Case Study:

Measurement reveals massive N_2O emissions in the SBR: 99% reduction through targeted process optimization

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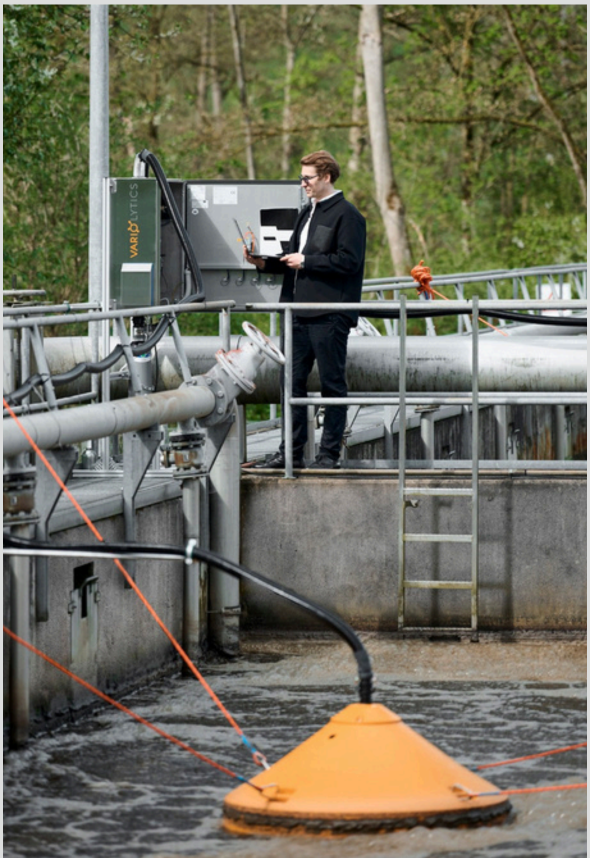
The case study is based on the master's thesis:
"Greenhouse gas accounting of the Nesselwörth wastewater treatment plant according to DWA-M 230 – Development of a climate balance and process optimization", Robin Weiblen, August 2025, Universities of Esslingen, Nürtingen, Reutlingen and Stuttgart.

Key facts

- Savings of up to 5,000 tonnes CO_2 equivalents are possible.
- Implementation within six months.
- Human-in-the-loop optimization supported by cloud-based data. Visualization in the Insight app.



1. Introduction

Greenhouse gas emissions in municipal wastewater treatment plants mainly arise from biological conversion processes. In addition to carbon dioxide (CO_2) and methane (CH_4), nitrous oxide (N_2O) plays a key role. Due to its high global warming potential, even small concentrations of N_2O can significantly contribute to the climate impact of wastewater treatment.

In practice, emissions are often assessed using emission factors from the literature based on average values. However, such generalized approaches can only partially reflect site-specific operating conditions and process dynamics. This is particularly critical for special treatment processes, where large uncertainties can occur.

The sequencing batch reactor (SBR) investigated in this study represents a special form of sidestream biological treatment of process water. Not all plants use SBR systems for centrate treatment. In addition, these reactors differ significantly in their operation and control strategies.

Initially, greenhouse gas emissions of the plant were estimated using a literature-based emission factor derived from the overall nitrogen removal rate. Based on this, emissions of 1,397 t CO_2e per year were calculated for the mainstream aeration tank, while only 255 t CO_2e per year were estimated for the sidestream SBR.

Subsequently, real emissions from the SBR system were measured directly. For this purpose, emissions of N_2O, CO_2, and CH_4 were recorded using an EmiCo lite system equipped with two measurement hoods installed on the water surface.

The measurement data revealed an unexpectedly high emission contribution from process water treatment. For the investigated SBR, actual annual emissions of 5,318 t CO_2e were measured. This value significantly exceeded the literature-based estimate. The analysis also showed that up to 25% of the incoming nitrogen load was released as nitrous oxide, while literature values typically report up to 2%.

These results highlight the importance of site-specific measurements as a basis for reliable emission assessment and targeted mitigation measures in biological wastewater treatment

2. Measurement and setup of the investigated biology

Measurement in the SBR for sidestream treatment

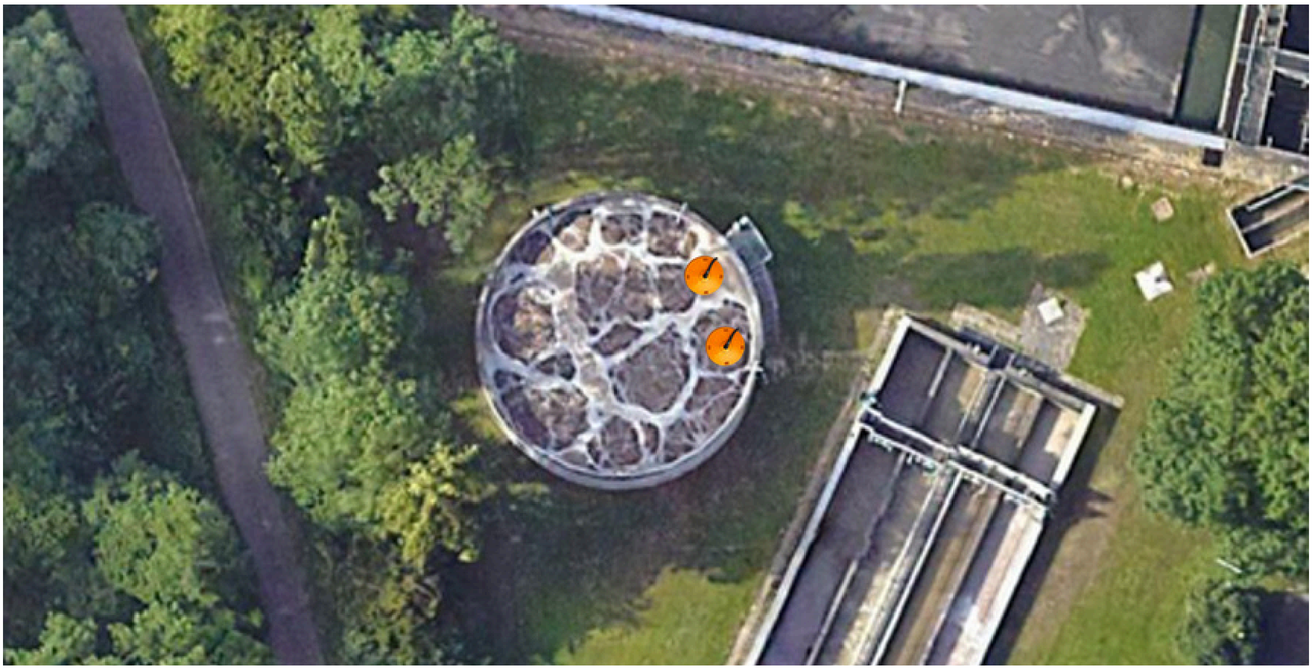


Figure 1: Aerial view of the investigated SBR with schematic hood placement.

In this case, the SBR was used not only for treating nitrogen-rich process water from sludge dewatering but also for treating external industrial wastewater.

The SBR process is a special form of intermittent nitrification and denitrification. All biological treatment steps as well as sedimentation take place in a single tank. The treatment process follows a defined time sequence. Influent and discharge occur discontinuously, resulting in cyclic alternation between aerobic and anoxic phases.

Measurement system and principle

Gaseous emissions were measured using the EmiCo lite system from Variolytics GmbH. Two floating plastic hoods were installed on the SBR tank to capture gases released during aeration. The off-gas collected under the hoods was continuously extracted and transported via heated tubing to the analyzer.

Inside the system, a sample of the gas stream from each hood is alternately drawn and analyzed using a membrane pump. Gas analysis is performed continuously using a non-dispersive infrared (NDIR) analyzer to measure nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2). Oxygen concentration is measured using an electrochemical sensor. In addition, off-gas temperature and volume flow are recorded.

The system is specifically designed for wastewater treatment plants and enables continuous monitoring of greenhouse gases in biological reactor off-gas. One EmiCo lite system can be connected to two gas collection hoods, with alternating sampling between the measurement points.

Emission rates are calculated based on measured gas concentrations and recorded volume flow, taking into account temperature-dependent gas density.

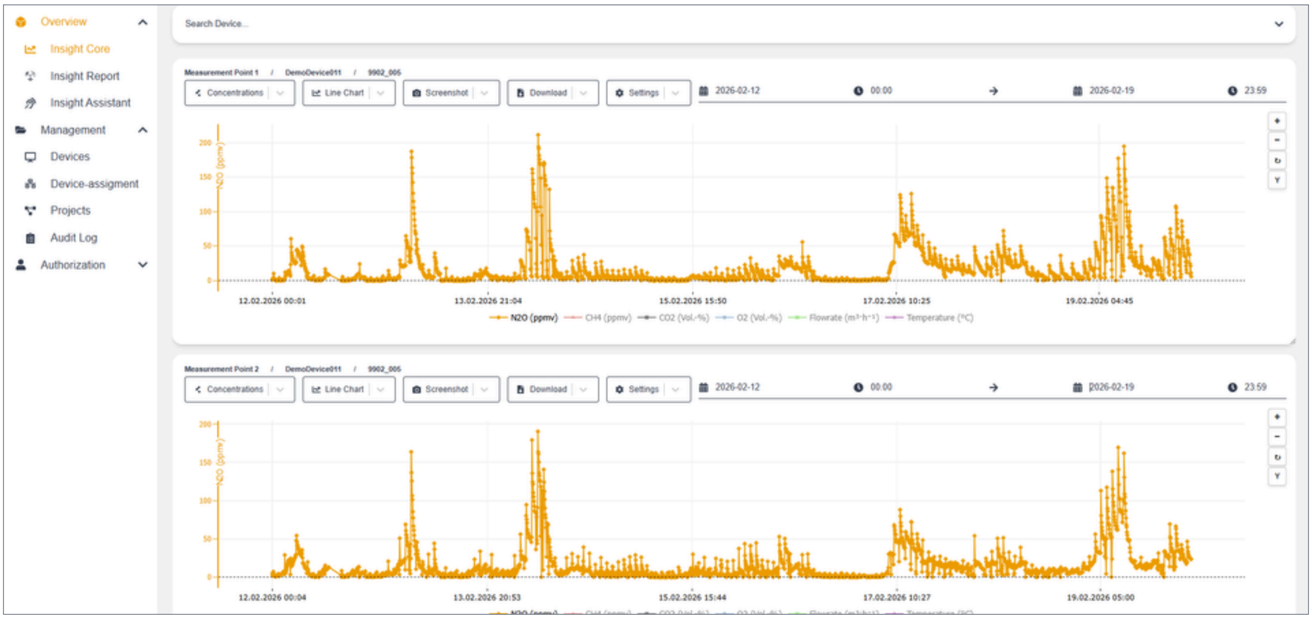


Figure 2: Screenshot of the current version of the Variolytics Insight software.

Measurement data were transmitted in real time to the Variolytics cloud and could be accessed and analyzed via the Variolytics Insight software using a standard browser. The application provides a clear visualization of emission data from both measurement points, enables export of data in .xlsx format, and allows calculation of cumulative N_2O and CH_4 emissions over defined time periods, weighted by their global warming potential.

The Insight application provides direct visibility into emission dynamics within the process. This is particularly valuable for process optimization. In this case, several operational parameters were adjusted, and their effects on nitrous oxide emissions could be monitored immediately via the measurement system.

3. Results

The measurements relevant to this case study were carried out between the end of March and June 2025. The emission measurement campaign included a representative two-week period in spring for quantitative assessment. This was followed by optimization trials for emission reduction extending into June.

The analysis of temporal emission patterns showed that nitrous oxide was mainly formed during anoxic denitrification phases. It was then released at the beginning of subsequent nitrification phases due to aeration. Based on this, three operational approaches to reduce emissions were investigated. These included extending denitrification duration by reducing the number of daily cycles, reducing the dosing rate of the external carbon source (glycerin), and increasing the COD/N ratio during denitrification.

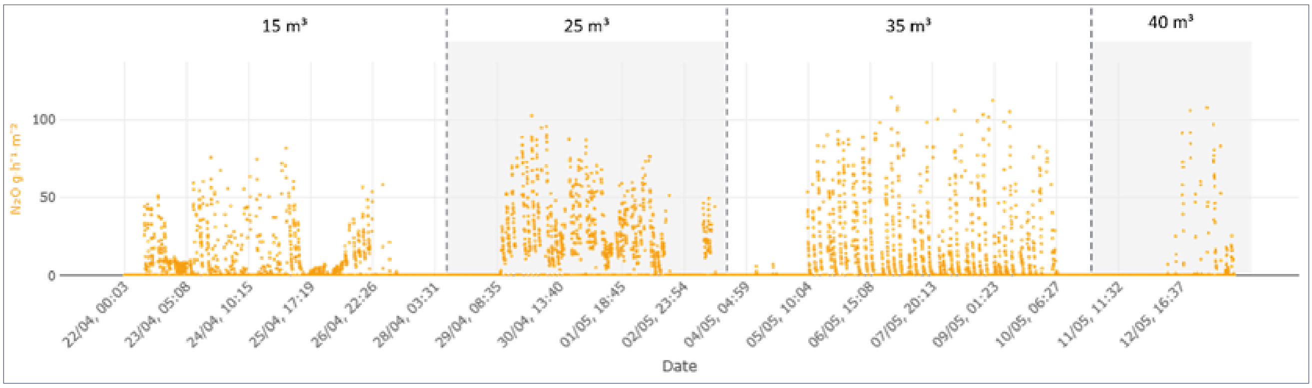


Figure 3: Nitrous oxide emissions at different cycle numbers and lengths.

In a first approach, it was tested whether reducing the number of cycles and extending aerobic and anoxic phases would reduce emissions. For this purpose, the batch volume per cycle was gradually increased from 15 m³ to 40 m³. This adjustment did not lead to a reduction in nitrous oxide emissions (see Figure 3).

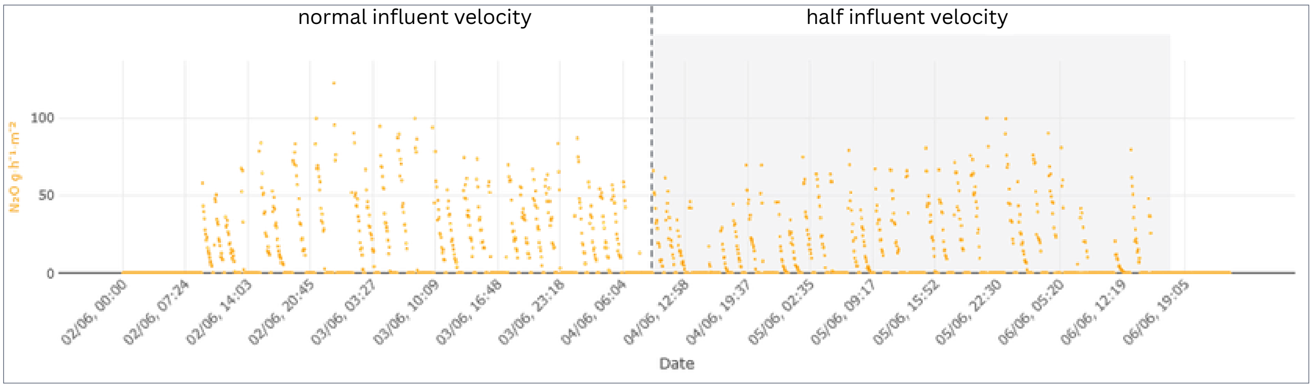


Figure 4: Nitrous oxide emissions with modified carbon dosing rate.

Next, it was examined whether short-term COD peaks caused by carbon dosing promoted N_2O formation. The dosing rate of the external carbon source was reduced by half. Despite extended denitrification phases, this approach did not reduce emissions. This indicates that dosing peaks were not the primary influencing factor in this case.

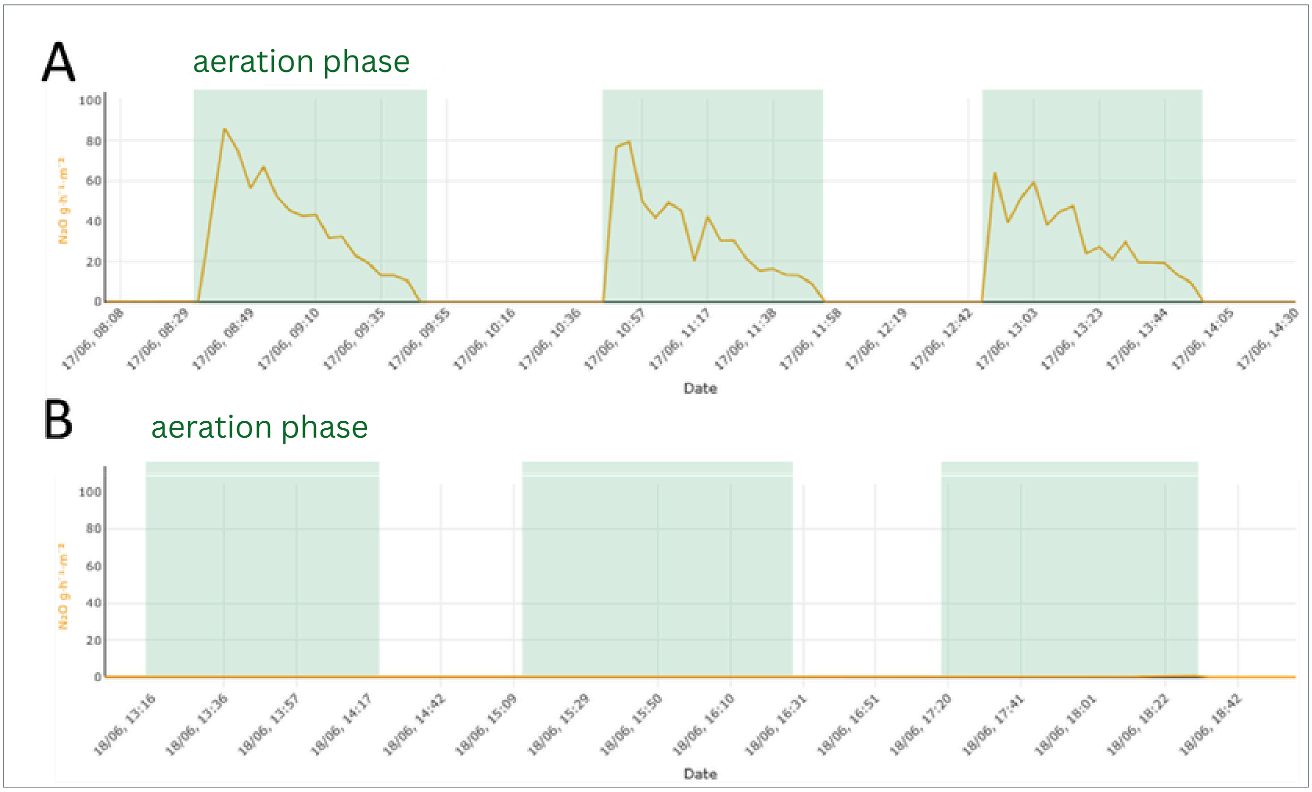


Figure 5: Nitrous oxide emissions at original (A) and increased carbon dosing (B).

A significant reduction in emissions was only achieved by increasing the COD/N ratio during denitrification. Increasing the carbon dosage from 5 L to 8 L per cubic meter of centrate resulted in a reduction of nitrous oxide emissions by up to 99%. Further optimization showed that a dosage of approximately 6 L per cubic meter was already sufficient to achieve a comparable effect.

The high relative reduction must be interpreted in the context of initially high emissions in the investigated SBR. The results are therefore specific to this process and cannot be directly transferred to other plants or SBR systems.

4. Summary

This case study shows that generalized emission factors can substantially underestimate actual greenhouse gas emissions in biological wastewater treatment. Only direct measurements combined with detailed analysis of operational emission patterns allow identification of root causes and development of effective mitigation measures.

In this case, data-driven optimization of denitrification conditions led to an almost complete reduction of nitrous oxide emissions in the investigated SBR, with reductions of up to 99%. This corresponds to savings of approximately 5,000 tonnes of CO_2 equivalents. Although the results cannot be directly transferred to other plants due to the specific operating conditions, the study demonstrates the significant potential of site-specific process optimization for climate strategies in municipal wastewater treatment.

A key factor was continuous emission monitoring and immediate availability of measurement data through the Insight application. This enabled rapid evaluation of operational adjustments in real time and supported an iterative, data-driven optimization process.

The case study provides a practical example of how digital emission measurement and process control can contribute significantly to the decarbonization of wastewater treatment.