Greenhouse gas emissions from wastewater treatment plants: measurements and carbon footprint assessment

The anthropogenic emissions of greenhouse gases (GHGs) into the atmosphere are of great concern, due to their effect on climate change. To curb the increased accumulation of GHGs in the atmosphere, the United Nations Framework Convention on Climate Change promotes the reporting of national anthropogenic GHG emissions. Wastewater treatment plants (WWTPs) emit two potent GHGs, namely methane (CH4) and nitrous oxide (N2O), but also carbon dioxide (CO2), which is not accounted as a GHG according to its biogenic origin (IPCC, 2006). Currently, CH4 and N2O emissions from WWTPs are estimated according to national and international guidelines. However, it is unknown how well these estimated emissions resemble actual plant-specific CH4 and N2O emissions; therefore, CH4 and N2O emission quantifications are needed to assure the reliable accounting of GHG emissions on the plant scale. Quantifying GHG emissions from WWTPs is a challenging undertaking, since emissions are fugitive, and are occurring across a large area consisting of several smaller sources at different emission heights and physical shapes. In the last two decades, this challenge has been addressed mainly by using on-site point measurements, namely measuring directly on individual emitting sources identified inside the facility. Usually, a single source is either completely encapsulated or partially covered, in order to measure GHG concentration in a known air volume or through a known air flow, i.e. the flux chamber techniques. Complete encapsulation of a single emitting source usually occurs when measuring leakages from biogas bearing process units, while partial coverage usually is used when measuring emissions from surfaces such as open basins surface. In the last few years, plant-integrated measurements have also been performed at WWTPs, using the mobile tracer gas dispersion method (MTDM). This method uses a ground-based remote sensing approach combining the controlled release of tracer gas from the WWTP with atmospheric plume concentration measurements. Since facilities having different plant layouts, and using different process units and technologies could require different applications of the method, further investigations are needed to identify how MTDM can be best applied at WWTPs. In addition to fugitive emissions of CH4 and N2O, WWTPs indirectly emit GHGs, mainly CO2, due to the consumption of chemicals and energy. The carbon footprint assessment allows the quantification of the overall contribution of a WWTP to climate change. The principal aim of this PhD thesis was to implement the MTDM application at WWTPs, in order to quantify plant-integrated CH4 and N2O emissions. Additionally, the influence of analytical instrument characteristics and tracer gas release on MTDM results was investigated. GHG emissions were quantified at six WWTPs, using the MTDM. At two facilities, plant-integrated and on-site point measurement approaches were compared. Finally, the PhD thesis assesses the importance of fugitive GHG emissions in the carbon footprint evaluation of WWTPs. Fair agreement of the plant-integrated CH4 emission rates was obtained when three analytical instruments, with different detection frequencies and precisions, were used in a simultaneous MTDM application at a WWTP. Emission rates differed between 1 and 18% from the mean emission rate quantified by all instruments. In the same campaign, the importance of a high plume signal within a plume traverse was shown, as this resulted in more reliable plant-integrated emission quantifications. An estimation of the MTDM detection limit was introduced by using inverse Gaussian plume modelling. Estimating the lowest detectable emission rate by MTDM was useful when little GHG was emitted from a large area, forcing measurements at a distance so far away that the analytical instrument, due to high atmospheric dilution, could not distinguish the plume from background concentrations within the plume traverse. The introduction of an indicator called “Underestimation due to Tracer Height release” (UTH) was useful in documenting that a potential vertical misplacement of the tracer gas had little influence on the final emission rate quantification. Information provided by UTH is relevant when the plume is traversed relatively close to a facility with emissions occurring from elevated heights, which incurs risk of underestimating the CH4 emission, because tracer gas released from the ground does not mix completely with CH4 potentially emitted from the top of a CH4-bearing process unit. The relevance of correct target gas simulation using proper tracer gas placement was demonstrated by applying MTDM for plant-integrated CH4 quantification. A minor emission rate overestimation was caused by a sideward misplacement of 250 m, whereas the emission rate overestimation increased by up to almost 50% when the tracer gas was misplaced 150 m upwind of the correct position. This large error in emission rate quantification was caused by the different travel distances of the target and the tracer gases. Plant-integrated CH4 emission rates were between 1.1 and 39.5 kg CH4 h-1, and corresponding CH4 emission factors were between 1.1% and 21.3% as kg CH4 (kg CH4 production)-1 and between 0.2% and 3.2% as kg CH4 (kg COD influent)-1. Plant-integrated N2O emission rates were between < 0.1% and 6.4 kg N2O h-1, and corresponding N2O emission factors were between < 0.1% and 5.2% as kg N2O-N (kg TN influent)-1. A comparison of plant-integrated and on-site measurements at two facilities showed that plant-integrated measurements generally provided more comprehensive emission quantifications – most likely because on-site methods may not quantify all emission sources. Plant-integrated methods are thus useful for carbon footprint evaluations of an entire facility – and thus for emission reporting. On-site approaches provided information about emissions occurring from specific sources identified inside the facility, which is important in the daily operation of the plant in optimising treatment technologies and reducing emissions. The carbon footprint was assessed at seven WWTPs. None of the utilities could be considered carbon-neutral, due to their positive net carbon footprint. The assessment revealed that fugitive GHG emissions were very important when evaluating the impact of wastewater utilities on climate change, because they could contribute up to 71% of the total burden. The importance of accurate GHG emission factors was highlighted by the performed sensitivity and scenario analysis. GHG emission factors were found to be sensitive model parameters, small changes to which led to large changes in carbon footprint results. GHG emission factors were also largely responsible for the uncertainty of the net carbon footprint evaluation. Additionally, using default values provided in emission reporting guidelines gave a net carbon footprint up to four times smaller or seven times larger compared to when measured plant-integrated GHG emission rates were used. Finally, when the carbon footprint was evaluated by comparing fugitive CH4 emissions measured during normal operational conditions and digester malfunctioning, the results were up to 320 times higher when problems at digesters occurred, suggesting a careful monitoring strategy that includes emission variations in the inventory year.