A Review of the Different Estimation Methodologies for Greenhouse Gas Emission from Waste Water Treatment System

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ABSTRACT

For the estimate of greenhouse gas (GHG) emission from wastewater treatment plants, many approaches have been used. General criteria for CH4 and N2 O estimates based on per capita total waste loads have been offered by the United States Environmental Protection Agency, World Resources Institute, and the Intergovernmental Panel on Climate Change (IPCC). In 2007, Bridle Consulting identified five distinct areas where greenhouse gases are released: bio-treatment, sludge treatment, chemical use, electricity use, and biogas generation. They also provided an empirical static model for the calculation of GHGs. A logical method for estimating GHGs from municipal treatment plants was proposed by Monteith et al. in 2005. Shahabadi et al.'s (2009 & 2010) complete mathematical model for estimating GHG emissions from on-site and off-site activities was first suggested. By Ashrafi et al. (2013), precise mechanistic models that dynamically characterise the behaviour of wastewater treatment facilities have been created.

The goal of the current study is to succinctly outline the different significant approaches and models that are available for the calculation of GHG emissions from wastewater treatment plants. As a follow-up to the current research, a comparison analysis will be done to determine each method's applicability and accuracy in estimating GHGs.

Keywords: Static and dynamic models, greenhouse gases, and wastewater treatment.

INTRODUCTION

Due to its likely abundance of water, an oxygen-rich atmosphere, and an appropriate temperature, Earth is the only planet in the solar system that can host life. Only Earth is known to have an atmosphere with the correct depth and chemical makeup, both of which are likely necessary conditions for supporting a variety of life forms on the planet. It is mostly composed of nitrogen (78%), which makes up the inert portion of the atmosphere; around 21% of it is oxygen, which is generally necessary for respiration processes in all living things; and just a little portion (0.036%) of it is carbon dioxide (CO2), which is needed by plants for photosynthesis. The atmosphere plays a crucial role in capturing enough of the energy emitted by the Sun to preserve the Earth's environment and support life. The Earth would progressively become hotter and hotter if the atmosphere were to totally absorb all of this energy. However, the Earth really absorbs it while also releasing it as infrared radiation. All of this increasing heat is not lost to space, but is instead partially contained by a few gases that are present in the atmosphere in very tiny amounts. Greenhouse Gases (GHGs) are the name given to these gases. Some of this heat is transferred to the Earth's surface via GHGs, which mostly consist of CO2, CH4, N2, O3, and water vapour. The majority of the thermal energy from the Sun would escape if these gases were absent from the atmosphere, making the Earth frigid (approximately 18°C) and unable to sustain life. A number of man-made gases have also been added to the atmosphere, most of which are more powerful than the preceding GHGs. These gases include sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and chlorofluorocarbons (CFCs). Recent human-made activities have greatly increased the amount of greenhouse gases (GHGs) in the atmosphere, which has raised the Earth's mean average temperature and is usually referred to as global warming.

sources of emissions of GHGs

The primary human-related sources of GHGs are as follows:

- The burning of fossil fuels and the clearing of forests, which increases the amount of CO2 in the atmosphere. Up to one-third of all human CO2 emissions are attributable to deforestation.
- Industrialization increases atmospheric levels of GHGs like CO2 and CH4.
- The sources of atmospheric methane include fermentation, manure management, rice farming, changes in land use and wetland habitat, covered vented landfill emissions, vented septic system waste, and wastewater management.
- The use of CFC in fire suppression and refrigeration.
- N2O concentrations rise as a result of agricultural activity.

Global greenhouse gas emissions by different sectors

Table 1 shows the global GHG emissions for the year 2004 from different sources and economic activity.

S. No.	Sector	% Emission	Remarks
1	Energy Supply	26	Due to fossil fuel burning
2	Industry	19	Emission from energy use excluded
3	Land Use, Land-Use Change, and Forestry	17	Decay of peat soil included, CO_2 removal by ecosystem not included
4	Agriculture	14	Biomass burning included
5	Transportation	13	Fossil fuel burning included
6	Commercial and Residential Buildings	8	Only includes on-site energy production and burning of fuel for heating purposes
7	Waste and Wastewater treatment	3	CO_2 emission from incineration of fossil fuel based (waste) products included.

GHG emissions from the treatment of wastewater

Wastewater treatment facilities are used to eliminate the germs that cause water-related illnesses, turn trash into useable resources, save water and nutrients, and stop contamination of both land and water sources.

Energy is needed in several operations in WWTPs as well as for lifting wastewater. At the point of production, GHG emissions are caused by the energy provided to WWTPs. Additionally, the wastewater treatment plants (WWTPs) release GHGs at various times throughout the process. At the time of material production, the materials utilised in construction, as well as the operation and maintenance of WWTPs, generate GHGs.

The WWTPs are acknowledged as one of the largest minor sources of GHG emission because of the aforementioned facts.

Techniques for Calculating GHG Emissions

Due to growing worries that global warming may have a negative impact on climate change, awareness of GHG emissions has risen globally in recent years. The Global Warming Potential (GWP) of the GHGs varies. A gas with a high GWP has a higher impact on the environment when it is released in smaller amounts than a gas with a low GWP. The heat-trapping potential of one kilogramme of N2O and one kilogramme of CH4 is equivalent to 296 and 23 kilogrammes of CO2, respectively. Both on-site and off-site operations at the WWTPs generate a significant quantity of GHG emissions.

Numerous organizations/research groups operating in the field and labs, as well as different pollution control bodies, have undertaken efforts to quantify and inventory GHG emissions. There are several models and approaches to choose from. On the one hand, there are methodology for calculating GHG emissions using emission factors and on the other, there are empirical static models , comprehensive dynamic models , and methodologies for calculating GHG emissions using emission factors. The following list of key techniques and models is provided.

Methodology used by the Intergovernmental Panel on Climate Change (IPCC) to estimate GHG emissions

To calculate greenhouse gas (GHG) emissions, the Intergovernmental Panel on Climate Change (IPCC) employs a thorough and rigorous approach. The process used by the IPCC is multi-step and is based on the greatest scientific information and expertise currently available. Here is a summary of the IPCC's general methodology:

Data Gathering: The IPCC gathers information from a range of sources, including as national inventories, scientific publications, business reports, and expert opinions. Information on land use changes, industrial operations, agriculture, and other pertinent fields are all included in this data.

The quantity of GHG emissions generated per unit of activity or energy spent is measured by emission factors, which are coefficients that are determined by the IPCC. Based on data from measurements and scientific study, emission factors are unique to many industries and activities.

The physical or commercial actions that cause GHG emissions are referred to as "activity data," which the IPCC gathers. This contains information on the creation and use of energy, as well as statistics on various industrial, agricultural, and forestry operations.

Models for Estimation: Based on the data gathered, the IPCC employs a number of models and approaches to estimate GHG emissions. To determine emissions for particular industries, areas, or nations, these models use emission factors, activity data, and other pertinent information.

The IPCC performs uncertainty studies to determine the range of potential emission levels while acknowledging the inherent uncertainties in calculating GHG emissions. This aids in giving stakeholders and policymakers a better grasp of the accuracy and bounds of the estimations.

Review and Consensus: The IPCC employs a stringent review procedure that includes professionals and scientists from all across the globe. The draught reports are looked through many times by specialists, governments, and the general public. The involved countries must unanimously approve the final evaluation reports.

Development of Scenarios: In addition to calculating current GHG emissions, the IPCC creates emission scenarios that examine potential future paths depending on various socioeconomic and technical suppositions. These hypothetical situations aid in the understanding of the possible effects of various policy options and directions by policymakers.

Techniques for estimating CH4

The amount of organic matter in the wastewater is the main cause of GHG emissions from the wastewater treatment system. In addition to this, a number of additional variables affect GHG emission. Climate, the existence, nature, and state of the sewage system, the kind of treatment method used, the effectiveness of that method, the state of the local economy, etc. Numerous information on the characteristics of wastewater, the scope and type of sewage systems, the level of treatment used, the ultimate discharge of effluent to the receiving bodies, etc., is necessary for the assessment of greenhouse gas emissions.

According to data accessibility, IPCC 2006 offers three tier techniques, which are detailed below7:

Tier 1 approach: Due to the restricted data availability for this approach, particular emission variables are taken into account while estimating GHG emissions.

Tier 2 approach: For the estimate of GHG emission, this method further takes into account country-specific emission factors and activity data in addition to the default values used in Tier 1.

Tier 3 approach: This approach is useful in situations when the majority of the needed data are accessible.

Both rural and urban locations often have different wastewater treatment systems and ultimate effluent disposal pathways. This diversity may also be seen from one area or nation to another.

With these concerns in mind, IPCC 2006 created an inventory table called "(Table 6.5)" that offers suggestions for elements to be included, values for different levels of urbanisation, and the extent to which various income groups use treatment or discharge pathways or methods. Beyond this, the IPCC 20067 also suggests a number of alternative default choices.

Methodology for Calculating the Probability of Emissions of Nitrous Oxide (N2 O)

It is divided into two groups. Direct emissions are those that originate straight from treatment facilities and are included in the first category. The second category, often known as indirect emissions, includes all emissions that occur after effluent (processed wastewater from a wastewater treatment facility) is discharged. The indirect emission may happen when treated wastewater is transported or when it is eventually dumped into an aquatic environment, such as a lake, river, wetland, or the ocean.

Because the direct emissions from nitrification and de-nitrification in the wastewater treatment process are often significantly less than those from the effluent disposal process, including its route, they may be regarded as a minor source. 3.2 g N2 O/person/year is the estimated overall emission factor to calculate N2 O emissions from wastewater treatment facilities. For the calculation of the indirect N2O emission from the disposal of wastewater and its IPCC 20067 also proposes several equations that are appropriate for pathways:

Methodology for estimation of GHG emission adopted by World Resources Institute, USA

The approaches for estimating GHG emission are recommended by the World Resources Institute in Washington, DC, USA. The Climate analytical Indicators Tool (CAIT) is a free analytical tool that can be used via the website "http://cait.wri.org" to make estimating easier and more user-friendly. Numerous items produced by CAIT each have a distinct value. Here are some of the products discussed:

Web-based interface programme called CAIT (online) offers sector-specific country-level GHG emissions statistics for 186 nations.

The following are three more CAIT modules that include various data and indicators:

CAIT-UNFCCC is a fundamental interface for accessing and evaluating official GHG emission statistics provided to the Convention Secretariat by UNFCCC signatory Parties.

A data and indication viewing interface for U.S. states is called CAIT-U.S.

An interface for data and indications about a nation's vulnerability and adaptability is called CAIT-V&A.

The Carbon Dioxide Information Analysis Centre (CDIAC), the U.S. Environmental Protection Agency (EPA), the International Energy Agency (IEA), the Energy Information Administration (EIA), and other organisations provided the data basis for the CAIT programme. However, for the trash sector, the US EPA provided the majority of the methodology and data.

Methodology for estimation of GHG emission adopted by Water Environment Federation

A Technical Practise Update (TPU) for the assessment of GHG emission, specifically from wastewater treatment plants, has been released by the Water Environment Federation. Brief summaries of protocols created by a number of significant organisations active in voluntarily prescribing GHG emission reporting criteria are provided.

These institutions include The Climate Registry (TCR), The Organisation of International Standards (ISO) 14064 GHG standard (2006), The World Resources Institute/World Business Council for Sustainable Development (WRI/WBCSD) GHG Protocol (2005, etc.). In order to provide better estimation techniques and emissions factors that may be used to more precisely characterise local facility-level emissions based on particular operational characteristics, WEF gathers data from the procedures and other pertinent field observations. The same process was used in each instance to create the GHG emission inventory. The process consists of choosing a base year, defining inventory boundaries, identifying and classifying facility GHG emissions sources, and then quantifying the emissions in terms of CO2 equivalent.

The United States Environmental Protection Agency (US EPA) devised a methodology for estimating GHG emissions.

The US EPA's recommended methods for estimating GHG (CH4 and N2 O) from the process of treating household wastewater are provided under two different headings, the first for CH4 estimate and the second for N2 O estimation. Similar to the IPCC, CO2 emission has no place since it is a biogenic source. Under the following four categories, CH4 may be emitted from both onsite treatment facilities, such as septic systems, and from off-site centralised treatment systems, such as publicly owned treatment works (POTWs):

Septic system, centrally treated aerobic and anaerobic systems, centrally treated aerobic and anaerobic systems, and anaerobic digester

The addition of all four of the aforementioned factors results in the total emission from the household wastewater sector.

N2 O Emission Estimation from Domestic Wastewater Treatment: The US EPA uses an approach that is similar to that outlined by IPCC, 2006.

The aforementioned approaches use a process to inventory GHG emissions by nation or area based on a variety of emission characteristics in order to forecast overall emissions. The nation or area taken into account for GHG inventories has a broad range of climatic and geographical circumstances, the ability to generate waste, and other social and cultural practises. Although not taken into account in GHG inventories, these variables have an impact on GHG emissions. For instance, Rajasthan in India has significantly distinct circumstances from Ladakh and Kashmir. However, using a country-specific emission factor for India won't provide a true picture of global GHG inventories. These approaches do not accurately estimate the GHG emissions from wastewater because they do not take into account all of the physical, chemical, biological, and microbiological processes that are involved in the wastewater route, wastewater treatment, and effluent disposal system. More precisely, the IPCC methodology excludes measures to reduce GHG emissions at wastewater treatment facilities.

The GHG emissions inventories based on the aforementioned approaches only serve as a guiding element to access and plan for GHG emission management. They are thus more committed to the computation or estimate of GHG inventories at the national or regional levels than to the assessment of individual plants or processes. Yerushalmi et al. 2011 provide more evidence for the aforementioned claim in this respect. One of the most significant drawbacks of the assumption is that CO2 emissions from the breakdown of biomass, food waste, etc. in wastewater treatment plants are not included since they are biogenic emissions. Thus, it's possible that the aforementioned techniques won't work to determine the GHG emissions generated by a certain wastewater treatment facility. It is important to note that food or biomass are seldom generated without the usage of fossil fuels. Consequently, CO2 emissions from the breakdown of organic waste in wastewater may be included in overall GHG emissions. GHG emissions are produced during the production, transmission, and transportation of the energy and materials used in WWTPs to the treatment sites. However, the inventories recommended by the aforementioned approaches do not include GHG emissions for the waste sector for consumption of energy and materials. Therefore, predicting GHG emissions using the aforementioned inventories does not provide an accurate picture of the industry.

Wastewater treatment facilities use a variety of procedures and treatment methods that release GHGs. The wastewater treatment plant should be based on abatement measures to decrease GHG production and avoid potential carbon GHG taxes since Kyoto and following protocols deemed wastewater treatment plants to be especially sensitive to imposing taxes and penalties on GHG emission. The wastewater treatment facilities may use treatment methods that lower carbon footprints and qualify for carbon credits.

By identifying the crucial process parameters that regulate GHG emissions, the operation parameters and process parameters of the WWTPs may be improved.

Many researches have attempted to provide process parameter and operating condition optimisation to lower total GHG emission from WWTPs9 while keeping the aforementioned in mind.

The following are the approaches used by many researchers in addition to the primary methodology mentioned above for estimating GHG emission from wastewater and wastewater treatment plants. The researchers have made an effort to examine the real mechanisms that cause GHG emissions using process and plant investigations. These techniques may be used to reduce wastewater emissions as well as GHG emissions due to wastewater treatment and disposal. For the purpose of estimating GHG emissions, researchers have sought to create static and dynamic models based on laboratory and field data.

Here is a quick description of these techniques:

Bridle Consulting (2007) adopted a method for estimating GHG emissions.

The following five components of a wastewater treatment system, namely bio-treatment, sludge treatment, chemical use, electricity use, and biogas generation, are said by Bridle (as stated in Snip (2010) to be GHG generating. An empirical individual model was suggested for each section to estimate GHGs. Bridle has suggested a complete model for bio-treatment that comprises of three processes—endogenous biomass decay, BOD oxidation, and nitrogen removal—where GHG creation is possible. The emissions resulting from the usage of chemicals are also included in the complete model. The model allows for an accurate estimation of the GHGs. The processes of anaerobic digestion and sludge reuse yield the highest greenhouse gases. It is possible to simulate the N2O emission dynamically and in greater detail. This provides a more accurate picture of how much N2 O is produced during wastewater treatment and generation.

The GHG emission estimate method used by Monteith et al., 2005

A logical method for estimating GHG emission from municipal wastewater treatment plants was established by Montheith et al. in 2005. The method may be used to calculate a facility's carbon-based GHG emissions per cubic metre of treated wastewater for various processes using either plant-specific data or more generic area data.

The main greenhouse gas (GHG) released by municipal wastewater treatment facilities is CO2, with very little methane (CH4). Full-scale data from 16 Canadian wastewater treatment plants were used to assess the technique, which was then deployed to 10 Canadian provinces. The process discovers ways to lower GHG emissions at municipal wastewater treatment facilities.

An acceptable system boundary and the inputs needed for the system were established in order to utilise the technique. When plant-specific data is available or not, methods for calculating GHG emissions have been devised. The processes within the systems that produce GHGs have been identified. The serialised calculations created to be used in the absence of plant level data were compared to the GHG emissions calculation utilising plant specific data. The approach calculates carbon-based GHG emissions, which are mostly CO_2 and CH_4. The emission of N_2O from wastewater treatment plants, a GHG component, has not been taken into account by this technique.

However, the author has recommended further research to be done to estimate N_2O at treatment facilities while also examining N_2O's potential as a GHG. The assessment of carbon-based greenhouse gas emissions is only applicable to on-site treatment operations inside system boundaries. According to the methodology's findings, CO_2 is the main GHG released by facilities in Canada.

Anaerobic digestion of solids produces methane, which is then burned to create CO_2, which lessens the potency of CH_4 relative to CO_2. This technique excludes the GHG emissions from off-site solids transportation, off-site chemical synthesis, and off-site treated effluent disposal. It also excludes off-site solids transportation and solids degradation.

Shahabadi et al.'s (2009 & 2010) method for estimating GHG emission

Shahabadi et al. (2009 & 2010)[19,20] proposed a thorough mathematical model that estimates all GHG emissions from on-site and off-site activities of wastewater treatment plants while taking into account various types of treatment processes, such as aerobic, anaerobic, and hybrid - anaerobic/aerobic processes. Due to the lack of relevant data, the emission estimating technique only estimates on- and off-site CO_2 and CH_4 generation. N_2O emission is not estimated. The off-site GHG emissions are calculated using the amount of power used for lighting, electrical equipment operation, and liquid mixing in reactors. Based on the plant's power requirement, the emission factor for the source of electricity production has been taken into account for this reason.

Estimates have been made of the off-site GHG emissions caused by the breakdown of residual biosolids in digester effluent. The effect of recovering and using biogas on GHG emissions has also been attempted to be estimated. They have also researched the effects of GHG emissions brought on by nitrogen removal. In the case of an aerobic treatment system, the total on-site GHG emissions expressed in terms of CO_2 equivalent per day were found to be higher than off-site emissions. However, the outcomes for the anaerobic and hybrid treatment systems were distinct from those for the aerobic treatment system. In the case of anaerobic and hybrid treatment systems, it indicates that total GHG emissions off-site were higher than those generated locally. The authors have also proposed GHG reduction solutions based on recovering and using biogas for energy production in lieu of burning fossil fuels, based on the data obtained.

To reduce the amount of energy used in the digester, authors advise using psychrophilic treatment rather than mesophilic and thermophilic treatment. The authors have suggested techniques to employ alternate nutrient removal processes, such as the anaerobic process, anammox, which removes nitrogen with a lower consumption of energy and reduced carbon usage, as part of efforts to reduce greenhouse gas emissions.

Yerushalmi et al. (2011) investigated how the primary process variables of aerobic, anaerobic, and hybrid wastewater treatment processes—which Shahabadi et al. (2009 & 2010)19, 20 considered—affected total on-site and off-site GHG emissions. The main clarifier's underflow rate, SRT, and the temperatures of the reactors and sludge digesters were determined to be the critical process parameters. The anaerobic sludge digester's operating temperature has the most impact on GHG production in the aerobic treatment system.

The study's findings have led the authors to suggest methods for reducing GHG emissions in various treatment process systems. By decreasing the removal ratio of VSS and increasing the removal ratio of BOD in the main clarifier, it is possible to achieve minimal GHG emission throughout the aerobic treatment process. Reducing the anaerobic reactor's waste ratio will reduce GHG emissions in anaerobic treatment systems. In a hybrid treatment system, GHG emissions are reduced by decreasing the main clarifier's VSS and BOD removal ratios, increasing its SRT and waste ratio, and decreasing its SRT in the anaerobic reactor.

Conclusions

As a result, inventories and measurement of GHG emissions are necessary. numerous pollution control agencies, other relevant organisations, and research organisations have presented numerous methodologies and static/dynamic mathematical models for this purpose. In 1997 and again in 20064,5, the IPCC most likely put forward the first comprehensive methodology/guidelines for estimating greenhouse gas emissions. IPCC 2006 offers three tier (tier 1, tier 2 and tier 3) techniques depending on the data's availability. To make the estimate easier to use and understand The World Resources Institute (WRI) USA has developed web-based interface software that estimates country-level GHG emission by industry8. A Technical Practise Update (TPU) for the estimate of GHG emission, specifically from wastewater treatment plants, has also been released by the Water Environment Federation. The Climate Registry (TCR), The Organisation of International Standards (ISO) 14064 GHG standard (2006), and other organisations' information, along with pertinent field observations, is incorporated by WEF (2009)15 to create better estimating techniques and emissions factors that can be used to more precisely characterise local facility-level emissions based on particular operating parameters. The US EPA has also recommended that the mathematical equations for estimating GHG (CH4 and N2 O) from the process of treating household wastewater be provided under two different headings, the first for CH4 estimate and the second for N2 O calculation. The US EPA's suggested approach is fairly similar to the IPCC's approach.

Due to its biogenic nature, none of the aforementioned organisations recommend any methodology for the assessment of CO2 emissions emitted due to the breakdown of organic waste in WWTPs. Furthermore, there is only a limited use for these approaches in measuring GHG emissions unique to plants. Several research groups have proposed several static and dynamic models to enhance the plant specific estimate process. After researching the real mechanisms responsible for GHG emissions during WWTP operations, Ashrafi et al. (2013) published their findings.

These techniques may be used to reduce emissions from wastewater treatment and disposal in addition to GHG emissions.

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