Characterizing N_2O emissions from WWTPs: The impact of plant size, reactor operation and aeration systems

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INTRODUCTION

Background

- **Nitrous oxide (N_2O)** is a well-known greenhouse gas produced and released in the biological sections of wastewater treatment plants (WWTPs).
- Due to the significant contribution to the carbon footprint of WWTPs, various attempts are currently being made to monitor and minimize N_2O emissions, also through dedicated regulation [1]
- Multiple studies have addressed N_2O emissions from full-scale WWTPs employing different treatment technologies and operational modes [2], focusing on medium and large-sized WWTPs.
- Considerably **less information is available for small-sized WWTPs** (< 20,000 PE), which in Denmark represent 16% to the overall treatment capacity [3].

Objectives

The **objective** of the study was to **evaluate the importance on N_2O emissions** from both main- and sidestream treatment processes **of**:

- WWTP size and/or capacity
- Operational mode of bioreactors (continuous-flow, sequencing batch)
- Aeration systems (bottom and surface aerators)
- Temporary changes and transient conditions in the operation of WWTPs

METHODS

A **measuring campaign** was conducted to **monitor N_2O emissions from three different WWTPs managed by** the same utility (**FORS A/S**, Denmark**)**.

When: June to September 2021, for a period of 14 days in each WWTPs.

How: Two N_2O wastewater sensors from Unisense Environment were used to measure N_2O concentrations in the water phase and emissions to the gas phase were estimated based on the supplier's recommendations [4]. A transportable sensor setup was employed, with a monitoring suitcase containing a mini pc that could be accessed remotely (Figure 1). Data was collected and stored in DIMS.CORE (DHI A/S, Denmark) installed on the mini pc to avoid setup in SCADA. N_2O emissions were monitored in three municipal WWTPs.

Figure 1 – Sensor controller box, monitoring suitcase and equipment for sensor mounting used during the N_2O monitoring campaign.

Where (Figure 2):
Bjergmarken WWTP (125,000 PE) includes biological treatment with BioDenipho™ configuration. N_2O sensors were placed in two aerated tanks (LT2 and LT3) of parallel lines.
Holbæk WWTP (60,000 PE) includes five parallel treatment lines operated in sequencing-batch reactor (SBR) mode with alternating anoxic and aerated phases and sidestream treatment of reject water with ANITA™Mox. N_2O sensors were placed in two parallel sequencing batch reactors (SBR4 and SBR5) and in the ANITA™Mox reactor.
Hvalsø WWTP (11,570 PE) and includes biological treatment with pre-denitrification and nitrification, whereby oxygen is supplied through surface aerators. N_2O sensors were placed before and after surface aerators.

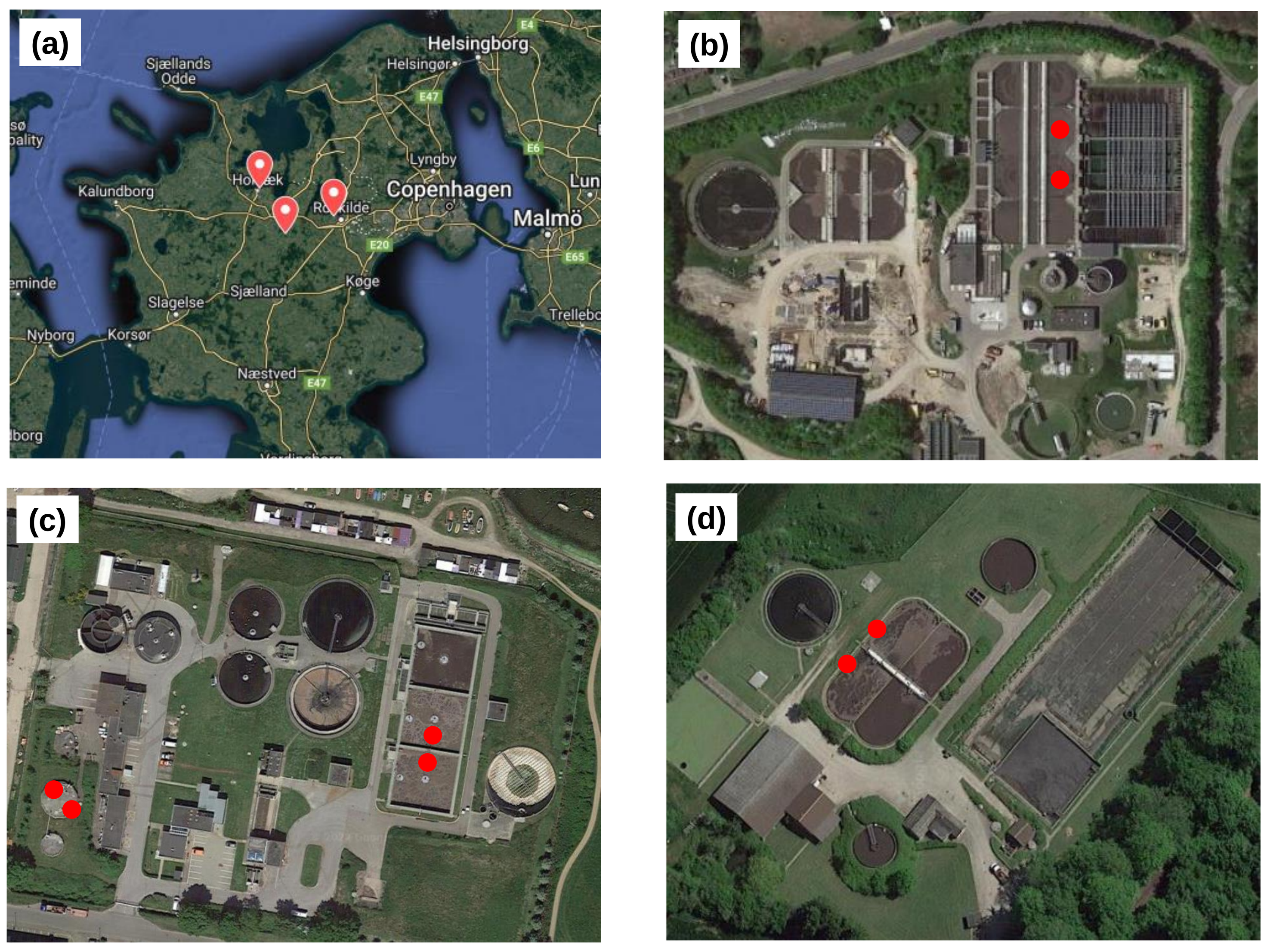

Figure 2 – Location of the monitored WWTPs (a) and aerial view of Bjergmarken (b), Holbæk (c) and Hvalsø (d) WWTPs. Measuring points for N_2O are indicated in red.

RESULTS and DISCUSSION

Bjergmarken WWTP
High variability in N_2O emissions was observed during the monitoring campaign (Figure 3). Very high N_2O emissions were measured in the first part of the monitoring campaign and were associated to temporary changes in process operation (namely inlet pumping, and aeration set points). After stable operation was achieved, short periods of elevated N2O emissions could still be detected. Overall, elevated emissions were observed in less than 10% of the monitoring time, leading to significant differences in emission factors calculated by considering (0.8% N_2O-N/N removed) and neglecting (0.4%) unusually high emissions.

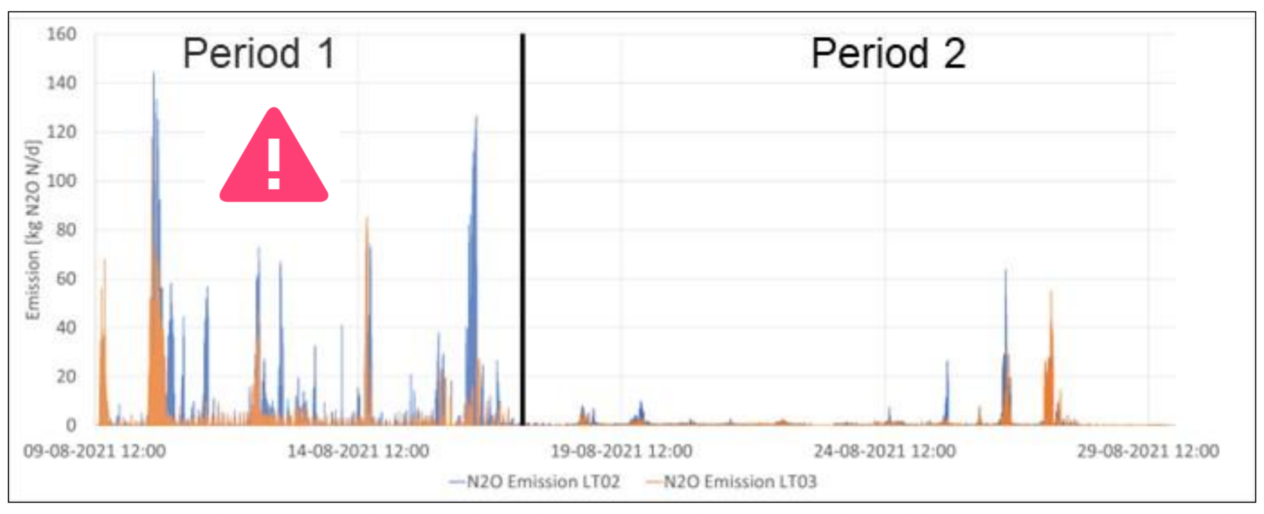

Figure 3 – N_2O emissions in Bjergmarken (process tanks LT2 and LT3) in two separate campaigns.

Holbæk WWTP
N_2O emissions in the two SBR tanks differed by a factor 4. Phase length can result in uneven load concentrations in the tanks and can thus lead to diverting N_2O emissions [2]. Strategies of load equalization could minimize emissions. Interestingly, low N_2O emissions from ANITA™Mox were observed (0.7-0.8%) as compared to other reject water treatment systems (e.g., 5.5% for DEMON; [2]). Continuous aeration and inflow, together with the use of biofilm systems, can be thus hypothesized as strategies for emission reduction in sidestream treatment [5].

Hvalsø WWTP
Monitoring results indicated **considerably low N_2O emissions** (0.00005% N_2O-N/N removed). This observation is of relevance to assess strategies supporting centralized treatment in medium- and large-sized WWTPs.

The overall results from the monitoring campaign, including calculated N_2O emission factors for main- and sidestream processes in the three WWTPs, are summarized in Table 1.

Table 1 – N_2O concentrations and emission data from the tree WWTPs managed by FORS A/S

Location	N_2O concentration [mg/L]	Daily emission CO_2eq [t CO_2/d]	Yearly emission CO_2eq [t CO_2/y]	N_2O-N/TN_{inlet} [%]
Hvalsø	0.0023 (± 0.0014)	0.02	0.009	0.00005
Holbæk				
SBR4	0.046 (± 0.082)	0.38	65	1.0
SBR5	0.0096 (± 0.0096)	0.09	16	0.2
ANITA™Mox	0.19 (± 0.12)	0.96	350	0.7-0.8
Bjergmarken				
Period 1 (P1)	0.20 (± 0.37)	31.6	5394.1	5.7
Period 2 (P2)	0.024 (± 0.061)	4.2	723.8	0.8
90^{th} percentile (P2)	0.014 (± 0.0074)	2.0	345.5	0.4

CONCLUSIONS

The **small-sized WWTP showed very low N_2O emissions** as compared to the other WWTPs investigated. While it may not be sufficient to draw definitive conclusions, this finding seems to indicate that small-sized WWTPs are overall low contributors to greenhouse gas emissions.

N_2O emissions from WWTPs showed considerable temporal and spatial variability, highlighting the need for detailed monitoring and supporting the refinement of emission factor calculation methods.

Transient periods with anomalies in influent loading and changes in WWTP operation (including equipment malfunctioning) may lead to **increased N_2O** emissions and should not be neglected in the carbon footprint evaluation of a WWTP.

While long-term measurements are certainly beneficial, **target monitoring during shorter periods can be a cost-effective** strategy to evaluate emissions in multiple location and identify underlying critical factors.

References: [1] Folketinget 2020 Klimaplan for en grøn affaldssektor og cirkulær økonomi. aftaletekst.pdf (regeringen.dk). [2] Vangsgaard, A.K. & Madsen, J.A. 2020 MUDP lattergaspulje – Dataopsamling på måling og reduktion af lattergasemissioner fra renseanlæg. [3] Miljøstyrelsen 2017 PULS-data fra alle renseanlæg og punktudledninger i Danmark. [4] Unisense 2020 N_2O Wastewater System Brugermanual, Unisense Environment A/S version marts 2020 downloaded 12/01 2022. [5] Christensson, M., Ekström, S., et al. 2013 Experience from start-ups of the first ANITA Mox plants. Water Science and Technology, 67(12), 2677-2684.

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