Modelling & Mitigation of N_2O Emissions from Water Treatment

Bilal Shariq
James Watt School of Engineering, University of Glasgow
2951593s@student.gla.ac.uk
www.hydronationscholars.scot

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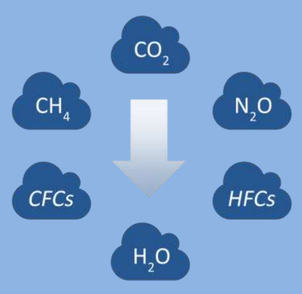
GHG Emissions in Wastewater Treatment Works



The ***net-zero emissions*** target[1] – net emissions account for the target year must be at least 100% lower than 1990 levels

Target year	
	UK-wide: 2050
	Scotland's own commitment: 2045

A Wastewater Treatment Plant (WwTP)

a major source of GHG emissions at city level

Direct emissions of CO_2 CH_4 N_2O

CO_2

primarily linked to energy consumption rather than organic matter conversion

CH_4

prevalent in sewerage systems and sludge handling

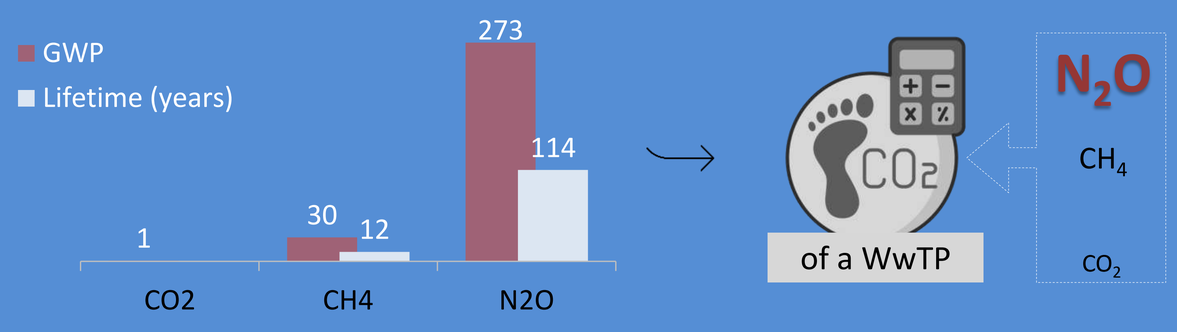
N_2O

~ **86%** of the WwTP's overall carbon footprint[2]

1. Climate Change (Emissions Reduction Targets) (Scotland) Act 2019
2. Song, C. (2024). *Nature Sustainability*, 7.

N_2O in WwTPs

Global Warming Potential (GWP)[3]: The relative amount of heat trapped by a GHG compared to CO_2 over 100 years.



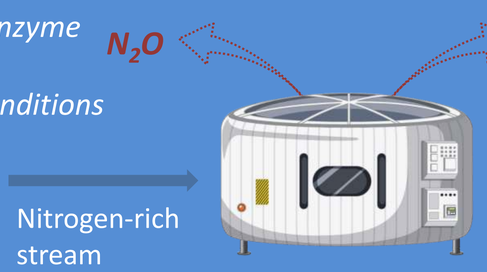
- N_2O emission factor (EF) = amount of N_2O emitted relative to the nitrogen load
- **1% increase** in N_2O EF can lead to a **30% increase in the overall carbon footprint**[4]

N_2O emissions **prime source**: **Biological Nitrogen Removal (BNR) process**

BNR: *the conversion of harmful nitrogen compounds (like ammonia) into harmless N_2 gas*

- involves Nitrification (ammonia → nitrate) and Denitrification (nitrate → nitrogen gas)
- is responsible for the **majority of N_2O emissions (~ 81 – 99.8%)** in a WwTP[5]

i. due to certain enzyme imbalances
ii. under low O_2 conditions



BNR Bioreactor

iii. due to incomplete denitrification (low C/N ratio ..)

Are there other comparable N_2O emission pathways?
Chemical reactions? Comammox?

Needs more research!

3. Understanding Global Warming Potentials (2024) U.S. Environmental Protection Agency.
4. Law, Y. (2012). *Phil. Trans. R. Soc. B*, 367.
5. Yang, Y. (2024). *Science of the Total Environment*, 930.

Challenges

Knowledge Gap: limited understanding of N_2O production pathways, mechanisms, influencing factors.

Lack of N_2O emissions data from Scottish WwT works.

Existing 'Off-the-shelf' solutions might be ineffective in Scottish contexts.

Scottish WwT works have specific characteristics (incl. trickling filters, decentralised plants, organic carbon removal) requiring tailored approaches.

Objectives

Develop a state-of-the-art N_2O biokinetic process model.

Monitor N_2O emissions in selected WwTPs in collab. with *Scottish Water* to refine and validate the developed model.

Calculate model-based N_2O footprints and associated uncertainties for the WwTPs across Scotland.

Develop N_2O mitigation guidelines, assisting Scottish water industries in reducing scope 1 emissions from water treatment practices.

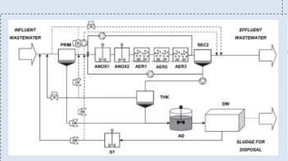
Aim

To develop a state-of-the-art N_2O estimation model to quantify emissions from Scottish full-scale WwT works, identify high-emission areas, and inform the development of targeted mitigation strategies.

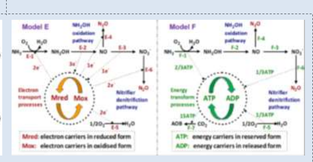
Methodology

N_2O data from monitoring campaigns

Data from Scottish Water



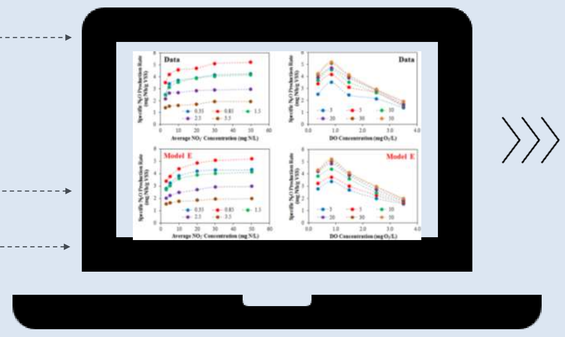
Plant layout model



N_2O focused biological model

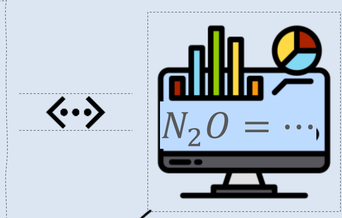
State-of-the-art benchmark simulation models

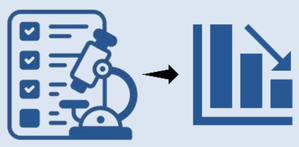
Developed N_2O model including further biokinetics of key microbes



Model implementation

Model-based estimations of N_2O





Mitigation guidelines

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