NO LAUGHING MATTER – GLOBAL LESSONS FOR NITROUS OXIDE

Hayden Porter[1], Amanda Lake[1], Ariane Brotto[1], Aprilia Vellacott[1], Jose Porro[2], Mikkel Andersen[3]

[1]Jacobs, [2]Cobalt Water Global, [3]Unisense Environment

[1]Email: hayden.porter@jacobs.com
[1]Email: amanda.lake@jacobs.com
[1]Email: ariane.brotto@jacobs.com
[1]Email: aprilia.vellacott@jacobs.com
[2]Email: jose.porro@cobaltwater-global.com
[3]Email: mha@unisense.com

ABSTRACT (500 WORDS MAXIMUM)

While water and wastewater sector greenhouse gas emissions make up just a fraction of New Zealand's total emissions, they contribute significantly to the emissions footprints of our local councils who operate these assets. Councils are responding to the global climate crisis and New Zealand's Net Zero Carbon Act by setting targets to reduce emissions; the three largest councils in New Zealand are targeting net zero emissions by 2050. Focus on direct process emissions of nitrous oxide and methane from wastewater treatment plants is becoming a focus as these emissions can contribute 50% or more of a council's total emissions.

Jacobs, Cobalt Water Global and Unisense Environment have been leading work globally on process emissions. This paper summarises our work in Europe, framed by the current state of science and recent Intergovernmental Panel on Climate Change (IPCC) guidelines and ongoing research. Using case studies from Denmark, the United Kingdom, and Netherlands we highlight where progressive European utilities are taking action to understand, quantify and mitigate process emissions through national and utility level programmes. A focus across the regions in the case studies has been on national/sector-wide emission factors and considering varied treatment types. Mitigation through facility level monitoring and evidenced based approaches show a pathway to contributing toward utilities' net zero goals. We discuss synergies and opportunities to undertake similar work here to deliver climate action in the water sector for New Zealand.

KEYWORDS

Nitrous oxide, greenhouse gas emissions, mitigation, carbon, net zero

PRESENTER PROFILE

Hayden is a wastewater process engineer for Jacobs, he has worked in both Canada and New Zealand designing wastewater treatment plants and has a keen interest in the climate impact of wastewater treatment processes.

INTRODUCTION

While water and wastewater sector greenhouse gas emissions make up just a fraction of New Zealand's total emissions, they contribute significantly to the emissions footprints of our local councils who operate these assets. Councils are responding to the global climate crisis and New Zealand's Net Zero Carbon Act by setting targets to reduce greenhouse gas (GHG) emissions. The three largest councils in New Zealand are targeting net zero emissions by 2050 (Christchurch City Council by 2045) and making significant reductions by 2030. Direct process emissions of nitrous oxide (N_2O) and methane (CH_4) from wastewater treatment plants (WWTPs) is becoming a focus as these emissions can contribute 50% or more of a council's total emissions.

Globally water utilities are committing to emissions reductions targets to play their part in global efforts to mitigate the effects of climate change. A group of utilities under Water UK were the first to commit to reaching net zero emissions by 2030 and have reported their baseline carbon emissions and ambition for mitigation in public net zero road maps. In our region a group of 13 water utilities across Australia and Watercare have joined the UK utilities in making commitments to reach net zero emissions under the United Nations (UN) Race to Zero campaign.

Where the electricity grid is relatively "green" such as here in New Zealand and in parts of Europe the relative contribution of process emissions from wastewater treatment make up a greater proportion of a utility's emissions. These present challenges on utilities' paths to net zero – in particular monitoring and mitigating these process emissions. Utilities in Denmark, Switzerland, the Netherlands, and the United Kingdom (UK) are showing considerable ambition and progress in this area.

CH_4 and N_2O are the main GHGs emitted during the collection and treatment of wastewater and in the on-site treatment and management of wastewater sludge residuals. These direct process emissions are reported as part of country inventories of national emissions. Of particular importance with these GHGs is their relative warming impact (global warming potential, GWP). The GWP, as reported in the Intergovernmental Panel on Climate Change, IPCC, in their fifth assessment report (AR5) of CH_4 is 28 and of N_2O is 265 relative to carbon dioxide which has a GWP of 1. As a result, these process emissions may form a very substantial part of a facility's operational carbon emissions.

This paper focusses on N_2O emissions which are predominantly associated with nitrification and denitrification processes within liquid stream processes.

This study provides a review of utilities taking action in quantifying and mitigating N_2O emissions – with case studies from three countries. It provides an overview of current global practice in accounting for N_2O emissions, including the 2019 International Panel on Climate Change (IPCC) refinement and locally the Water New Zealand Carbon Accounting Guidelines for Wastewater treatment: CH_4 and N_2O (Water NZ, 2021). It considers current practice in monitoring at country and facility levels and discusses how these efforts inform mitigation work.

The study included:

- Overview of N_2O production and emissions from WTTPs and the state of research and practice to understand EFs
- Review of existing N_2O EFs adopted at international (IPCC) and country-level
- Discussion of the programmes being implemented to address the challenges in quantifying emissions given the reported range and variability in N_2O EFs globally, with case studies and lessons from the United Kingdom Water Industry and from progressive utilities in Denmark and the Netherlands
- Recommendations for utilities in utilising existing emissions methodologies and developing their own strategy to monitor and mitigate emissions, aligned with global best practice.

The IPCC is the international body for assessing the science related to climate change. It was created by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) in 1988 to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation (IPCC, 2018). The IPCC provides internationally agreed methodologies for measuring national GHG emissions from the different sectors of the economy based on published research conducted around the world.

RESULTS

PRODUCTION OF NITROUS OXIDE

The production pathways of N_2O in wastewater treatment are highly complex. It occurs as a by-product of nitrification through two distinct pathways, or as an obligatory intermediate of denitrification (Figure 1), in addition to abiotic production to a lesser extent. In general, the importance of one pathway over another will depend on the environmental and operational conditions of the treatment process.

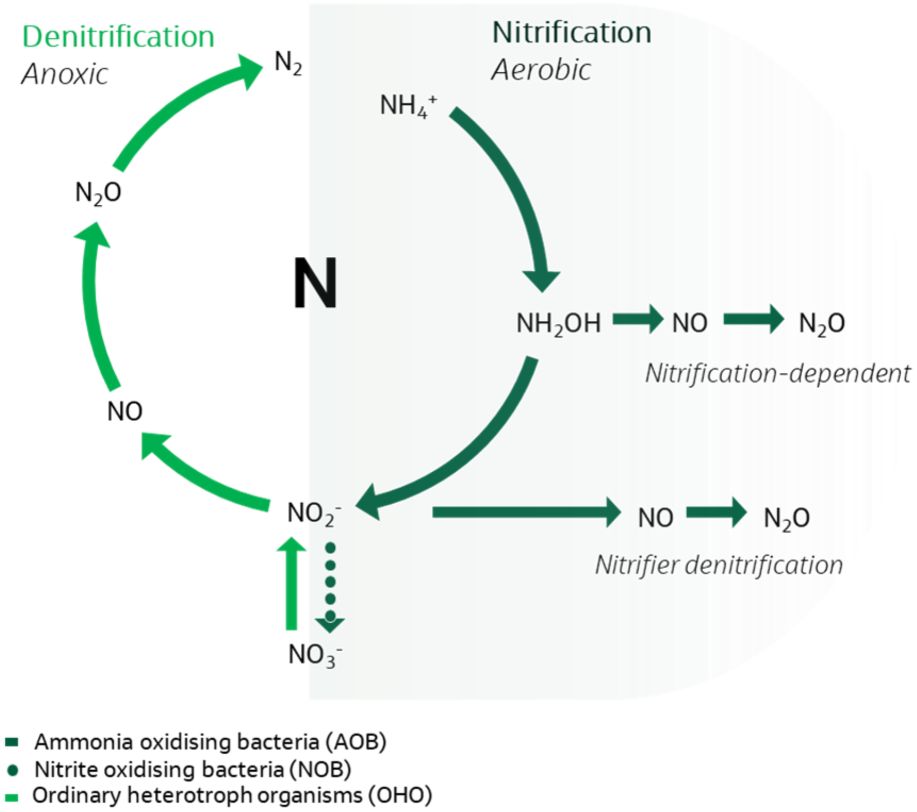


Figure 1: *Pathways of nitrous oxide production in the nitrogen cycle.*

EMISSION FACTOR METHODS

Within the water sector, the IPCC Guidelines (2019 Refinement Volume 5 – Waste, Chapter 6 – Wastewater Treatment and Discharge. Volume 1: General Guidance for Reporting) provide an overview of GHG inventories and provides guidelines for the reporting of N_2O from wastewater treatment works. The IPCC Guidelines include sections covering uncertainties, consistency, quality assurance and quality control and verification.

The IPCC Guidelines provides the methodology for calculation of emission rates for quantifying GHG emissions using an emission factor (EF) and using activity data (AD) relevant to the particular activity. The IPCC provides a three-tier level methodology to select the EFs and activity data which is set out below:

- Tier 1 (good practice) method: uses default values for the EF and activity parameters. It is considered good practice for countries with limited data.
- Tier 2 (good practice) method: uses a country-specific EF based on field measurements and country-specific activity data.
- Tier 3 (advanced) method: uses a country-specific method – for example, based on plant-specific emissions from large WWTPs. It is for countries with good data and advanced methodologies, where direct measurement methods provide a more accurate measurement from each facility.

The three-tier method represents the level of methodological complexity and data requirements. A progression from Tier 1 to Tier 3 represents an increase in confidence in the GHG estimates, and generally requires more extensive resources for site measurement and data collection. Developing sufficient data to support emissions assessments at Tier 2 (country- specific) and Tier 3 (plant-specific) is the current focus for a number of utilities in Europe who are intent on accurate measurement to facilitate mitigation of N_2O across their treatment works.

ASSESSMENT OF EMISSION FACTORS

After over two decades of research and N_2O monitoring campaigns at full scale WWTPs, there has been scientific consensus that applying a single emission factor (e.g. IPCC Tier 1 as global factor or Tier 2 as country-level factor) is challenging.

Key reasons for this are that:

- Significantly high spatial and diurnal variability is observed in N_2O emissions across all studies. With recent understanding achieved through long term monitoring campaigns in particular; it is recognised that short term monitoring campaigns may not inform the range of emissions which are generated. (Vasilaki et al., 2019; Ni et al., 2015; Pan et al., 2016; Gruber et al., 2021)
- A single emission factor does not allow for the recognised differences between different process types and operating conditions. Specific plants and process configurations with sudden operational changes have been associated with higher N_2O emissions (Vasilaki et al., 2019; Pijuan et al., 2014; Pan, et al., 2016).
- A single EF does not allow for geographical and climatic differences – it has been shown that N_2O emissions from tropical climate zones are higher than from temperate zones, as a factor of temperature and bacterial activity (Brotto et al., 2015).

Recognising the variability in EFs, work globally has included compiling EFs from monitoring campaigns undertaken throughout the world. This study built on the extensive compiled EFs developed by Vasilaki et al. (2019) in Figure 2 which shows EFs of nitrous oxide in mainstream biological nutrient removal (BNR) and non-BNR processes ranging from 0.001% (or 0.00001 kgN_2O-N/kgN load) of incoming total nitrogen (TN) for an Activated Sludge Plant (ASP) to 12% (0.12 kgN_2O-N/kgN load) of incoming TN for a Plug-Flow Reactor (PFR) with anoxic/aerobic zones (Figure 2). A study published this year by Hua et al. (2022) includes an even larger dataset with similar variability in EFs presented in terms of kgN_2O-N/kgN removed. Significant variability in the duration and methods utilised is present in the published literature which makes comparison and analysis of the data points challenging.

Note that in Figure 2 the graph includes only those reported in kgN_2O-N/kgN load. Shaded green areas indicate EFs from non-biological nitrogen removal processes (non-BNR). Abbreviations used are as follows: ASP: activated sludge plant, AO: anaerobic-oxic activated sludge process, A2O: anaerobic-anoxic-oxic activated sludge process, BAF: biological aerated filter, CAS: conventional activated sludge process, EA: extended aeration process, IA: intermittent aeration process, MBBR: membrane bioreactor, MLE: modified Ludzack-Ettinger, OD: oxidation ditch, PFR: plug-flow reactor, SBR: sequencing batch reactor

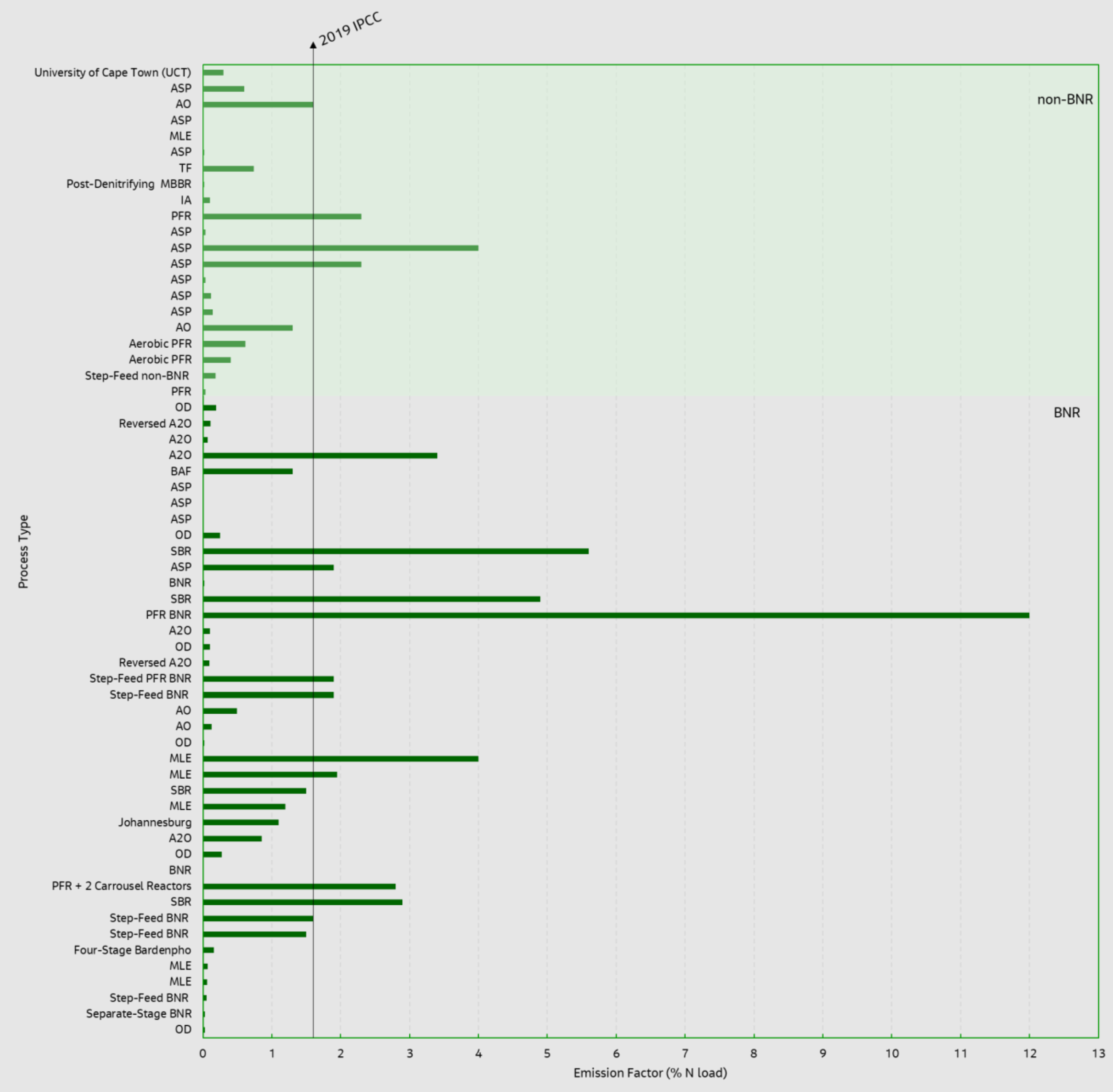


Figure 2: EFs of N_2O *emissions in % N-load (kgN_2O-N/kgN load) from literature review (Vasilaki et al., 2019) and edited by Jacobs to include additional published research (n = 61).*

IPCC GLOBAL GUIDELINES AND WATER NZ GUIDELINES

Despite the acknowledged limitations of using a single EF across the industry many utilities reporting their GHG footprint must rely on the IPCC guideline Tier 1 approach. The 2019 Refinement to the 2006 IPCC Guidelines (the 2019 Refinement) uses linear regression of a selected 29 point dataset based on full-scale monitoring (with variable duration and measurement methods) at activated sludge processes worldwide and introduces an EF of 1.6%, also with large data range from minimum 0.016% – maximum 4.5% of incoming TN. The IPCC approach has been reviewed by De Haas & Andrews (2022). Their review includes discussion of the IPCC 2019 Refinement data and method of linear regression based on incoming total nitrogen across a range of nitrifying and denitrifying activated sludge treatment facilities. It corrects errors between the source data and the EFs used in the IPCC estimate and finds a corrected EF of 1.1% is appropriate. The corrected EF is confirmed with the inclusion of additional data points from the literature and some pilot-testing of novel technologies within the linear regression arriving at the same 1.1% EF.

The Water NZ Carbon Accounting Guidelines for Wastewater Treatment (2021) references earlier work by de Haas and Ye (2021), which included a similar review of the IPCC data as De Haas and Andrews (2022) but with a recommended EF of 1%. The Water NZ Guidelines have taken the conclusions of this work and provisionally recommend a fixed emission factor of 1% or 0.01 $kgN_2O\text{-}N/kgN_{influent}$. This is a significant 27 fold increase from the previously presented IPCC 2006 EF of 3.2g N_2O/PE/yr, which is equivalent to 0.0004 $kgN_2O\text{-}N/kgN_{influent}$ when the Water NZ default per capita load of 5.5 kgN/PE/yr is used. For councils/council-controlled organisations (CCOs) who have previously reported their emissions using the 2006 IPCC factor, updating their inventories to the new Water NZ guideline will create a significant uplift in their wastewater process GHG emissions. This may impact on their paths to net zero whether they have made a commitment already or are looking to do what they can to align with the New Zealand governments net zero ambitions.

The variability in reported emission factors from the globally reported literature, as discussed, highlights the reason for focus in Europe by progressive utilities and countries on facility (IPCC Tier 3) and country-level (IPCC Tier 2) emissions understanding. To improve certainty around facility emissions, facility level focus and an emissions baseline is required, only then can utilities begin to mitigate emissions. Here in New Zealand, we are yet to undertake any long-term monitoring for wastewater process emissions across the country and so can learn from the approaches taken elsewhere. In terms of areas of focus the process types employed here in NZ in terms of connected population are approximately 60% activated sludge (with a full range of AS processes), approximately 20% pond-based systems and the remaining 20% fixed-film/media (predominantly trickling filters; this was prior to the recent November 2021 first at the Christchurch WWTP) (Water NZ, 2021). As such, the bulk of N_2O emissions are coming from AS processes and this should be the first area of focus to work to reduce these emissions.

COUNTRY AND FACILITY LEVEL FOCUS

Guidelines for utilities in site level monitoring to develop Tier 2 or 3 emission factors are lacking: whilst providing the tiered methodology, the IPCC Guidelines do not provide discussion of how utilities should monitor different process types, across what duration of monitoring, and how results should be used to derive emission factors and to drive mitigation. This is an emerging area of focus – with the recently published International Water Association (IWA) publication Quantification and Modelling of Fugitive Greenhouse Gas Emissions from Urban Water Systems, IWA Publishing (Ye et al., 2022) providing a global review. There is also second phase of research by the United Kingdom Water Industry Research (UKWIR) - a collaborative industry research body across UK and Irish water companies which is seeking to develop a best practice manual for monitoring and European practice in mitigation. The IWA GHG monitoring sub-group of Climate

Smart Utilities is also seeking to develop guidance for utilities in their process emissions monitoring.

Key considerations for monitoring campaigns to support the quantification of emissions and eventual development of mitigation strategies is summarised in a recent UKWIR publication and considers elements for measuring emissions and to support baselining site emissions (UKWIR, 2020):

- selection of sites to monitor – considering site configurations, availability of data and considering available approaches to site prioritising based on risk of N_2O (knowledge based, simple risk models, artificial intelligence and machine learning based accounting methods)
- sampling programme specification
- selection of instrumentation (including liquid versus off-gas methods)
- availability of wider WWTP data
- data quality, quantity, storage, and utilisation
- consider long term monitoring which significantly impacts emission factors (over 12 months to include seasonal variation)
- use of continuous monitoring versus intermittent monitoring data to derive emission factors – with a need for long term continuous data allowing maximum insight into the formation and variability of emissions which is crucial for mitigation
- consider process variations, stability, and operational considerations (e.g. variability in loading, hydraulics return) and potential variability across lanes
- analysis of data to develop site emission rate and factor
- use of site emission factor to baseline emissions

Following baseline assessment of site emission factors, various approaches exist to support the development and implementation of mitigation strategies as discussed below. Ongoing monitoring is likely to be required to confirm reductions achieved and for continued optimisation for low N_2O operation – though focus from progress to date is very much still on monitoring and mitigation trials.

MITIGATION EFFORTS

Mitigation remains an emerging area of focus and a site-specific consideration having established an understanding of existing emissions. Full-scale mitigation remains limited with exceptions including Porro et al. (2017) and a publication from a collaborative project by a South Australian water utility, SA Water, the University of Queensland and others which showed full-scale implementation of monitoring, mitigation, and mechanistic modelling of a sequencing batch reactor Duan et al. (2020).

Full-scale implemented mitigation strategies (Figure 3) include DO control – with both high and low DO conditions potentially contributing to N_2O emissions, balancing incoming ammonia peaks and management of carbon for denitrification. Other strategies being trialled include avoiding accumulation of nitrate/nitrite through optimised control and the impact of longer solids retention time (SRT).

Other potential levers for mitigation include the use of recirculation and recycle flows to minimise gradients and provide dilution and pH considerations- as yet these have received even more limited focus.

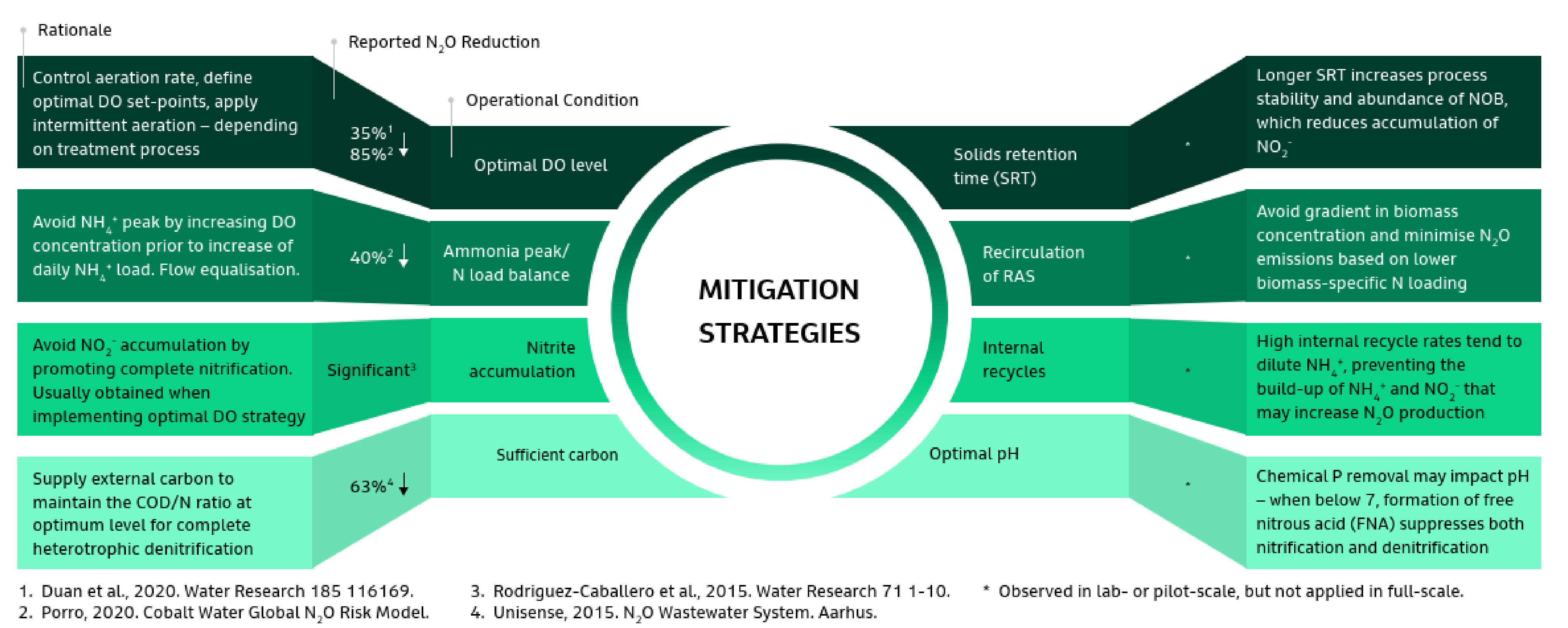


Figure 3: Mitigation strategies for nitrous oxide (Brotto & Lake, 2022)

LESSONS FROM EUROPE

A number of progressive utilities in Europe have taken steps to quantify and mitigate their N_2O emissions through action at facility-level and at industry-level. Sharing their experiences provides beneficial contribution to wider work by water utilities and sectors and this section provides a discussion of this experience.

EXPERIENCE FROM DENMARK AND SWITZERLAND

Danish wastewater treatment is characterised by a high degree of total nitrogen removal and biological phosphorus removal.

The Danish water sector is a global leader in terms of developing an industry-wide monitoring programme and has to date undertaken full-scale monitoring across ten WWTPs over a period of up to 2 years (Figure 3). This data has shown the variability in seasonal emissions and for different facilities and the significance of TN loadings and magnitude of EFs for liquor return streams.

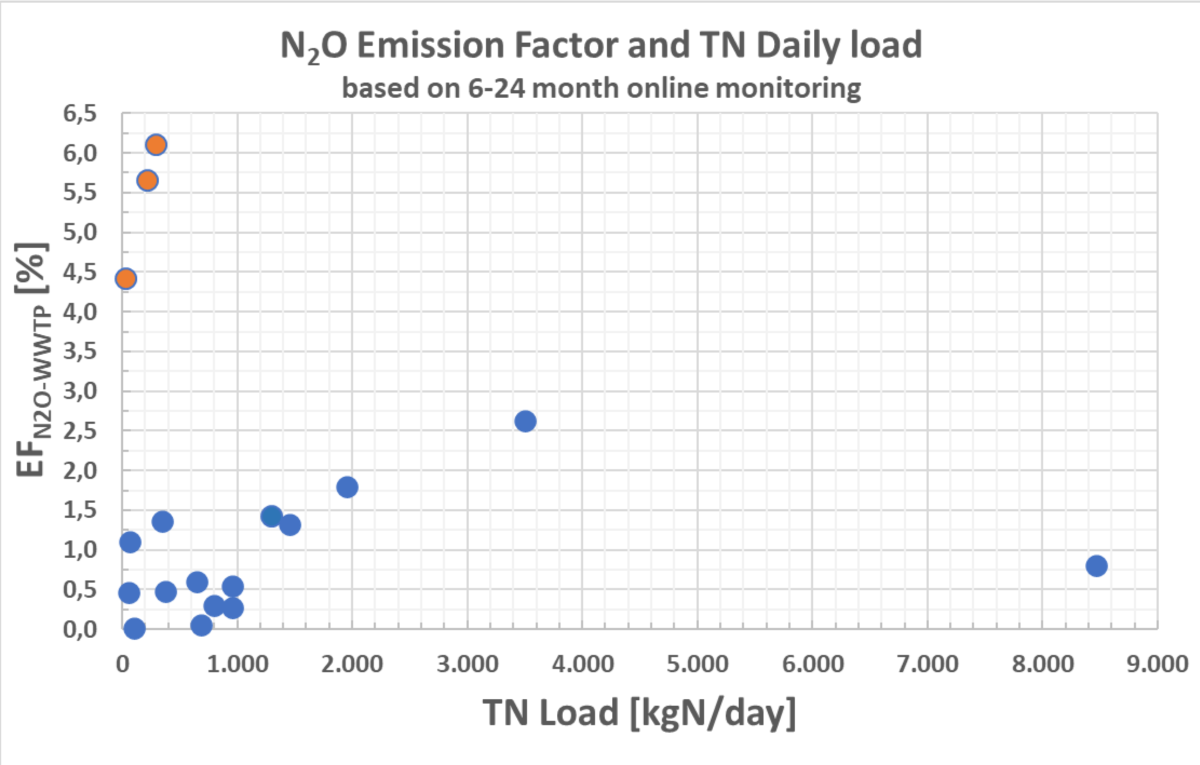


Figure 3: EFs of N_2O *emissions from long-term full-scale monitoring in Denmark. Orange dots represent sidestream deammonification processes (Unisense Environment, 2020)*

Denmark has used this industry-wide monitoring programme to develop a revised country-specific EF of 0.84% which, in the absence of measured data, is intended to be used by utilities in N_2O reporting and to drive ambition to mitigate emissions. This approach has allowed improved understanding at a country-level given the type and operational performance of WWTP assets. Concurrently, multiple utilities have implemented mitigation through process performance analysis and optimisation, implementing N_2O emissions reductions of up to 85%. In a progressive regulatory approach, a bill aiming to limit releases of N_2O into the atmosphere by Denmark's larger WWTPs is under implementation and facilities serving over 30,000 population equivalents (P.E.) will be required to comply by 2025, as part of a broader effort to make Denmark's water sector climate-neutral by 2030.

In mitigation studies in Denmark, optimising DO has reduced N_2O emissions and has also shown the relationship between N_2O emissions and loading and the accumulation of nitrates. In a summary of the Danish industry's various collaborative projects (Figure 4), N_2O online sensor signals have been used for optimisation and control of DO and has shown a 30-80% reduction in N_2O and a 50% reduction in a sidestream deammonification process. One of the findings has shown the cost effectiveness of this online monitoring and DO control based mitigation when considering application of a shadow carbon price.

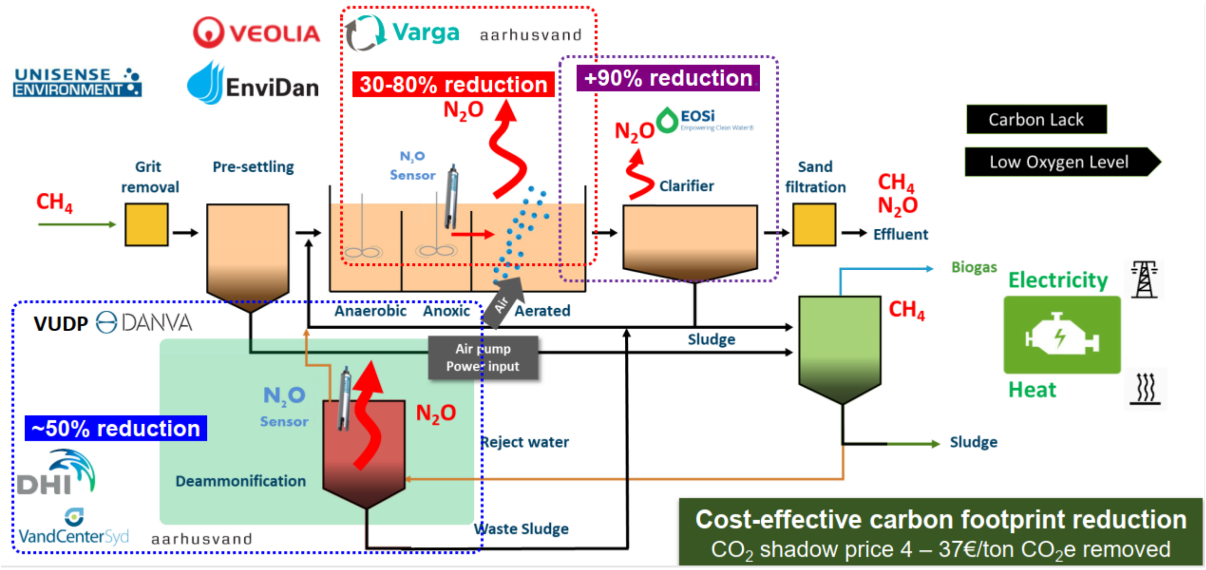


Figure 4: N_2O *reductions achieved in various mitigation projects (Unisense Environment, 2021).*

Gruber et al. (2021) estimated country-wide emission factors for Switzerland. Their study included monitoring campaigns of at least 1 year at 14 WWTPs in Switzerland (including historical studies). They proposed three categories of countrywide emissions factors based on the process for nitrogen removal employed. The three EFs for Switzerland are described below on percentage basis of kg N_2O-N/kg N load for each process type:

- Carbon removal only: 0.1-8%
- Nitrification only: 1.8%
- Nitrogen removal: 0.9%

The EF for carbon removal plants remains uncertain. Carbon removal processes may be assumed to have minimal emissions however, the study (and the Water NZ Guidelines) discusses the significant impact on N_2O emissions caused by partial nitrification when sludge age is not tightly controlled, this is an important consideration when accounting for emissions from this type of process. The EF for nitrogen removal processes shows agreement with the Danish country-specific EF.

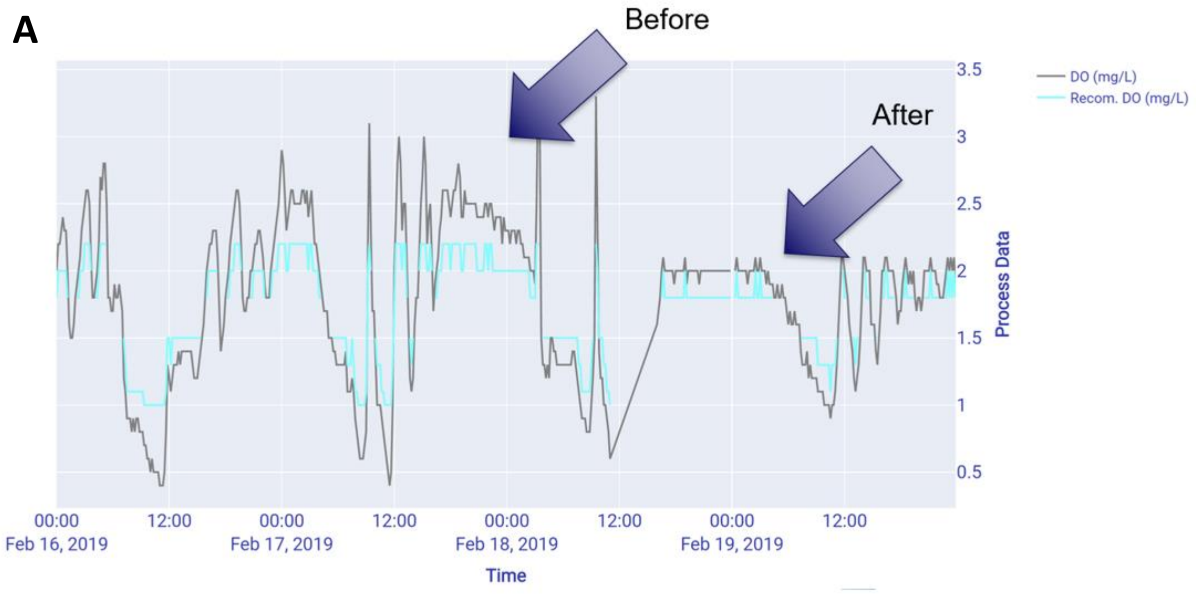
The study concludes that year-round, stable nitrification-denitrification is a key factor in reducing N_2O emissions (Gruber et al. 2021).

EXPERIENCE FROM THE NETHERLANDS

Like Denmark, typical treatment configurations in the Netherlands include full nitrification and denitrification.

In the Netherlands, data-based approaches analysing N_2O emissions have been applied at two treatment works – with operational conditions of liquid phase N_2O, dissolved oxygen (DO), ammonia and nitrate levels analysed to identify key N_2O production triggers, risk of production and to develop mitigation based on the knowledge-based AI approach of Porro et al., (2017). This has seen the implementation of optimised DO control to minimise N_2O production. Several days of one trial are shown to illustrate the impact, Figure 5a shows the measured DO more closely following the proposed DO after the implementation and in Figure 5B we see the impact of that on the predicted and measured N_2O concentration. Short term trials have resulted in overall GHG emission reduction for the WWTP of 70% in promising results.

Additional process benefits from applying control strategies at two Netherlands facilities include reduced ammonia peaks, improved denitrification, improved process compliance, and no net increase in grid energy consumption. In collaborative work led by the Foundation for Applied Water Research (STOWA), utilities in the Netherlands are also working to develop an evidence base for emissions from WWTP facilities. Whilst industry wide progress is ongoing to consider the development of a national emission factor, the facility level focus has allowed participating utilities to undertake monitoring and mitigation of N_2O and to develop site specific control strategies which have offered wider benefits.



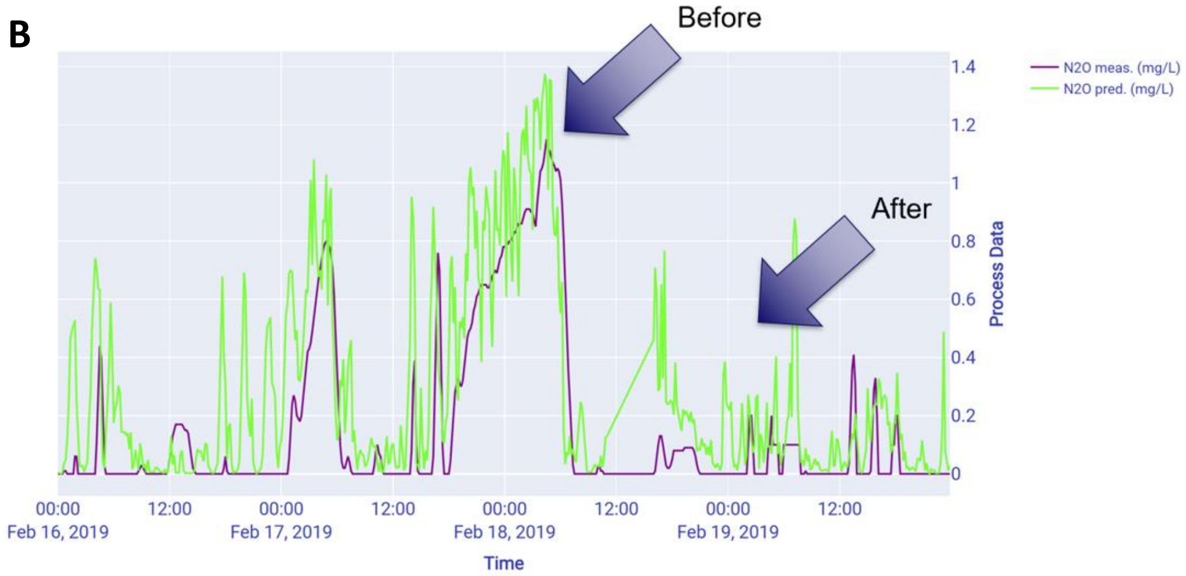


Figure 5A and 5B: N_2O *emissions from short term mitigation trial at Land van Cuijk WWTP, Netherlands*

Work on machine learning-based approaches, applied in the Netherlands, has shown the variation in N_2O emission accounting using IPCC emission factors and machine learning-based accounting methods – exhibiting good alignment between direct measured and calculated N_2O emissions using a machine learning-based accounting method (Figure 6).

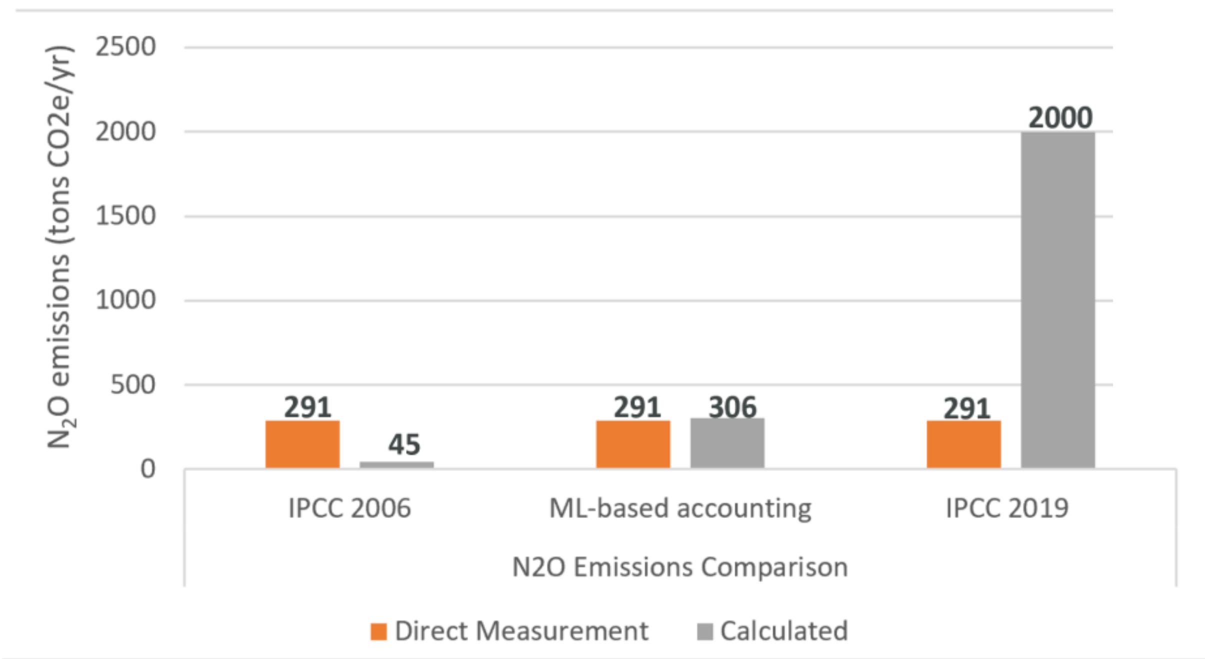


Figure 6: Comparison of N_2O *accounting methods for WWTWs in Netherlands – direct measured versus guideline and predicted values - RWZI Soerendonk, Netherlands (Porro et al. (2021) courtesy IWA EcoSTP Conference, 2021).*

UK INDUSTRY WIDE PROGRESS

Wastewater treatment in the UK is characterised by a mix of suspended growth and fixed-film processes and includes a large proportion of load which is treated for nitrification only. Many of the country's largest facilities lack any denitrification capability and a significant (at least 30%) of nitrogen load is treated through secondary or tertiary fixed-film processes – including trickling filters for which there is very limited evidence base for N_2O emissions.

Water utilities report their operational emissions through a sector level carbon accounting workbook, owned by UKWIR. This is reviewed and updated regularly; a recent review was undertaken of the process EFs in this to evaluate the existing industry-level N_2O EF being used and to make recommendations for improving emission quantification (UKWIR, 2020).

This review recognised that the existing N_2O EF is not well supported by science and requires revision through an in-country monitoring programme. It also supported multiple water companies in starting their journey to understanding and reducing N_2O emissions and progress to date includes:

- installation of liquid phase monitoring by a number of companies;
- research into quantifying N_2O emissions from biofilm processes, in particular from trickling filters which may be providing carbonaceous and/or nitrification function for primary treated wastewater;
- development of a further collaborative research programme to quantify emissions across multiple asset types and multiple sites with an objective to develop country level emission factors; and
- ongoing collaboration for sharing of results across companies as monitoring starts in earnest -with a current UKWIR project seeking to analyse results from multiple company monitoring campaigns and to develop a 'best practice guide' for monitoring and mitigation of N_2O.

Sector level research to date has informed sector level climate action - a 2030 net zero route map for operational emissions from water utilities in England and Wales and a 2040 commitment for operational and capital carbon net zero in Scotland. However, this sector level work recognises the uncertainty and risk associated with process emissions and in particular that utilities are likely to be under-accounting for N_2O emissions which puts the route maps at risk.

At a utility level, in their Net Zero Strategy to 2030, English utility Anglian Water recognise the great uncertainty in the magnitude of N_2O emissions and have assessed the impact of these emissions adopting existing sector reporting EF for N_2O versus higher EFs calculated by improved methods and the current IPCC EF of 1.6% (Figure 7). Anglian Water have committed to understanding their N_2O emissions through installation of monitoring at four of their large WWTP sites to improve understanding by 2025, to share this evidence across other water utilities and to use this to establish an improved baseline and data to support mitigation.

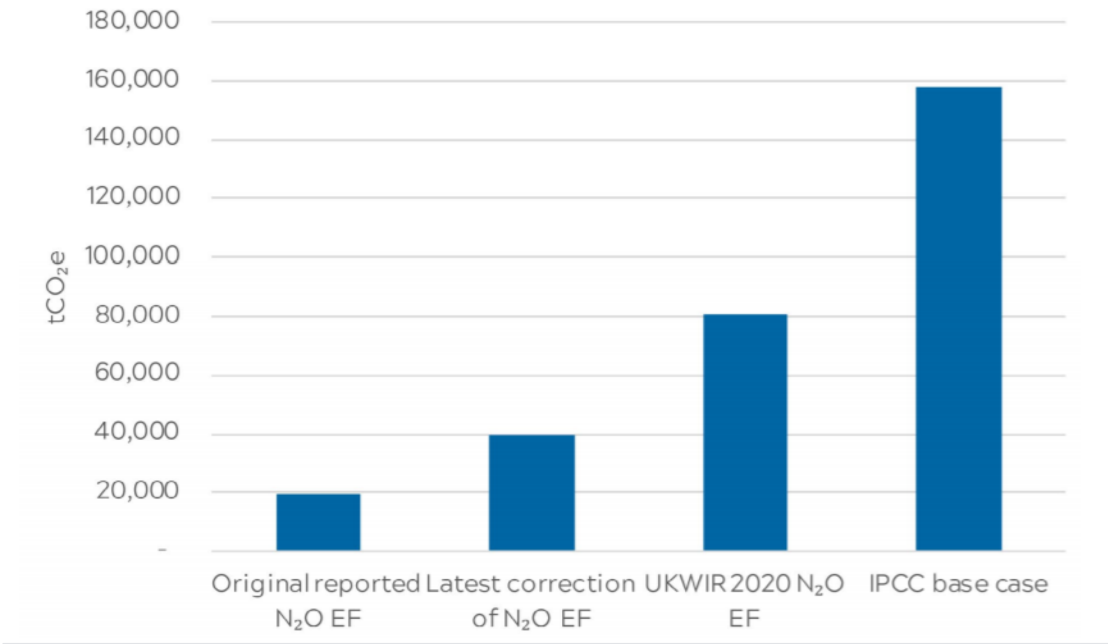


Figure 7: Estimate of water recycling process emissions of N_2O *applying different emission factors (Anglian Water, 2021).*

DISCUSSION

The approaches being applied across Denmark, Switzerland, the Netherlands and the United Kingdom at sector level offer valuable examples of progressive action in water sector and utility led climate action to quantify and reduce N_2O emissions.

Whilst IPCC guidance provides a high-level methodology, guidance for deriving emission factors aligned with lower Tiers 2 and 3 is lacking and the results show current focus and progress in this area at company and sector level from Europe.

Existing work at sector level highlights the variability in these emissions and the importance of collaborative work to support a derivation of country-level emission factors. However, quantifying accurate EFs across single and multiple treatment facilities remains challenging. Existing work in Denmark and Switzerland highlights the importance of long-term continuous monitoring to capture seasonal variation. Relatively simple process control and optimisation interventions have shown significant emissions reductions; sustained N_2O monitoring over time will support these initial results.

In the Netherlands, knowledge based and innovative machine learning methods for N_2O accounting offer opportunities to improve quantification and to address mitigation.

Across all four geographies, focus includes development of an industry wide emission factor as well as focus at facility level quantification and mitigation. Considering process type and extent of treatment (e.g. total nitrogen reduction) is likely to be critical to the development of accurate EFs at country level where multiple treatment types are implemented (for example in the UK). Comparing country-level or emerging country data with the IPCC emission factor offers utilities an idea of the potential magnitude of emissions when considering their net zero baseline – however accurate baseline requires site level monitoring.

While monitoring of N_2O emissions is getting underway here in New Zealand we must rely on the work of others globally to estimate the current state of our process emissions. The adoption of the current practice in New Zealand in the Water NZ Carbon Accounting Guidelines will lead to an increase in the reported emissions by councils who have published their emissions baselines according to the older IPCC 2006 EFs. For those councils that do not yet account for or publish their emissions it provides the means to do so. The progression toward measurement and mitigation seen globally will ramp up here locally, especially in response to the path set by both central government, rate payer expectations and through green financing requirements.

Mitigation strategies require facility level monitoring and analysis but offer significant opportunities to achieve reduction based on evidence to date – though this remains focused on facilities with full nitrogen removal in suspended growth processes. Experience to date suggests that cost and carbon savings may be achieved in addition to wider process benefits when mitigation is achieved. For successful baseline understanding including when and where N_2O is produced, high quality data from facilities is required. Emerging data-based approaches are being implemented in addition to process optimisation. In all examples, high quality data and a strong knowledge base appears key to success.

CONCLUSIONS

Sharing global best practice in the monitoring and mitigation of N_2O from WWTPs is vital to allow successful reduction of the most potent GHG emitted in wastewater treatment. Given the emerging state of understanding around production pathways and mitigation strategies, approaches available to progressive utilities to quantify and reduce their emissions are not fully clear, as they are process-, operating condition-, and site-specific. Ongoing work by European water utilities has increased the evidence base for N_2O emissions and EF derivation and contributed to improved global understanding and action to reduce N_2O.

Here in New Zealand, we are beneficiaries of the work of progressive countries and utilities and the data they have shared to date. We have an opportunity to contribute to the global body of knowledge as we begin to grapple with wastewater process emissions here.

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