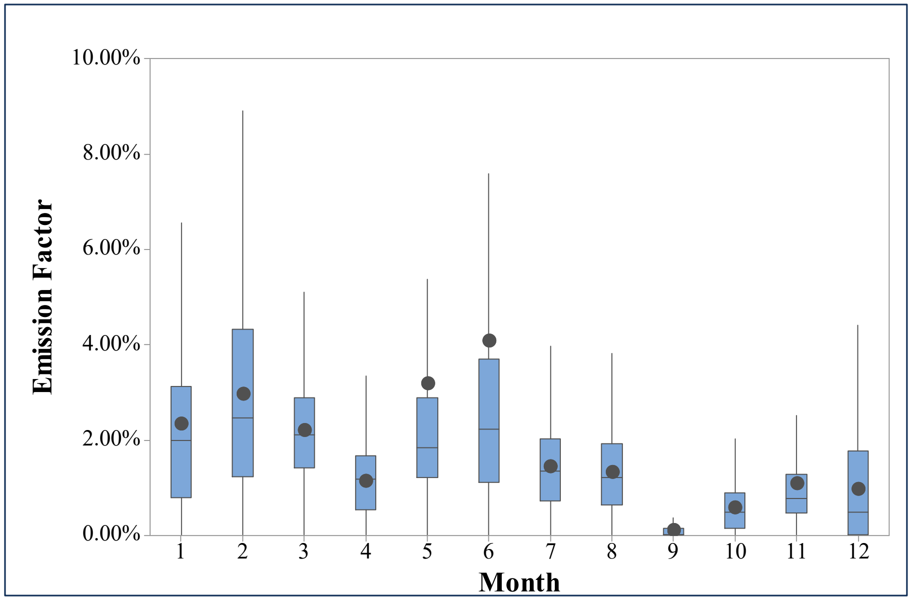
a) T-N load to ASP; b) Flow to ASP; c) N2O-N emission;
d) Emission factor; e) temperature in ASP; f) T-N removed

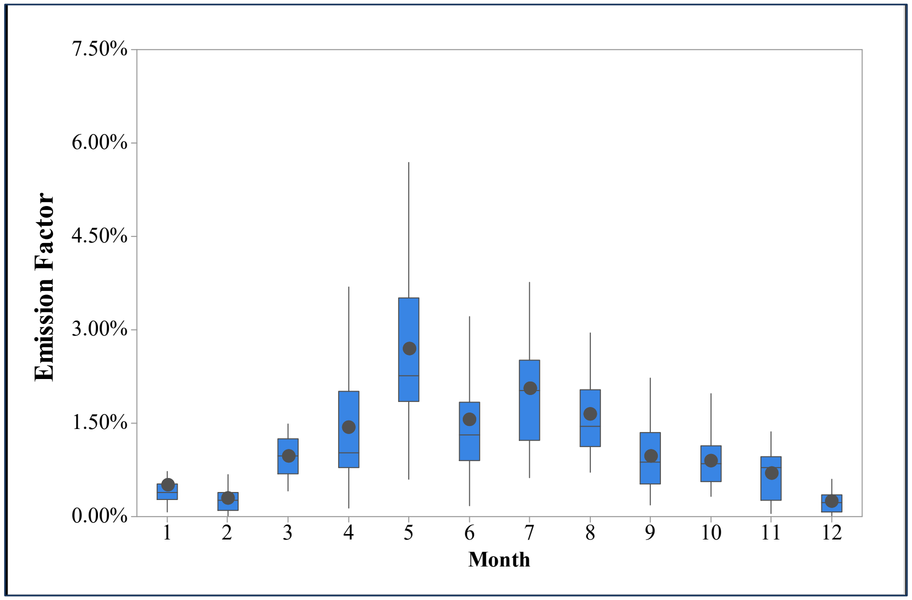


a) b) c) d) e) f)

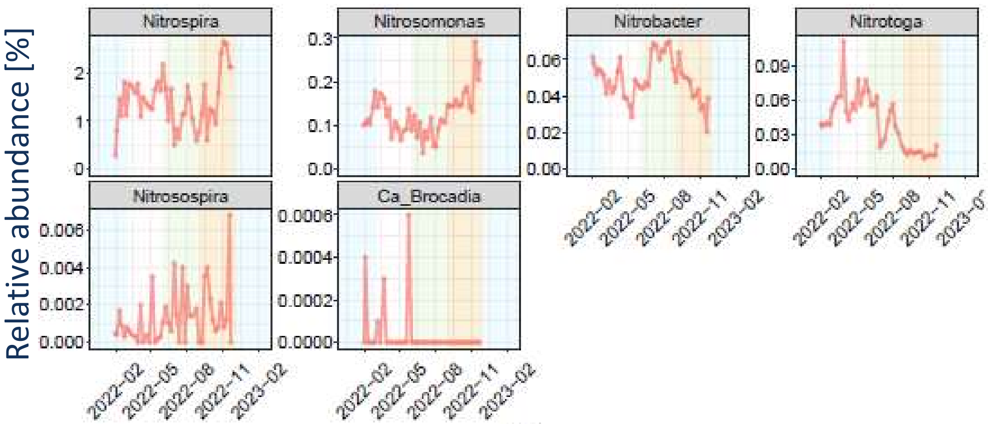
THE RESULTS; SEASONAL VARIANCE

- SPERNAL WWTP
- EGÅ WWTP





RESULTS
CHANGES IN MICROBIAL COMMUNITY @ EGÅ



- MIDAS project at Aalborg University (DK)
- Temporal variance in AOB and NOB´s at Egå WWTP
- Seems to be some variance?
- Following the development

CONCLUSION AND RECOMMENDATIONS

- We still need to measure – though it´s expensive (CAPEX/OPEX) and troublesome
- Standardisation is utmost needed!
- Average EF is not a fair option if used as a regulative instrument (CO2(e)-taxes)
- Research on seasonal variance in the microbial communities and N_2O pathways may provide insights.
- Further research on N_2O formation and emission reduction from e.g.
  - nitrification, denitrification and SND etc.
  - Equalisation-control
  - Aeration-control
  - Control levers
- Cover the tanks/WWTPs?
- Convert and/or reuse N_2O?
- The “molecular sieve”?

ACKNOWLEDGEMENTS

- Pete Vale (Severn Trent)
- Peter Wardrop (Melbourne Water)
- Ziye Dai (Severn Trent)
- Anders Lynggaard-Jensen (Aarhus Vand)
- Erling Brodersen (Aarhus Vand)
- Maiken Bjørn Madsen (Aarhus Vand)
- Jakob Kaltoft (Aarhus Vand)
- Bharani Srinamasivayam (Severn Trent)
- Tom Wardley (Severn Trent)

- Pilot- and full-scale staff
- Sensor and mechanical staff

- ARES partners
- MUDP for funding
- and those who slipped my mind

ADDITIONAL INFO

- Aarhus Vand Ltd: https://www.aarhusvand.com/
- Aarhus ReWater: https://www.aarhusvand.com/collaboration/aarhus-rewater/
- Contact info: morten.rebsdorf@aarhusvand.dk

New developments, catalytic elimination

ANNA KATRINE VANGSGAARD, ENVIDAN AND AMANDA LAKE, JACOBS

inspiring change

ABATEMENT TECHNOLOGIES

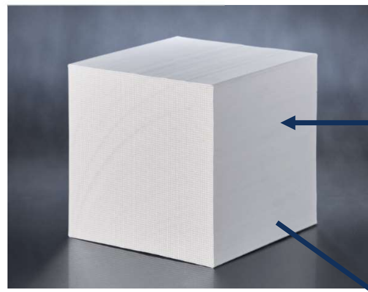
Moving from looking at reductions in the biological treatment to removing in ventilation off-gas as pst-treatment

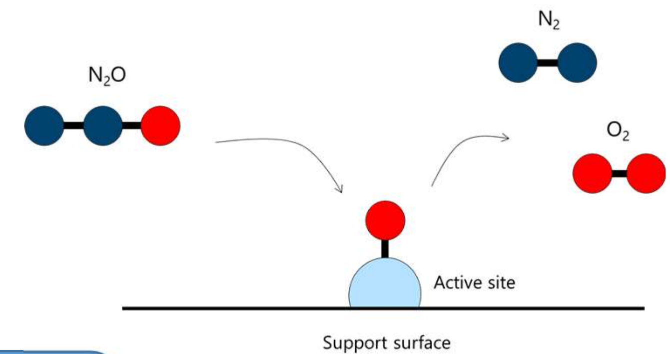
- Thermal destruction
- Catalysis and thermal destruction
- Biologicial conversion
  - Trickling filters
  - Other

All are at feasibility study level with business case scenarios evaluation - both economically and environmental

Catalysis - a simple abatement process

TOPSOE





Gas from Anammox, CAS tanks, …

Ambient temperature

N_2O < 200 ppm

Blower

Heat exchanger

Heater

Catalytic reactor

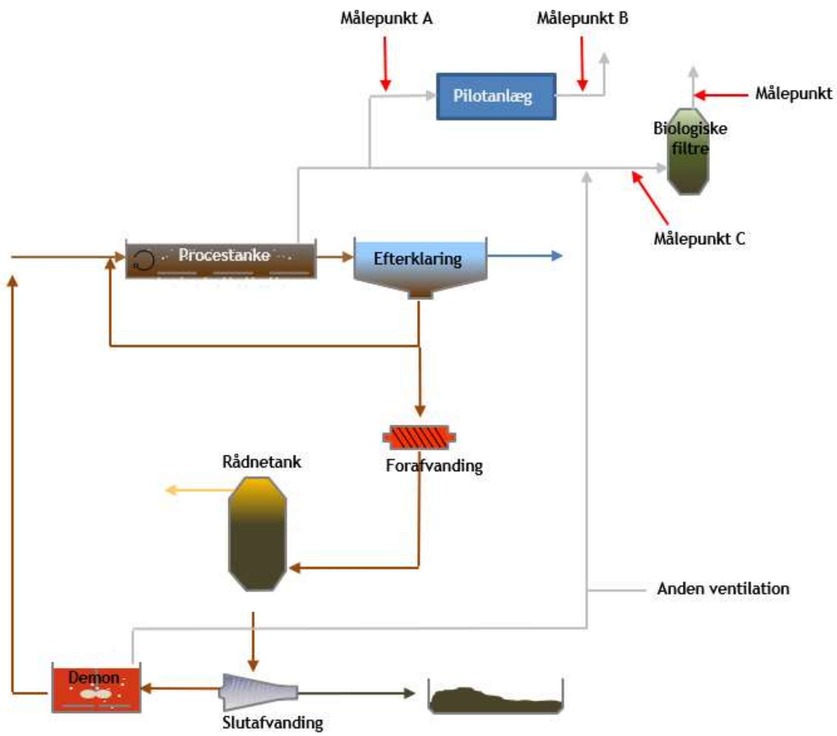
~ 400°C

To stack

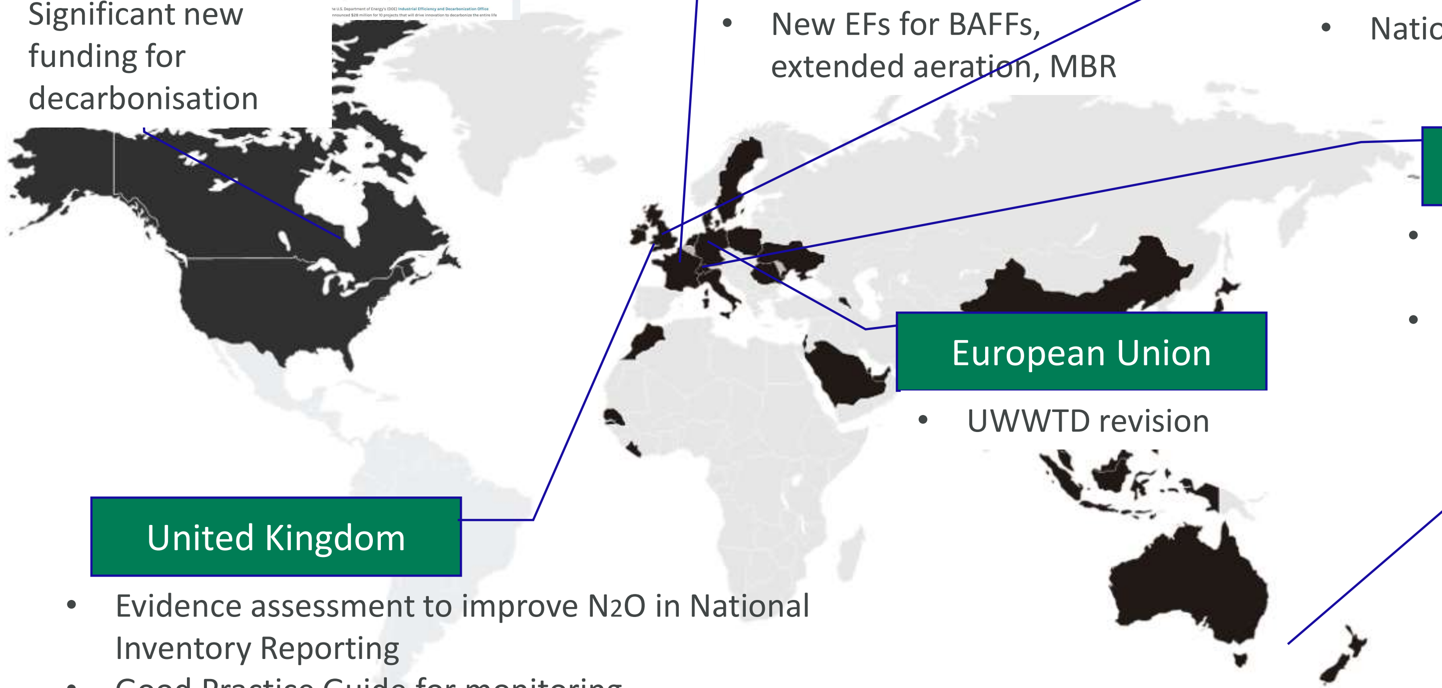
Essentially all N_2O removed

INSTALLATION ON FIRST SITE

IWA the international water association CLIMATE SMART UTILITIES



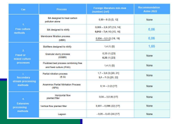
GLOBALLY INTERESTING WORK



United States

- Significant new funding for decarbonisation

France



- New EFs for BAFFs, extended aeration, MBR

Sweden

- National study IVL

Switzerland

- N2O abatement in national offsetting programme
- N stripping, RTO, process control, sidestream treatment

European Union

- UWWTD revision

United Kingdom

- Evidence assessment to improve N2O in National Inventory Reporting
- Good Practice Guide for monitoring
- Implications of TN reduction and existing assets
- Technology trials, net zero WRRFs

Australia and New Zealand

- Collective database
- Monitoring protocol

THANKS FOR LISTENING

For more information or questions do not hesitate to get in contact:

Anna Katrine Vangsgaard,
akv@envidan.dk

Amanda Lake

amanda.lake@jacobs.com

WHAT NEXT: LAST WEBINAR

Climate Smart Water Futures within Planetary Boundaries-
IWA GHG working group

- 03 October

UPCOMING IWA WEBINARS & EVENTS

CLIMATE SMART UTILITIES

Learn more about future online events at
http://www.iwa-network.org/iwa-learn/

the international water association
CLIMATE SMART UTILITIES

شكرآ

Learn more at

http://www.iwa-network.org/iwa-learn/