PRINCETON UNIVERSITY

andlinger center for energy+the environment

Greenhouse Gas Emissions from the Wastewater Sector

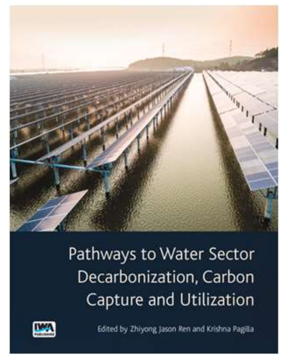
Z. Jason Ren

Professor
Department of Civil and Environmental Engineering

Associate Director for Research
Andlinger Center for Energy and the Environment

Princeton University

@zjasonren
zjren@princeton.edu
http://ren.princeton.edu

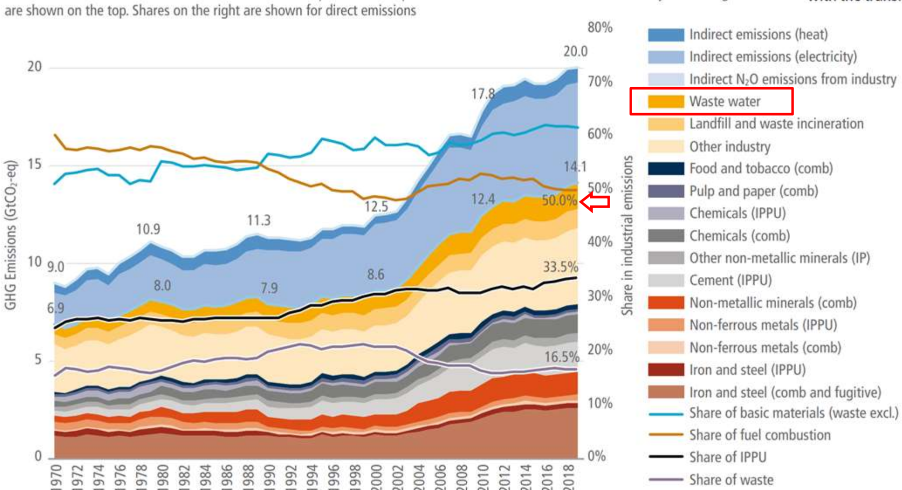


1

Waste is a major contributor to industrial greenhouse gas (GHG) emissions

The largest incremental contributors to industrial emissions in 2010–2019 were industrial processes at 40%, then indirect emissions (25%), and only then direct combustion (21%), followed by waste (14%; Figure 11.4). Therefore, to stop emission growth and to switch to a zero-carbon pathway more mitigation efforts should be focused on industrial processes, product use and waste decarbonisation, along with the transition to low-carbon electrification (Hertwich et al. 2020).

(a) Industrial emissions by source (left scale) and emissions structure (right scale). Comb – indicates direct emissions from fuel combustion. IPPU – indicates emissions from industrial processes and product use. Indirect emissions from electricity and heat generation are shown on the top. Shares on the right are shown for direct emissions

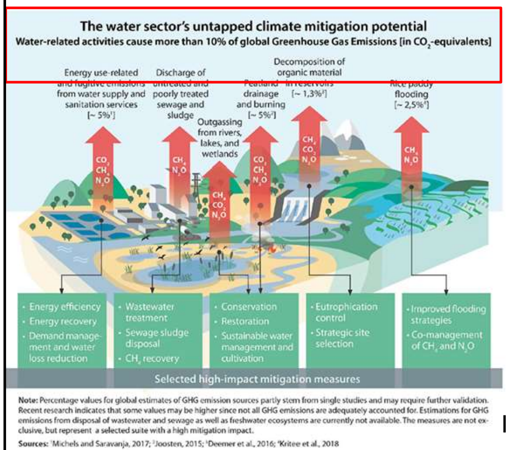


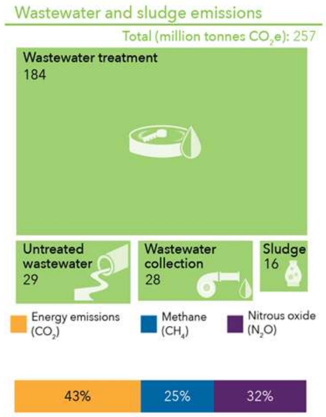
Waste decarbonization should be a focus for zero-carbon pathways

IPCC, 2022: the Sixth Assessment Report

2

Greenhouse gas emissions from wastewater sector is unique, important and need better understanding





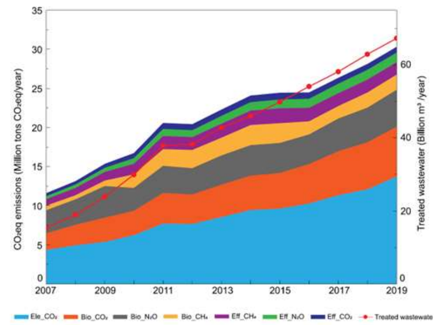
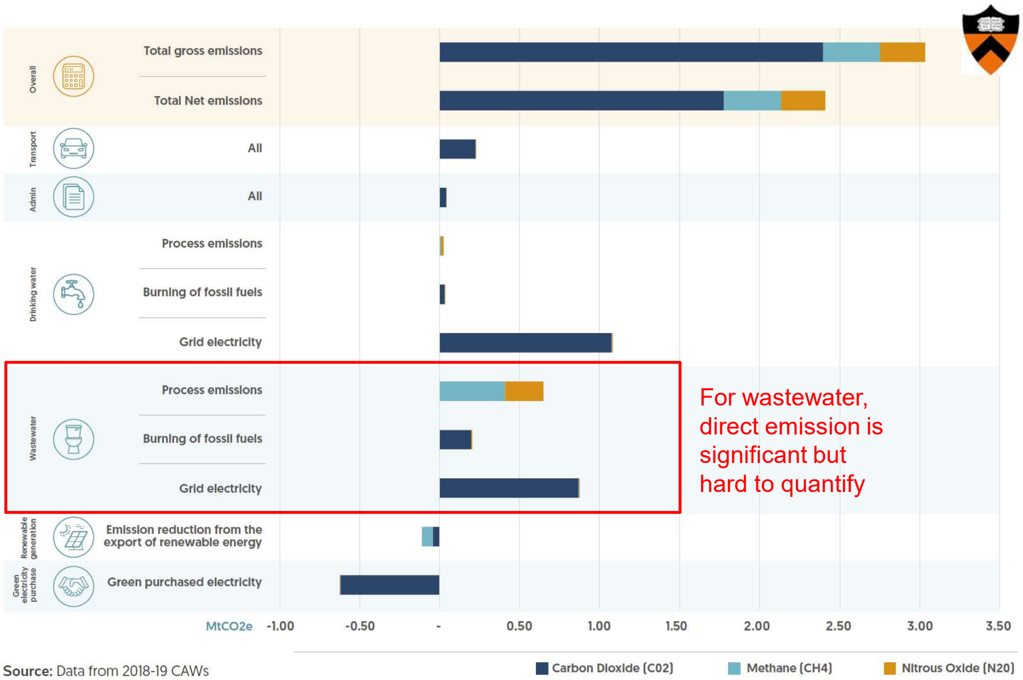


Fig. 3 China's GHG emissions from wastewater treatment (in n

In 2021, EPA estimated that in the United State
- The treatment of wastewater emitted 42.0 MMT CO_2 Eq.
- Cement production was responsible for emitting ~41.3 million $MtCO_2e$.
- Emissions from iron and steel production and metallurgical coke production were 41.7 MMT CO_2 Eq.
(direct emissions)

US Water Alliance, 2022
Global Water Intelligence, 2022
Wang et al., Scientific Data, 2022
U.S.EPA, 2023

3

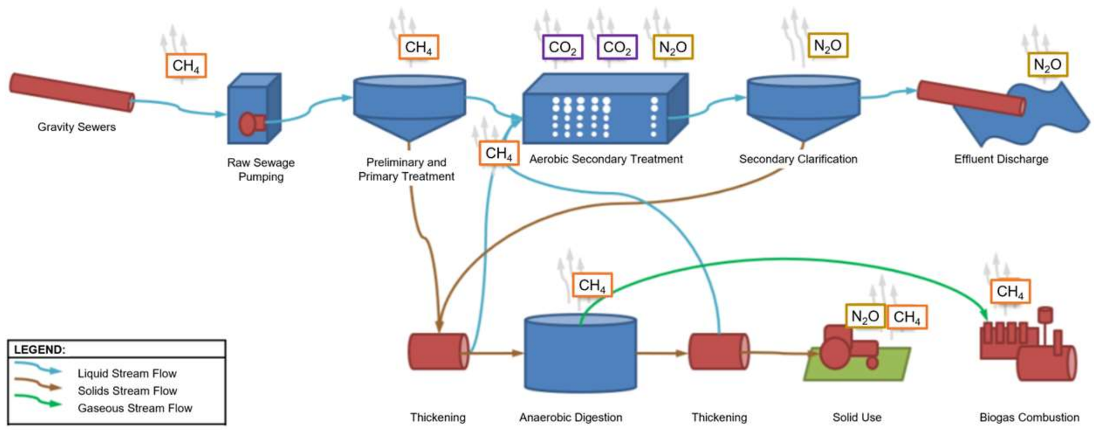


Source: Data from 2018-19 CAWs

Water UK: Net Zero 2030 Route Map, 2020

4

Domestic wastewater treatment as an important urban source of CH_4 and N_2O

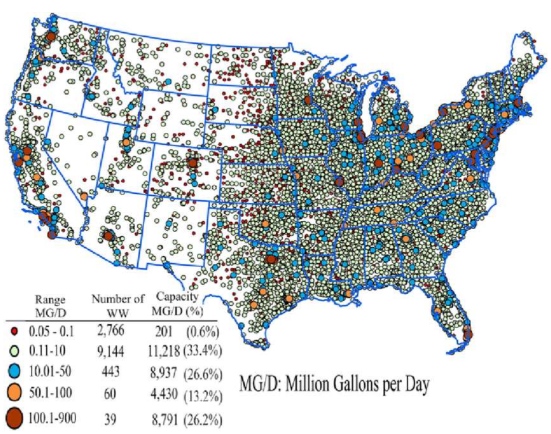


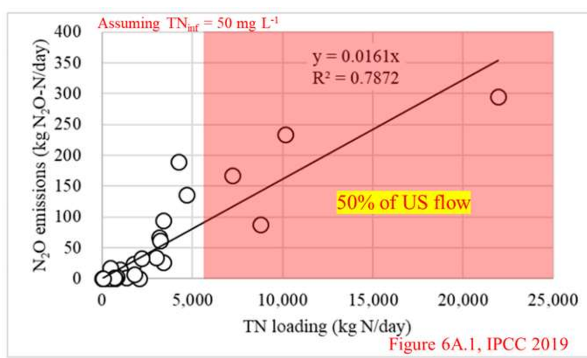
Revised from Brower, Lang & Willis, WEF Fact Sheet, 2021

5

A single national-level emission factor oversimplifies the estimated emissions

- The top 1% of treatment plants in the U.S. treats 45% of the wastewater
- The top 50% of the plants treats over 98% of the wastewater



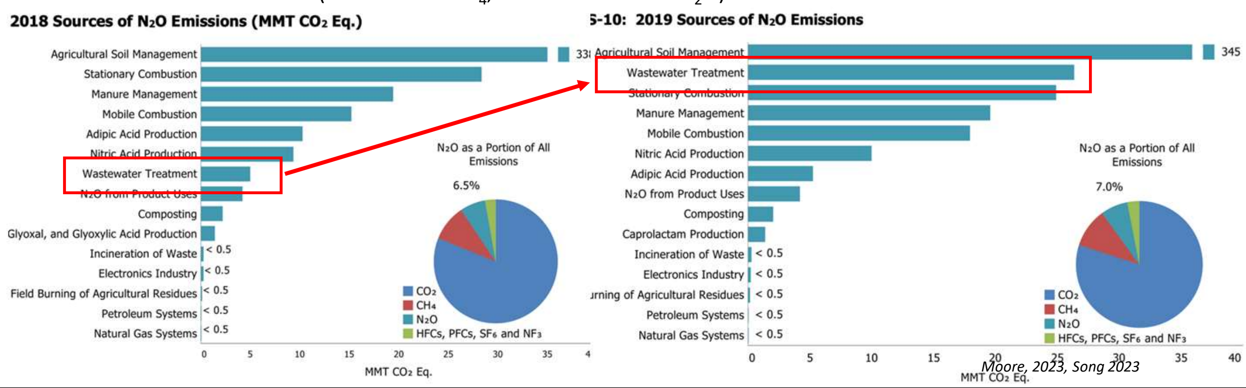


EPA, 2012

6

High discrepancies between estimated and actual CH_4 or N_2O emissions

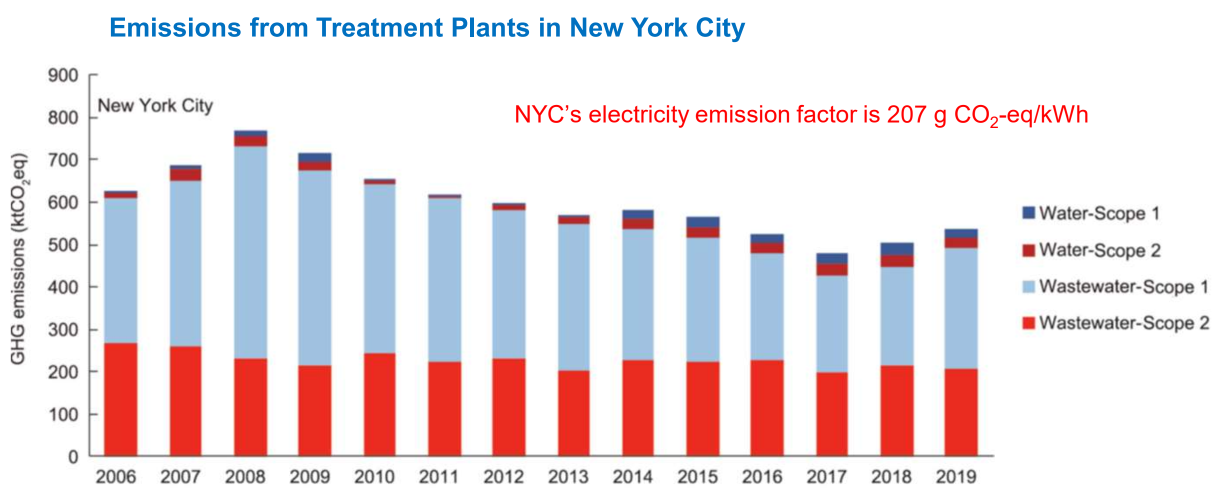
- The most recent EPA inventory highlighted wastewater treatment as 2nd largest anthropogenic N_2O source after agriculture.
- Waste sector is also the 3rd largest CH_4 source in the U.S, behind agriculture and energy, emitting equivalent of 624.2 MMT CO2 per year.
- The new IPCC 2019 N_2O emission factor (1.6% influent TN emitted as N_2O-N) is orders of magnitude higher than its 2006 (0.032% influent TN emitted as N_2O-N), which tripled the emission estimates of WRRFs N_2O emissions
- However, the current inventories are based on very limited literature and studies and doesn't represent the diverse emission scenarios (7 studies for CH_4, and 31 studies for N_2O).



Moore, 2023, Song 2023

7

Not every utility is created equal



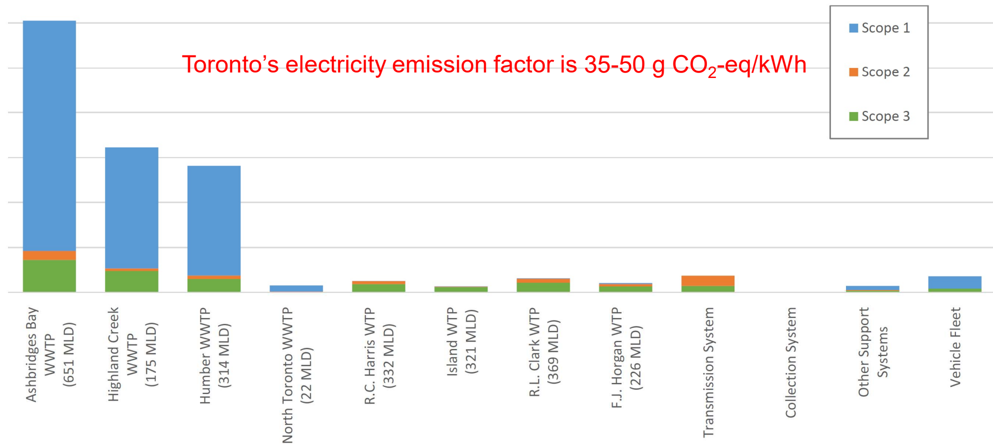
New York City Mayor's Office of Sustainability, 2021; Lam, et al. Engineering 14 (2022) 77–85

8

8

Not every utility is created equal

Emissions from Treatment Plants in Toronto

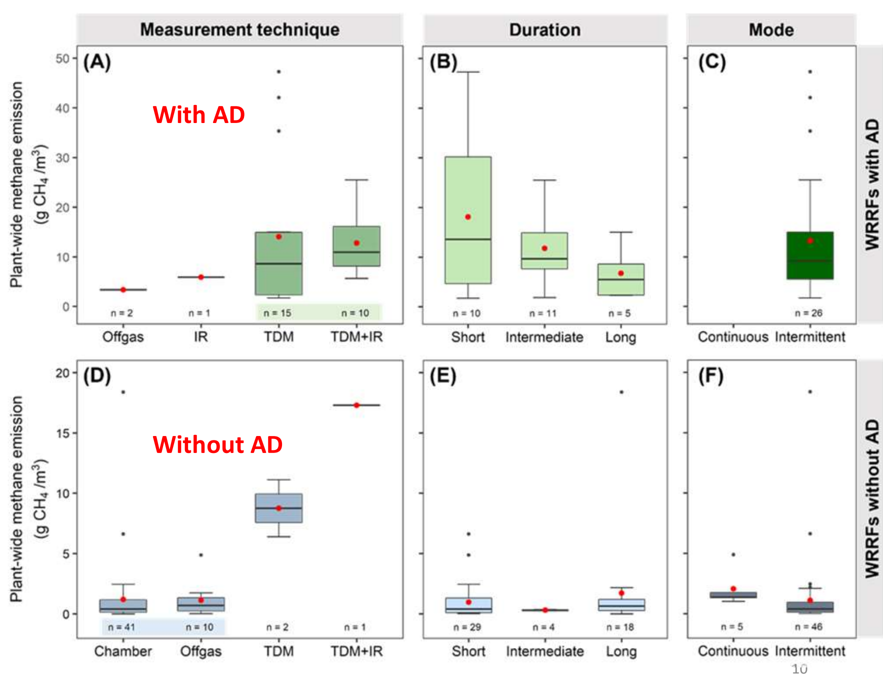


By Emily Zegers, Toronto Water

9

Methane emission results vary based on measurement techniques, monitoring period, and monitoring mode

Depending on
- the timing of the monitoring
- the frequency of emissions, and
- the extent to which a one-time sampling (or few repeated samples) represents the emissions profile



10

Rather than relying on a national EF, utilities can conduct their own measurements

- Mobile Lab with GHG Sensors for Facility-integrated Measurements

- Sample 10+ facilities in one day
- Can be operated by one person
- No on-site access is required
- Inverse Gaussian Plume methods for integration

Prof. Mark Zondlo, Princeton

Instrument	Measurement Type	Frequency (Hz)	Precision
LICOR LI 7700	CH_4 (1.6 µm)	10	6 ppbv @ 10 Hz
Custom NH_3	NH_3 (9.06 µm)	10	0.7 ppbv @ 10 Hz
Custom N_2O/CO	N_2O (4.54 µm)	10	0.2 ppbv @ 10 Hz
	CO (4.54 µm)	10	8.2 ppbv @ 1 Hz
Arduino GPS	Location	10	3 meters
Airmar WX200	Temperature	1	1.1°C
	Barometric Pressure	1	1 hPa
	Wind speed	1	0.5 m s^{-1} + 10%
	Wind direction	1	5°

[1]Tao at el. 2015; [2]Miller et al. 2015; [3]Golston et al. 2020

11

11

Both CH_4 and N_2O inside WRRFs show elevated concentrations

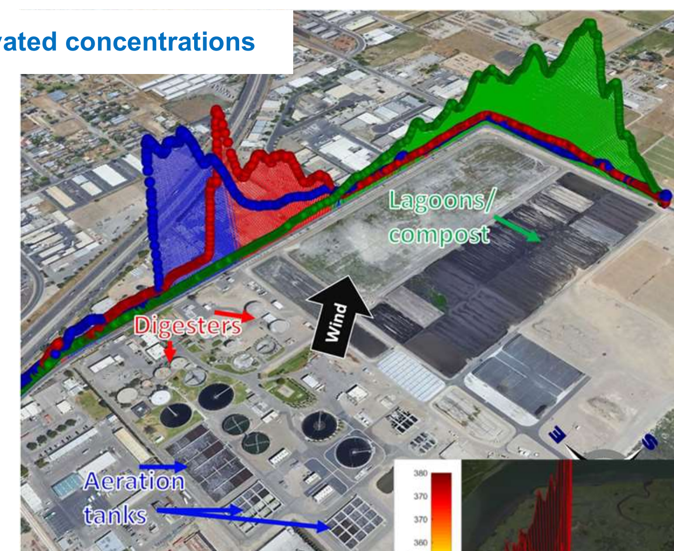
- Blue: N_2O
  - Empirically determined to be from aeration tanks
  - Max: 360 ppb (background is 338 ppb)
- Red: CH_4
  - Main source: digesters
  - Max: 3.6 ppm (background is 2.1ppm)
- Green: NH_3
  - Primarily from lagoons/compost
  - Max: 411 ppb (background is 9 ppb)

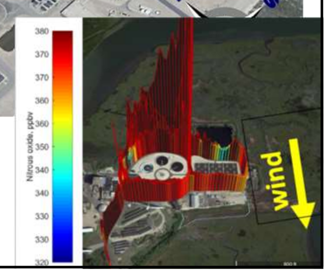
Environmental Science & Technology
pubs.acs.org/est
Article

Underestimation of Sector-Wide Methane Emissions from United States Wastewater Treatment

Daniel P. Moore, Nathan P. Li, Lars P. Wendt, Sierra R. Castañeda, Mark M. Falinski, Jun-Jie Zhu, Cuihong Song, Zhiyong Jason Ren, and Mark A. Zondlo*

Cite This: Environ. Sci. Technol. 2023, 57, 4082−4090 Read Online

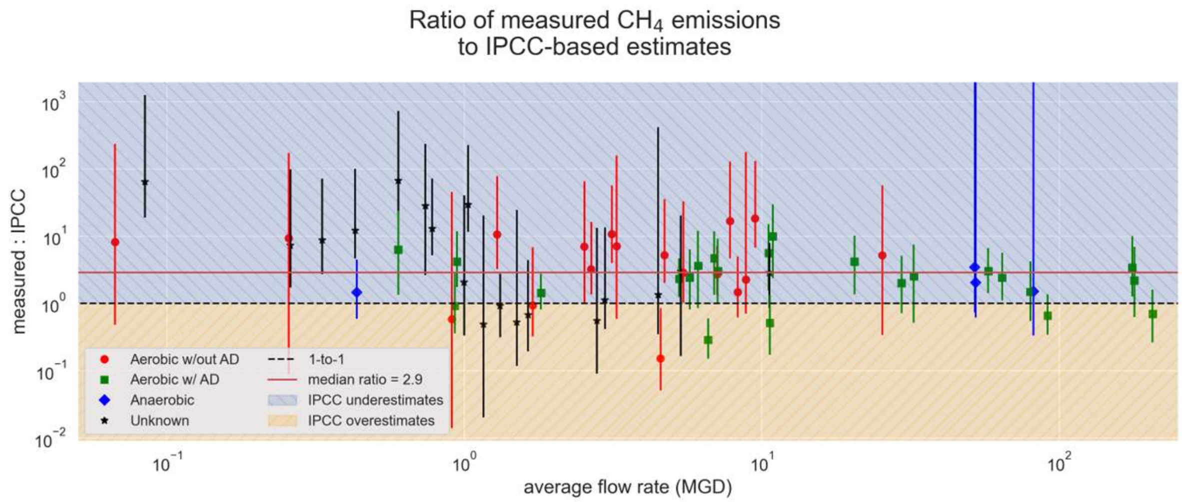




12

Measured 63 plants with 95 observational periods:

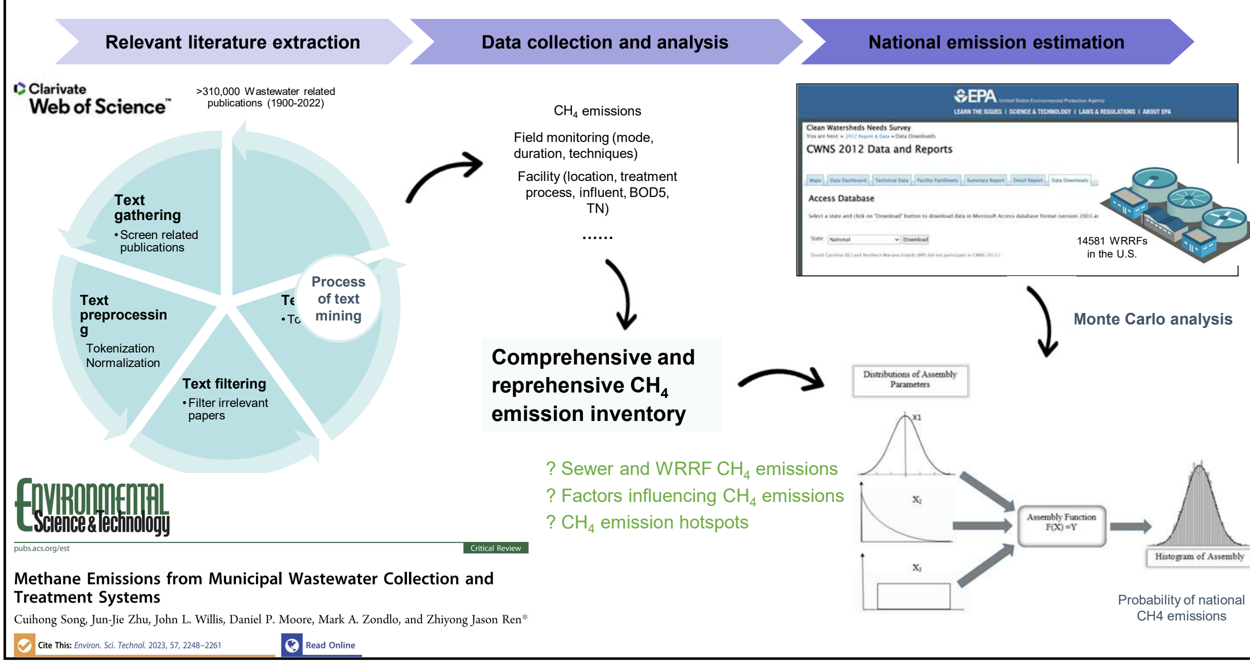
Results show CH_4 emissions are 1.9 times (95% CI: 1.5–2.4) greater than current EPA inventory



Moore, et al., ES&T, 2023

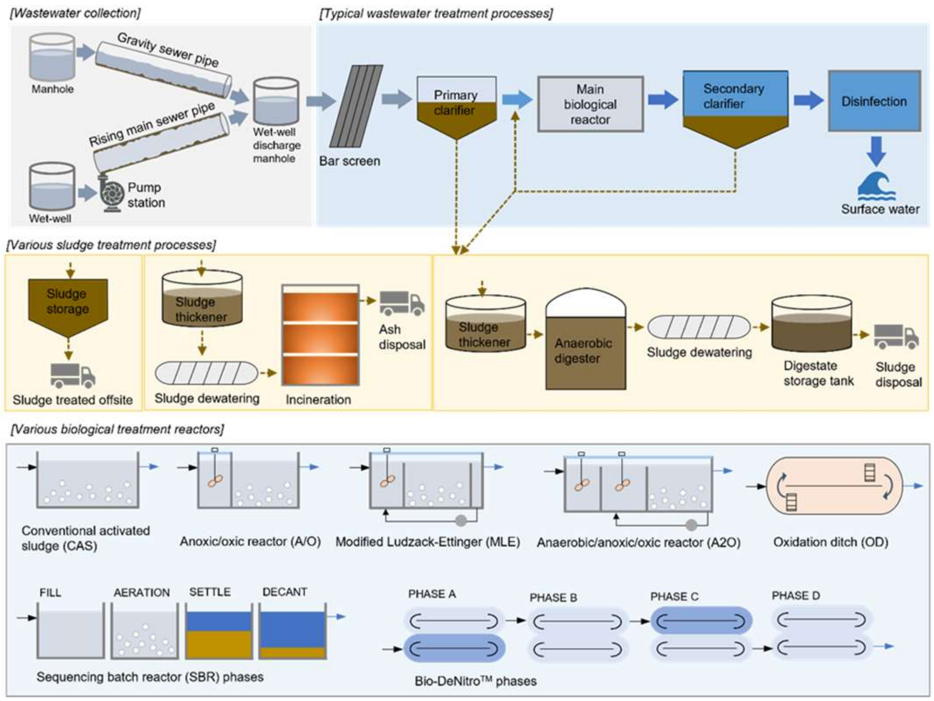
13

Leveraging big data for comprehensive analyses of wastewater methane emission



14

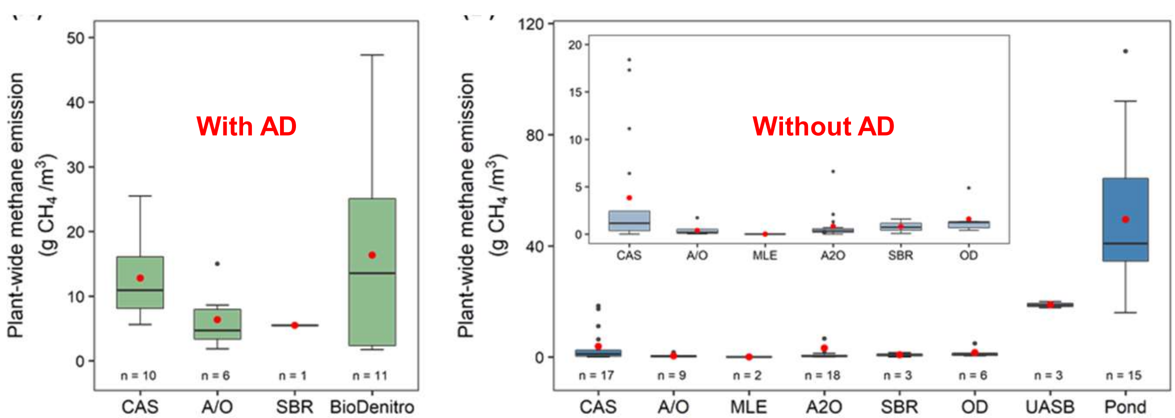
A comprehensive literature mining and analysis on wastewater methane emissions



Song, et al., ES&T, 2023

15

Plant-wide CH_4 Emissions Vary Significantly Among Different Treatment Processes



- **Plant-wide CH_4 emissions vary by orders of magnitude, from 0.01 to 110 g CH_4/m^3**
- **High emissions are associated anaerobic digestion or stabilization ponds.**

16

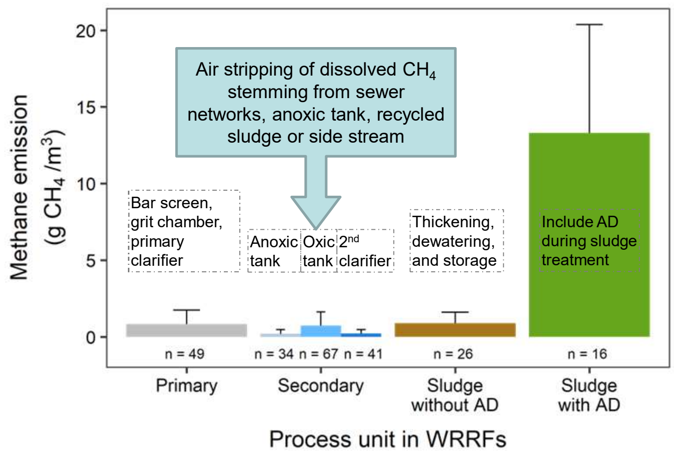
16

Treatment Unit Level CH_4 Emissions

- Sludge treatment with AD has the highest emission of 13.3 (7.3-20.1) g CH_4/m^3
- This is an order of magnitude higher than other treatment units

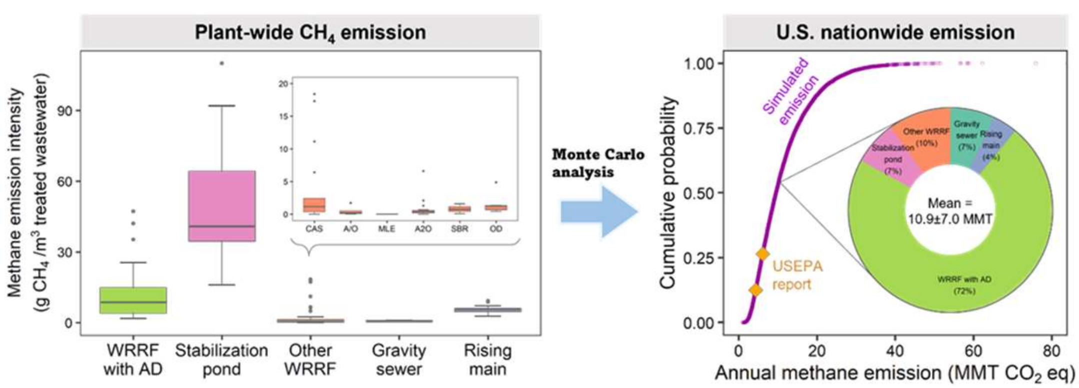
Potential mitigation strategies

- Sludge with AD: install vacuum degassing, switch digester feeding from in parallel to in series
- Sludge storage: reduce temperature or increase O_2 supply, add ammonia for sanitizing purpose
- Secondary treatment: separate treatment of return sludge or sidestream deammonification
- Primary treatment: reducing CH_4 production in sewer



17

The overall estimated annual CH_4 emission is 2x the IPCC Tier 2 estimates, but different plants vary significantly



- A total of 10.9 ± 7.0 MMT CO_2-eq/year of CH_4 is estimated to emit from the sewer networks and WRRFs in the U.S.
- This is about twice the IPCC (2019) Tier 2 estimates (4.3-6.1 MMT CO_2-eq/year).
- Around 80% of the total emissions come from WRRFs with AD (7.9 ± 6.7 MMT CO_2-eq/year) and stabilization ponds (0.7 ± 0.4 MMT CO_2-eq/year)

18

Song, et al., ES&T, 2023

18

PRINCETON UNIVERSITY

Some Thoughts

- The wastewater sector GHG emission is complex and needs better understanding
- IPCC based single emission factor method is not sufficient
- Much more monitoring and quantifications are needed
- Both unit (technology) and plant level characterizations are needed
- Technology deployment, policy making, and net-zero emission plans should be guided by such information

THE Water Research FOUNDATION

zjren@princeton.edu
http://ren.princeton.edu
@zjasonren

19