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Greenhouse Gas (GHG) Emissions from Urban Wastewater System: Future Assessment Framework and Methodology

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ABSTRACT

Over the last two decades much scientific effort has been expended on the radiative gaseous emissions in the atmosphere. Although there are no regulatory requirements for managing gaseous emissions at present, the long term indications are, that impact relater to air pollution must embrace the broad diversity and challenges associated with urban wastewater cycle management. This study has been considered as a precursor to development of a comprehensive impact assessment of gaseous emission from urban wastewater infrastructure and treatment facilities. It has been carried out in consideration of the future climate change scientific projections, including socio-economic and environmental impacts. Major progress could be gained from systemic approaches in relation to factors influencing emission and the collected data demonstrates correlation between wastewater quality, treatment and energy used with the level of emission. An early attempt was made to attribute environmental impact and costs on per capita basis, as the weight of responsibility to take action is shifting to the community and individuals. The presented framework and methodology offers reliable evaluation of gaseous emissions is an integrated context comprising technology, environment, social and economic factors.

Key words: GHG emissions, urban wastewater system, assessment framework and methodology

1.0 INTRODUCTION

The study of gaseous emission, climate change and air pollution is committed to physico-chemical identification, inventories, measurement and assessment methods as well as on quantitative study of the actual anthropogenic sources and its direct contributions. The causes brought on by human activities include: (i) emissions from wastewater discharges, (ii) sewage collection and transportation, (iii) wastewater treatment plants (WWTPs) and (iv) associated activities.The level of uncertainty in the wastewater industry's "carbon profile" is unacceptable in the emerging business environment of carbon pricing, and managerial commitments to "zero carbon emission". Methane and nitrous oxide emissions in particular have much higher global warming potentials than carbon dioxide (Foley *et al*., 2007).

A team of scientists from Columbia University found evidence that emissions of nitrous oxide from wastewater treatment

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may be significantly higher than previous estimates. Nitrous oxide is a powerful greenhouse gas that is almost 300 times stronger than carbon dioxide (Casey, 2010). The emission of these gases has also been linked to health effects in humans and domestic animals.

Increasingly the attention, necessities and expectations to reduce emissions are rising and turning to businesses or individual's obligations and at least in part on a per capita principle. Serious consideration of these issues can be possible only on the basis of good information. However, there is generally a lack of information related to emission from wastewater system including various treatment processes. The main reasons include the absence of regulatory requirements for managing gaseous emissions, complex and expensive fugitive emission monitoring and lack of reporting and compliance standards.

Water authorities in many parts of the world are adopting "carbon neutrality" objectives aimed at reduction of the GHG emissions predominantly, by using electricity from renewable sources. Current methodologies and estimates of greenhouse gas emissions for the wastewater sector have focused on energy use for and wastewater management (e.g. electricity and fuel consumption).

On the local, regional and global scales, there is growing concern about the negative environmental impacts of air pollution and its adverse impact on human health, fauna and flora. The main advantage of this study is in the accounting of gaseous emissions that is transparent and verifiable. This is especially helpful, as it is particularly challenging to provide gaseous emission estimates on wastewater cycle including sewage infrastructure and treatment facilities. The inventory provides further ability to utility operators to develop its long term strategy and comply with a broad range of any future emission and sustainability issues including reporting, emission reductions, and emission trading.

2.0 ASSESSMENT FRAMEWORK

The definition of assessment framework for gaseous emissions from urban wastewater system appears necessary to the development of future adaptation strategies and knowledge to manage emissions from wastewater cycle. It should be developed to interact with the adaptive responses that could address emission sources, infrastructure, the pathways for gaseous emissions and its concentrations, mitigation capabilities and technologies. The main tasks in this framework incorporate several areas including:

- Understanding emission generation processes (spatial, temporal, physical, bio-chemical) with the key motivation issues including the pathways for gaseous emissions and concentrations;
- Identification of appropriate and reliable parameters as a basis for the adaptation of the strongly variable combined wastewater flow to the actual treatment capacity;
- Establishment of credible methods of obtaining data and information from defined emission sources;
- Quantification and predictions of gaseous emissions.

Amongst the broad diversity of wastewater sector the analysis of gaseous emissions could be assessed in two essential emission categories:

- Direct emission related to wastewater sources and activities that promote fugitive gaseous emission related to physical and bio-chemical processes that are characteristic to wastewater and its by-products during the wastewater cycle;
- Indirect emission - energy use associated with the wastewater transportation, pumping, various treatment processes, effluent disposal, residuals management, etc.

The main factor in this regard is the use of biological wastewater treatment, aerobic or anaerobic treatment technology, sludge processing and also the electricity used. While assessment of emission related to energy consumption (CO_2 equivalent) is relatively straight forward, quantifying direct fugitive emissions from wastewater systems is an area of uncertainty for the industry, with less developed and less reliable methodologies. The diffused emissions include substances such as: CH_4, CO_2, VOCs, NO_x, CO, PM10, Mercury, Cadmium and Lead, hydrogen sulphide (H_2S), ammonia (NH_3), and sulphur dioxide (SO_2), which have adverse affect on air quality, environment and public health.

At a practical level, the proposed framework is about setting a standardised model that can be applied for the development of complete emission inventory by using emission factors, spatial and temporal scales, emission modelling, calibration, verification and reporting.

In this sense, the future research should refer to creating awareness by combining the assumptions taken by existing research, theory as well as practical knowledge, data and practices across multiple disciplines, to enable integration in a trans-disciplinary way. A key prerequisite for a comprehensive inventory of emissions from sewers and wastewater treatment plant (WWTP) requires reliable information about the treatment process operation and its behaviour on varying spatial, temporal, hydraulic, COD and nutrient loads.

3.0 CHARACTERISATION OF GHG EMISSIONS FROM WASTEWATER

Wastewater pathways often differ from rural, urban, developed and underdeveloped countries. The most common urban system in developed countries consists of the network of underground sewer pipelines (gravity or pressure), holding tanks and pumping stations; and centralised wastewater treatment plant discharging effluent to rivers or ocean outfalls.

Wastewater originates from a variety of residential, commercial and industrial sources and it is a primary source of gaseous production. The gases found in sewer drains are oxygen, nitrogen, carbonic dioxide, carbonic oxide, ammonia, carbonate of ammonia, sulphide of ammonium, sulphuretted hydrogen and marsh gas. This mixture is continually changing, according to the degree of putrefaction of the foul matters, which form sediment and a slimy coating of the inner surfaces in sewer pipes (Commonwealth of Australia, 2008). During collection process, sewage is subjected also to combination of anaerobic or aerobic conditions including mixing, infiltration, dilution, stagnation, heating, cooling, bubble and surface volatilisation, etc. under which the initial decomposition takes place. Raw sewage contains urea and faecal materials that contain high level of nitrogen. During transportation of wastewater through pipes the majority of nitrogen is converted from organic nitrogen to ammonia in the process called ammonification or hydrolysis.

Municipal sewage treatment plants play an important role in the abatement of water pollution, but they also produce a large amount of gaseous emissions to atmosphere. The discharge of large volumes of fugitive gases that contains low levels of chemical constituents may still lead to an excessive contribution to air pollution. Most centralised wastewater treatment methods consist of combination of biological processes (activated sludge reactors, trickling filters, anaerobic digesters, etc) that promote biodegradation of organic matters by micro-organism and production of anthropogenic CH_4, and N_2O gaseous emissions.

Methane (CH_4) production is directly resulting from anaerobic decomposition of the organic matter present in sewers. The methanogenesis or CH_4 production rate depends primarily on the concentration of the degradable organic material in wastewater measured by Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD). The main environmental factors which influence methane production include; retention time, pH, temperature, presence of sulphate reducing bacteria and methanogens (Guisasola *et al*. 2008).

Nitrous Oxide (N_2O) and nitric oxide (NO) production is associated with breakdown of nitrogen components that are common in wastewater eg protein, urea. Biological nutrient removal (BNR) processes have the ability to transform the ammonia and organic nitrogen compounds into nitrogen gas, which can be released to the earth's atmosphere. The two-phase process involves nitrifying bacteria (Nitrosomonas), that oxidize ammonia to create nitrate (aerobic phase) while denitrifying bacteria reduce nitrate, turning it into nitrogen gas, which is then released to the atmosphere (anoxic phase). N_2O and NO can be released during both of these processes; however it is mainly associated with denitrification. Aerobic treatment process produces relatively small emissions, whereas anaerobic processes emission can increase by 50-80% (Ki Young Park *et al.* 2000).

The hydrogen sulphide (H_2S) gas evolves from the anaerobic decomposition of organic matter or from the reduction of mineral sulphites and sulphates. H_2S gas mixed with the sewage gases (CH_4, + CO_2) is highly corrosive to sewer pipelines, manholes, concrete junction chambers, mechanical and electrical equipment. Unless air or oxygen are deliberately injected to control sulphade concentration, the anaerobic conditions will be created to provide optimal conditions for gas formation. The experimental study carried out on the full scale sewage system (Guisasola *et al*. 2008) confirmed a strong correlation between formation of sulphide and methane gases and the hydraulic retention time. The observed common factors also include:

- Sulphide and methane gasses are generated as a result of bacterial metabolism therefore the time factor plays decisive role
- Production rate is positively correlated with the hydraulic retention time and the longer the detention time, the higher the gas production rate
- Production rate of methane in sewers could be correlated with the similar emission corresponding with CO_2 emission from energy usage in the wastewater treatment plant.

Carbon Dioxide (CO_2) production is attributed to two main factors; treatment process and electricity consumption. During anaerobic process the BOD_5 of wastewater is either incorporated into biomass or it is converted to CO_2 and CH_4. A fraction of biomass is further converted to CO_2 and CH_4 via endogenous respiration. Short-cycle or natural sources of atmospheric CO_2 which cycles from plants to animals to humans as part of the natural carbon cycle and food chain do not contribute to global warming. Photosynthesis-produced short-cycle CO_2, removes an equal mass of CO_2 from the atmosphere that returns during respiration or wastewater treatment. Digestion processes, either aerobic or anaerobic, also only emit short-cycle CO_2.

Volatile Organic Compounds (VOCs) emission occurs during entire wastewater cycle. A significant fraction of VOCs is released to atmosphere by gas-liquid mass transfer. VOCs production during wastewater transportation in sewers occurs during turbulent flow and air exchange between ambient atmosphere and wastewater. The transfer rate of emission is affected by physicochemical properties of chemicals, fluid and flow characteristics. There is a growing concern that several VOCs that are present in wastewaters, especially industrial effluents, find their way to the atmosphere. In particular VOCs such as benzene, chloroform, ethyl benzene, toluene, *m*-xylene and *o*-xylene are found in refinery and petrochemical wastewaters in significant amounts as well as in many municipal wastewaters (Bhattacharya, 1989) and (Al-Muzaini *et al.* 1991).

4.0 EMISSSION GENERATION FROM ELECTRICITY USE

Electricity consumption in the operation and management of the wastewater treatment plants, pipelines and pumping stations is directly related to the quantity of transported and treated wastewater, as well as an extent and type of infrastructure, degree of treatment that is required by the environment and customers. A great deal of energy is consumed in all stages of water cycle involving water supply and wastewater production (residential, commercial, industrial) as well as managing wastewater and its by-products products, transporting materials and products from one life-cycle stage to another.

Emission assessment (increase or abatement) from renewable and non-renewable energy sources is calculated based on consumption data and application of emission factor expressed as $kgCO_2/kWh$ that takes into account the type of fossil fuel combustion used in energy generation. Emission from fossil fuels is dominating and the level of emissions has significant environmental as well as economic implications now and more in the future. Electricity consumption varies depending on the treatment technology used such as sludge thickening, anaerobic digestion, dewatering, incineration and the consumption intensities could be expressed as functions of biomass loading on each unit process.

5.0 GHG EMISSIONS LIFE CYCLE FRAMEWORK

The relationship and interactions between wastewater generation, treatment, energy use and gaseous emissions is a complex one. Any attempts in emission quantitative and qualitative assessment are challenged by availability of accurate and relevant inventory and agreement on framework and methodology. Operational electricity consumption can be relatively easily metered therefore calculation and conversion to equivalent units of emission ($kgCO_2/kWh$) could be relatively straight forward. In some cases energy balance may be more complicated by use of various sources of energy (heat, renewable) or substantial energy is recovered and reused. The assessment of fugitive emissions remains unresolved, due to lack of consensus and definitive input in the following areas:

- Accurate inventory and methodology including spatial and temporal characterisation (gases types, quantity, quality, timeframe, boundary, concentration, load, etc) of gaseous substances
- Understanding of physical and biochemical processes, triggers, activities at various stages of the wastewater cycle, metabolic and operational changes
- Embodied energy or energy used over the life-cycle of wastewater assets, materials, important due to the focus on reducing the use of non-renewable energy sources (Randolph *et al*. 2007).
- No mandatory requirements to manage gasses generation (liquid phase) and emission (gas-phase) targets

The future of sustainable emission assessment lies in the adoption of a systemic approach that promotes a shift from the individual economic, social and environmental components of sustainability to one which recognises the inter-relationships between the components (Davidson *et al*. 2009) within the decision making framework.

Energy recovery potential exists in the form of methane gas that is generated during anaerobic treatment of wastewater, but utilization of methane is not attractive while treating small quantity of low strength wastewater and it is usually vented or flared. Due to global energy insecurity, there is emergent interest in using clean energy source (wind, solar) and minimal or zero use of hydrocarbons. The framework for emission assessment is shown in Figure 1. It responds to requirement for more consistency in the gaseous generation and emission practices. The framework is intended to promote convergence among processes, technology and sustainability requirements and it builds upon a number of long-standing procedures and activities that describe wastewater cycle, environmental compliance, technological process characteristics, regulatory policies, social and community expectations.

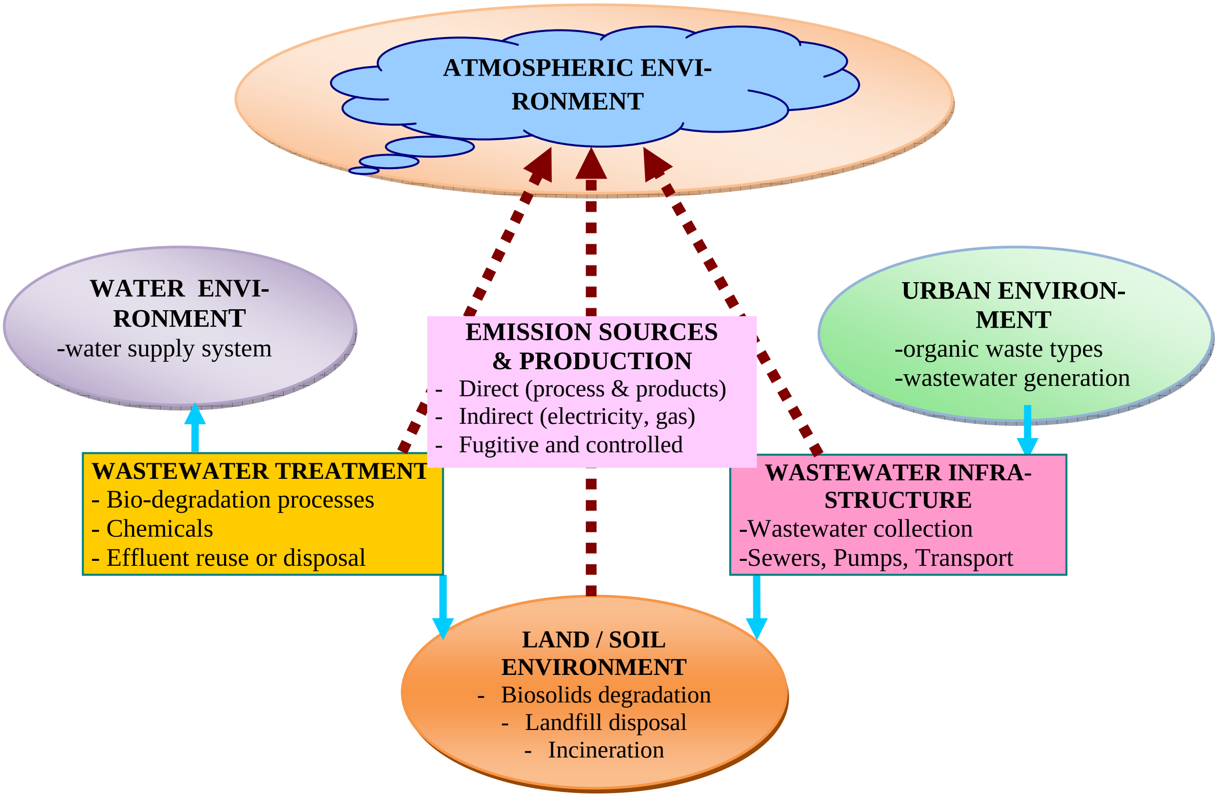

Figure 1 GHG emission assessment framework from wastewater cycle

Based on the above framework, a full emission assessment related to wastewater cycle can be developed and it should consist of the following four parts:

• Definition of the scope, goals and objectives involving specific references related to input / output within defined assessment boundary;

• Inventory of the materials and energy used during all stages in the wastewater processing with the main focus on an inventory of gaseous releases throughout the entire production cycle;

• Impact assessment that examines potential and actual effects related to the use of resources and atmospheric releases;

• An assessment of the changes and implementation of necessary improvements

Such an exercise would require extensive resources and it would still result in a significant dilemma due to inconsistencies with protocols and a lack of quantitative information. These are mainly related to environmental impact and the extent to which these emission sources have on the global warming. For obvious and practical reasons it would be reasonable to apply a streamlined or simplified version that can be limited to items (2) and (4), that include quantitative emission inventory and consideration of necessary improvements that could result in reduction of gases generation and emissions. For the purpose of this analysis, priority consideration should be given to the following gases: methane (CH_4), nitrous oxide (N_2O), hydrogen sulphide (H_2S) and carbon dioxide (CO_2).

6.0 GHG EMISSION FLUXES FROM WASTEWATER TREATMENT OPERATIONS

Flux rates of gaseous emissions can be calculated by subtracting gas concentration at the beginning of the accumulation period from the concentration at the end of the accumulation period that are relative to the time elapsed. Wastewater treatment is also considered a global warming mitigation factor. Without proper treatment, the carbon in discharged wastewater will eventually enter the ecosystem as CH_4 (or CO_2), without the potentials for offset associated with biomass segregation and biogas energy recovery. The methodology used to estimate indirect greenhouse gas emissions form electricity use is based on Technical Guidelines (DCCEE, 2010) and the following formula:

$$\mathrm{Y_i} = Q_i \times \frac{\mathrm{EF_i}}{1000} \tag{1}$$

where,

Yi - the total indirect greenhouse gas emissions in year (i) (CO_2-e)

Qi - the quantity of electricity purchased by the desalination plant from the electricity grid in year (i) (kilowatt-hours)

EFi - is the emission factor for electricity consumed in NSW in year (i) (current factor = 1kWh = 0.967 kg of CO_2-e

During the wastewater treatment process major energy reductions can be gained by applying primarily anaerobic processes to convert the energy of the incoming wastewater pollutants to methane, which could be used to generate electricity, potentially eliminating any net energy input to the process. In aeration basins, air is bubbled through wastewater using submerged diffusers to deliver oxygen to aerobic bacteria that degrade organics and oxidize nitrogen species. Volatile organics, many of which cause foul odours, are stripped from the water during aeration. While most of the research focuses on the emission sources, it is important to consider distribution paths as well as an ultimate destination and cumulative effect on air, water and soils. Key constituents responsible for gaseous emission in wastewater treatment process are: BOD_5, SS, N & P.

Direct emission estimation (Eair) takes into account the following elements:

- Eair - air release rate, (kg/day)
- A - wastewater surface area, (m^2)
- Cair concentration of substances in air (g/m^3)
- V_{air} gas flux rate i.e., volume flow per unit of wastewater surface area. (m^3/m^2) and it can be calculated using the following formula:

$$\mathrm{Eair} = \frac{C_{air} \times V_{air} \times A}{1000} \tag{2}$$

Emission factors for wastewater treatment process are applied to estimate emissions and it relates to the quantity of substances emitted from a source, to activity associated with those emissions. Emission factors are usually expressed as the weight of a substance emitted, divided by the unit weight or volume of wastewater discharged from the whole process, or from an individual unit operation. Emission rates (Commonwealth of Australia,

2008) are estimated for individual steps in a treatment process by the application of equation;

$$\text{Eair} = \frac{\text{EF} \times \text{Q} \times \text{Top} \times (1-0)}{10^6} \quad (3)$$

where,

Eair = annual air emission of ammonia, tonne/yr

EF = uncontrolled emission factor, g/m3

Q = daily volume of wastewater treated, m3/d

Top = Time of operation (days during the calculation period; say a year),

f = emission control equipment efficiency

According to (WSAA, 2009) continued improvement standards from primary to tertiary wastewater treatment resulted in fourfold increase in energy consumption. Calculation of emissions can be done using theoretical or experimental emission factors by using BOD_5 that represents the amount of organic fraction in the wastewater stream. The calculations of CH_4 emission can be expressed in kilograms of CO2-e per capita per year, using the following formula:

$$\text{GHG} = BOD_5 \times (1\text{-Fsl}) \times \text{Fan} \times \text{EFw} \times 21 \quad (\text{kg } CO_2\text{-e}) \quad (4)$$

where,

Fsl—Default fraction of BOD_5 removed as sludge. Should be readily available from internal records of wastewater treatment plants (default value of 0.54)

Fan — Default CH_4 emission factor for wastewater with value of 0.65 kg CH4/kg BOD_5

EFw—Fraction of BOD_5 anaerobically treated. This value varies according to wastewater treatment type (Commonwealth of Australia, 2010).

The BOD_5 calculation is done by allowing the following parameters:

- Average volume /person/ day = 210 L (EP= equivalent population)
- BOD_5 concentration in wastewater ranges from ~110-350mg/L

Average daily BOD5 load can be calculated as follows:

$$BOD_5/\text{y} = 200\text{mg/L} \times 210 \text{ L} \times 365 \text{ days} = \sim 15.3\text{kg/p/y}$$

Wastewater quality has direct relation to emission loading. Table 1 illustrates typical concentration of pollutants, production and load of various substances based on per equivalent population factor (EP) per day. EP basis are defined as units (people) representing combined daily wastewater flow from an average customer and it is defined as follows:

$$EP = EP_{residential} + EP_{commercial} + EP_{industry} + EP_{other} \quad (5)$$

where:

$EP_{residential}$ = Residential Equivalent Population

$EP_{commercial}$ = Commercial Equivalent Population

$EP_{industry}$ = Industrial Equivalent Population

EP_{other} = Other Activities Equivalent Population

Table 2 presents information for Australian emission estimation based on average residential sewage quality. Emission Analysis from Energy Use at Wastewater Treatment & Water Reclamation Plant of Sydney Olympic Park Authority was conducted (Table 3). This factor defines the infrared radiation trapping potential of these substances relative to that of CO_2 and establishes these ratios as a number to estimate the global warming potential of that substance. This ratio times the quantity emitted results in the CO_2 equivalency of those emissions. Due to different heat-absorbing and the decay rate characteristics, each GHG generally has a different global warming potential (GWP) as shown in Table 4. Because of this variation, the emission factors used to calculate greenhouse gas emissions are stated in terms of carbon dioxide equivalents (CO2-e).

7.0 PERFORMANCE INDICATORS FOR GHG EMISSION ASSESSMENT

In the attempt to quantify emission it is important to define standards and indicators as a measure of how well the technology is meeting the needs and expectations. One of the primary tasks is to explain the role of Environmental Performance Indicators (EPI), how they have been applied to assess performance of the water reclamation scheme performance. Table 5 defines the most relevant indicators that have been selected to address sufficient flexibility and adaptability to range of wastewater treatment processes.

Table 1 Emission calculations based on typical wastewater (list constituents and concentrations are adapted from Tchobanoglous et al.2003)

Constituent	Unit	Range	Typical	Load / EP (kg/EP/day)	Load based on 5000 EP/d (kg/day)
Influent flow rate (EP)	l/p/day	190-270	210	–	–
BOD_5	mg/L	110-350	190	0.0399	199.5
TOC	mg/L	80-260	140	0.0294	147
COD	mg/L	250-800	430	0.0903	451.5
Total Nitrogen (TN) as N	mg/L	20-70	40	0.0084	42
Ammonia (NH4-N)	mg/L	12-45	25	0.00525	26.15
Nitrite (NO2-N)	mg/L	0-trace	0	0	0
Nitrite (NO3-N)	mg/L	0-trace	0	0	0
Total Phosphorous (TP)	mg/L	4-12	7	0.00147	7.35
Organic	mg/L	1-4	2	0.00042	2.1
Inorganic (PO4-P)	mg/L	3-10	5	0.00105	5.25
Chlorides	mg/L	30-90	50	0.0105	52.5
Sulfate	mg/L	20-50	30	0.0063	31.5
VOCs	mg/L	100 - 400	100-400	–	–

Table 2 Air emission factors for wastewater treatment (de Haas & Lant, 2009)

Substance (GHG)	Unit	Air Emission Factor	Process Capacity (EP)	Potential Emission Load (ton/day)	Potential Emission Load (ton/year)	Annual Cost of CO_2-e emission (1 ton=$40)
Carbon dioxide (CO_2)	kg CO_2-e/day/EP	0.26	8,000	2.11	769	$30,777
Methane (CH_4)	kg CO_2-e/day/EP	0.80	8,000	6.40	2,336	$93,440
Nitrous Oxide (N_2O)	kg CO_2-e/day/EP	0.30	8,000	2.40	876	$35,040

Table 3 Emission Analysis – Energy Use at Wastewater Treatment & Water Reclamation Plant

Energy Usage Area	**Input Parameter**	**Energy Usage (kWh/kL)**	**Energy Usage (kWh/y)**	**Emission (kg O_2/Y)**	**Cost of CO_2-e emission**
Wastewater treatment input (kL/y)	800,000			GHG coef.	1 ton CO_2-e
Treatment efficiency rate (%)	85			0.967	$40
Actual wastewater effluent Production (kL/Y)	680,000	0.60	408,000	394,536	$15,781
Stormwater input	550,000	0.15	82,500	79,778	$3,191
Microfiltration input (kL/Y) (effluent+stormwater)	1,230,000				
MF Efficiency Rate (%)	70				
Actual CMF filtrate production (kL/Y)	861,000	0.23	198,030	191,495	$7,660
Reverse osmosis input (kL/Y)	700,000				
RO efficiency rate (%)	75				
Actual RO permeate production (kL/Y)	525,000	1.10	577,500	558,443	$22,338
Recycled water disinfection	198,030	0.01	1,980	1,915	$77
By-products (biosolids, CMF backwash, retentate)	664,000	0.05	33,200	32,104	$1,284
Recycled water supply (kWh/Y)	198,030	0.28	55,448	53,619	$2,145
Total annual impact			1,356,659	1,311,889	$52,476

Wide selection and variability of pollutant in wastewater create additional complexity associated with addressing each pollutant of concern and its environmental impact. Although this might be important in specific situations such as industrial trade wastes production, when it comes to urban wastewater such impact is usually related to a group of pollutants and their aggregated impact. To carry out detailed assessment on such scale might be impractical, costly and might not necessary deliver desired outcome in the long run. This challenge can be successfully resolved by integrating pollutants, its concentration limits, volumes and time into a single combined unit - a Pollution Factor (PF). For consistency of measurement and application in wastewater cycle, the following PF formula has been adopted:

$$PF = \sum C_i \times \sum V \ (\%) \quad (6)$$

where,

PF = emission factor used for estimation of emissions to water or air

C_i = emission concentrations, in units of pollutant per unit of time

V = loading, unit of weight, volume, or duration of pollutants per unit of time.

Table 4 Characterisation factors used for GHG potential calculation (AARC, 2010)

Substance	GWP	Atmospheric Lifetime (years)	Acidification (SO_2 equiv)	Eutrophication equiv. PO_4^{3-}
Carbon dioxide (CO_2)	x 1	50-200	–	–
Methane (CH_4)	x 21	12	–	–
Nitrous Oxide (N_2O)	x 310	150	–	–
Hydrofluorocarbons (HFC's)	x 140-11700	264	–	–
Perfluorocarbons (PFC's)	x6,500-9,200	10,000	–	–
Sulphur hexafluoride (SF_6)	x 23900	3,200	–	–
SO_2	–	–	1.20	–
NO_X	–	–	0.50	0.13
NH_3	–	–	1.60	0.35
H_2S	–	–	1.88	–
COD	–	–	–	0.02
N	–	–	–	0.42
P	–	–	–	3.06

Table 5 Performance Indicators for emission assessment

Item	EPI - Environmental Performance Indicator	Relevance to Emission Assessment
1	Population	Resources demand
2	Wastewater generation per capita / per day	Contamination
3	Wastewater treatment / per day	Pollution reduction
4	Volume treated per capita / per day	Pollution reduction
5	Loads of BOD5, P and N	Pollution reduction
6	Removal of BOD5, P and N	Pollution reduction
7	Energy used / kL of wastewater treated	GHG, Use of resources
8	Energy used / kL of product water	GHG, Use of resources
9	Amount of nutrients TP & TN recycled	Pollution reduction
10	Biosolids production per kL of wastewater	Pollution reduction
11	Energy recovered , heat, electricity	GHG, Pollution reduction
12	Ratio of energy from renewable source	GHG, Pollution reduction

The science of the 'greenhouse effect' that leads to the warming is generally well understood, however substantial uncertainties remain in knowledge of some of the affects and the overall magnitude of changes. This selection was developed to ensure consistency of assumptions, input parameters, spatial and temporal boundaries adopted during assessment process. The performance indicators represent standard interface between the wastewater sources, treatment technologies and its products. The integral characterisation means a shift between mass flows that are exchanged during the transformation process (raw wastewater, products, treatment technology and emissions). Meaningful aggregation is necessary to reveal which changes in a process will lead to overall reduction or increase of emissions.

8.0 CONCLUSION

- The proposed future framework and methodology could help in evaluating gaseous emissions from aerobic, anaerobic wastewater treatment systems as well as impact related to energy use. It also could determine the contribution of individual processes to air emissions.
- The opportunity exists for more effective implementation of emission mitigation strategies based on minimizing the consumption of energy, the recovery and use of biogas for energy generation to replace fossil fuel combustion. Other options could involve conversion of carbon to methane via anaerobic processes and used as a source of energy for on-site consumption. The debate over the costs of GHG emission reduction is inconclusive and has become more complex as disagreements over the existence global warming and the scale of impact leading to decisions for determining the costs.
- Many organisations face a complex mix of challenges from a range of stakeholders to demonstrate effective actions aimed at emissions reduction. A holistic change management and a comprehensive behaviour change programs should provide a strong platform to launch a successful gaseous emissions reduction agenda. A truly integrated assessment of climate policy would include both the costs and benefits of mitigation in the analysis.

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