Climate impact from nitrous oxide emission - a Danish case

A general development trend in the optimization of wastewater treatment plants (WWTPs) operation is to strive for energy neutrality or even net energy production through energy savings and increased biogas production. This is the case for all larger Danish plants as well as for many other European WWTPs. Yet, looking at the environmental and climate impacts, ample scientific studies emphasize the importance of not only looking at energy use but also taking the emission of the greenhouse gas nitrous oxide (N_2O) from the WWTPs into account.

In this technical note, the importance and role of N_2O at WWTPs is briefly summarized and based on 2-years of data from Danish WWTPs, an estimate is given of the price for monitoring and the CO_2 shadow price for minimizing the N_2O emission. In Denmark process emission regulations are building and drives a gradual shift in focus from energy neutrality toward climate neutrality. The case thus serves as an example of how government or sectoral investments can strongly boost the shift towards climate neutrality in the water sector.

Background

One of the most important roles of WWTPs is the removal of nitrogen and phosphorous based nutrients, which otherwise, in large concentrations, leads to eutrophication of the receiving water bodies. In the later decades, EC's nitrates directive and the Danish national water environmental strategies have hence led to a significant reduction of nutrients in the WWTP effluents.

The removal of nitrogen is facilitated by microorganisms which transform ammonium (NH_4^+) to nitrate (NO_3^-) and subsequently to free molecular nitrogen (N_2), which is emitted to the atmosphere. There are several intermediate chemical compounds and potential by-products in the reaction path from NH_4^+ to N_2, and one of these is N_2O. If the operation of the WWTP is optimized in the right ways, there is no significant emission of N_2O, as the compound is quickly transformed into other nitrogenous compounds. However, under certain operational conditions, an accumulation of N_2O in large concentrations may occur. This leads to emissions that contribute significantly to the total climate impact (carbon footprint) of the plants.

Nitrous oxide is 298 times stronger greenhouse gas than CO_2 and several case studies have shown that the climate impact from N_2O emission is comparable to, or even larger than, the climate impact from the energy used at WWTPs. When the energy consumption is minimized, it becomes even more important to take N_2O emission into account – especially because single-sided energy optimizations can be shown to increase the emission of N_2O. Furthermore, a substantial part of the electricity in the future will be based on green sources, whereby the climate impact fraction from N_2O will increase compared to present values. Many studies indicate that there are strong variations of the N_2O emissions among the WWTPs. Recent efforts have expanded the knowledge of N_2O emissions from Danish WWTPs, but it is necessary to further monitor the N_2O emission at individual plants and estimate the full potential for optimizations and climate impact minimizations.

Energy neutrality vs. Climate neutrality

An energy neutral WWTP is a plant producing more energy than what is consumed, or a plant that is at least self-sufficient with sustainable green energy. A climate neutral WWTP is a plant with no or negative carbon footprint of operation where the energy and process related greenhouse gas emissions (fossil CO_2, CH_4 and N_2O) are considered in the total carbon footprint. Fig. 1 compares a present 2020 and future 2030 scenario of the contribution to the CO_2 emission from a WWTP. Energy will increasingly stem from sustainable sources based on green technologies that significantly lower the CO_2 emission from energy consumption. N_2O will thus be a major contributor to the CO_2 emission from WWTPs and turning to reduction of N_2O emission instead of energy production will thus be a key step to achieving climate neutral wastewater treatment.

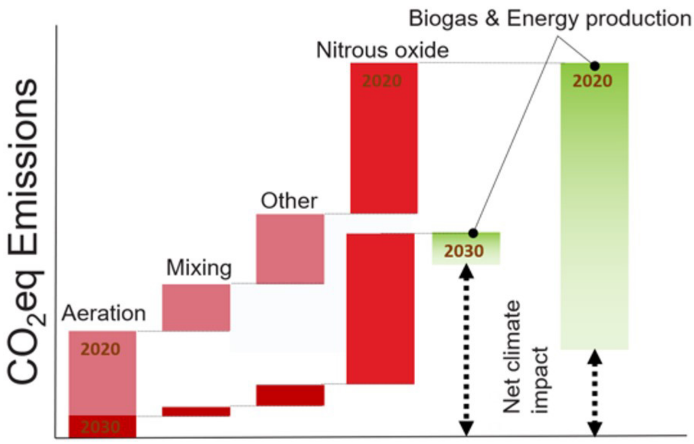

Figure 1

Distribution of Danish WWTPs

In Denmark >700 WWTPs are treating a total of 7.3M person equivalents of wastewater yearly totaling to 29.630 Ton N. Figure 2 shows a size distribution of the plants, and it is worth noticing that there is a long tail of very small plants and only a few larger and medium sized plants.
The bulk part of the Danish wastewater is treated at the larger WWTPs, and the 30 largest plants account for 53% of the wastewater treatment, and the 50 largest plants account for 66% of the treatment.

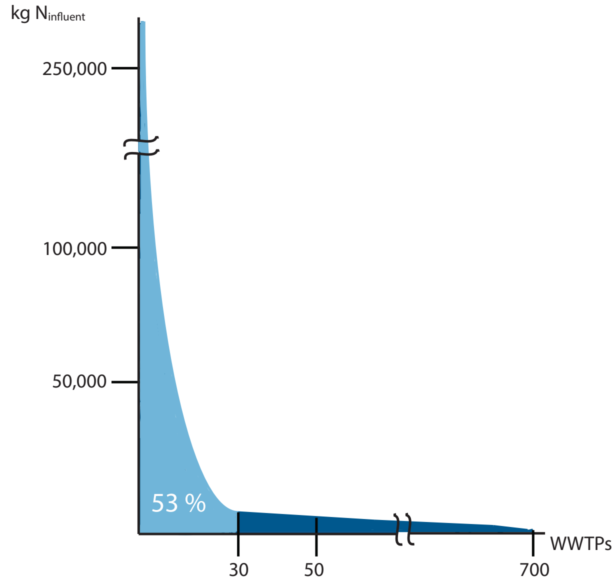

Figure 2: Size distribution of Danish WWTPs.

Emission from the large Danish WWTPs

To quantify the N_2O emission from Danish WWTPs, the Danish Environmental Protection Agency (EPA) launched a 2-year project to collect data on N_2O emissions from WWTPs. In the period from 2018-2020, the N_2O emission from nine different plants was monitored and data shows that an average of 0.84% of the total influent N is released as N_2O. The total climate impact can thus be calculated, which is shown in Figure 3. Danish and international case studies have shown a span in the N_2O reduction potential ranging from 25 – 90%, when the plants are continuously monitored for N_2O emission and the data are used as input for relevant optimizations of the plant operation.

		30 largest	50 largest	Total
N_2O emission (Ton)		208	257	391
CO_2-eq (Ton)		61.848	76.540	116.444
Reduction potential (Ton CO_2-eq)	Low – 40%	24.739	30.616	46.577
	Mid – 60%	37.109	45.924	69.866
	High – 90%	55.663	68.886	104.799

Figure 3: Climate impact from N_2O emission from Danish WWTPs

The economy of climate optimizations

Installing a Unisense N_2O Wastewater System consisting of two sensors and a control box gives rise to initial investment costs of approximately 12k €. Such a system would be suitable for monitoring at a plant size of 100.000 PE, which is a good average size in the fraction of larger Danish WWTPs. Depreciating the control box in a 5-year period and adding installation, continuous service, maintenance, calibration and sensor head exchange, the yearly expenses sum up to approximately 13.8k € for a WWTP which chooses to install a N_2O monitoring system. For a 100.000 PE plant, a carbon shadow price can thereby thus be calculated, which is shown in the table in Figure 4. A 60% reduction of N_2O emission was assumed.

N_2O emission (ton)	5
CO_2-eq (ton)	1566
CO_2 saving	940
Yearly expenses (€)	13803
CO_2 shadow price (€/ton)	15

Figure 4: Shadow price for reduction of N_2O emission

Conclusion

Compared to many other climate investments, a low carbon shadow price can be achieved by monitoring and mitigating the N_2O process emission from WWTPs. In a Danish perspective with more than half of the Danish wastewater being treated at the 30 largest plants, an initial investment of about 400k € would allow monitoring and subsequent mitigation. With the approval of the Danish parliament agreement on the climate action plan, that will increase CO_2 reductions by 1.4 million tonnes, the water sector with contribute significantly to this goal cost-effectively.