The estimation of greenhouse gas emission in leachate treatment plant and its carbon credit revenue

Tengku Nuraiti Tengku Izhar\textsuperscript{1,2,3} and Lim Pei Xuan\textsuperscript{1}

\textsuperscript{1}Faculty of Civil Engineering Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
\textsuperscript{2}Water Research Group (WAREG), Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
\textsuperscript{3}Geopolymer and Green Technology, Center of Excellence (CoE), Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.

E-mail: nuraiti@unimap.edu.my

Abstract. Landfilling disposal method has led to the more concern environmental issue around the world, which are greenhouse gas emissions. According to IPCC (2006), the waste sector is a major contributor to greenhouse gas (GHG) emissions, which accounts for about 5% of the global greenhouse budget. This 5% is methane (CH\textsubscript{4}) emissions from the anaerobic decomposition of solid waste and carbon dioxide (CO\textsubscript{2}) from the decomposition of wastewater. Methane is one of the most important greenhouse gas (GHG) due to it has about 21–23 times global warming potential than CO\textsubscript{2}. The CH\textsubscript{4} and N\textsubscript{2}O emissions released in leachate treatment systems are the second-largest sources of greenhouse gases. The study is aimed to estimate methane emissions in leachate treatment plant in Landfill Rimba Mas Perlis, Malaysia, and its carbon credit revenue. The CH\textsubscript{4} emission from the leachate treatment plant was estimated by using the United Nations Framework Convention on Climate Change (UNFCCC) methodology AM0013 and its economic benefit was determined based on the Clean Development Mechanism. From the study, the greenhouse gas emission in a leachate treatment plant has contributes to a reduction in carbon emissions by 233.21 tonnes/yr which could attract the carbon credit of RM 8,162.35 based on RM35/tonnes of CO\textsubscript{2}. The results indicate the anthropogenic emission in the leachate treatment plant can bring direct economic benefits to the local.

1. Introduction

Nowadays, huge amounts of solid waste are produced as a result of rapid population, industrial, and economic development, particularly in developing countries such as Malaysia. In Malaysia, the population grows gradually at a rate of 2.4% per year, and at the same time municipal solid waste generation was also expected to increase steadily [1]. Solid waste is becoming one of the world's most debatable environmental issues. Landfilling is the most commonly accepted and widely used way of disposing of municipal solid waste worldwide as well as in Malaysia [2]. Approximately 80–90% of MSW is landfilled and mostly open dumping in Malaysia [3,4]. This method of disposal has led to the environmental problem that is greenhouse gas emissions from the landfill and leachate treatment plant.

Greenhouse gases emissions have become a widely common environmental concern issues around the world in recent years due to it has the potential of causing global warming. In general, the term greenhouse gas means the gases that could absorb the solar radiation or destroy the protective layers in the upper atmosphere and cause greenhouse impact. The main gases in greenhouse gases (GHGs) are carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}), nitrous oxide (N\textsubscript{2}O) and the other gases are ozone, fluorocarbons,
and others. Landfill leachate is generated as a result of the percolation of rainwater through waste, chemical, biological waste processes and the inherent water content of the waste itself. Leachate generation occurs due to the biodegradation of MSW provided by anaerobic and/or aerobic microorganism combined with the characteristics and precipitation of residue. Leachate has a dark colour and contains inorganic salts, probably heavy metals, ammonia nitrogen and organic refractory and biodegradable matter. According to IPCC (2006) [5], the waste sector is a major contributor to greenhouse gas (GHG) emissions, which accounts for about 5% of the global greenhouse budget. This 5% is methane (CH$_4$) emissions from the anaerobic decomposition of solid waste and carbon dioxide (CO$_2$) from the decomposition of wastewater. Methane is one of the most important greenhouse gas (GHG) due to it has 21–23 times global warming potential than CO$_2$ [6]. The CH$_4$ and N$_2$O emissions released in leachate treatment systems are the second-largest sources of greenhouse gases. However, apart from the global warming potential of greenhouse gas, it is also a renewable energy that can gain economic potential for a country. Thus, this study is conducted to study the greenhouse gas emissions in a leachate treatment plant and its potential benefit sustainability.

2. Materials and methods

2.1. Greenhouse gas emission from leachate treatment plant by using United Nations Framework Convention on Climate Change (UNFCCC) methodology AM0013

The AM0013 Methodology is adapted to this project. AM0013 Methodology is based on the Methane Extraction and Power Generation project in Bumibiopower, Malaysia. The project involved a closed anaerobic system that will produce and collect consistently high quality methane rich biogas from palm mill effluent from Pantai Remis Palm Oil Mill in 2004. CH$_4$ emissions from open lagoon wastewater treatment system and CO$_2$ emissions were investigate from the 2004 project. This methodology applies to projects involving methane avoidance activities involving organic wastewater treatment plants, which meet specific technical conditions.

2.2. Emission calculations

The emission calculations involved are baseline emission and project emission calculations. Table 1 described the calculations description.

| Calculation          | Source                        | Gas       |
|----------------------|-------------------------------|-----------|
| Baseline             | Wastewater treatment (lagoon system) | CH$_4$, N$_2$O |
| Grid electricity generation |                          | CH$_4$       |
| Project              | Wastewater treatment (lagoon system) | CH$_4$, N$_2$O |

2.2.1. Baseline emission calculation. Baseline emissions include the open lagoon emissions, the grid-related electricity generation emissions replaced by this project and the emissions associated with the aerobic lagoon system discharge. The baseline emissions are determined using the following equations, as per the IPCC Guidelines:

$$COD_{inf}(kg/yr) = COD_{raw} \times \text{Capacity} \times \text{Time}$$  \hspace{1cm} (1)

where, COD$_{inf}$ represents the yearly influent COD of anaerobic lagoons without the project activity, COD$_{raw}$ is COD concentration of raw leachate, capacity is leachate treatment capacity, time is operation time.
3\[CH_4_{\text{emis}}(kg/yr) = COD_{\text{inf}} \times B_0 \times MCF\] (2)

where, \(CH_4_{\text{emis}}\) refers to \(CH_4\) emissions from the open lagoons, \(B_0\) is maximum \(CH_4\) of producing capacity, MCF represents \(CH_4\) correction factor.

3\[E_{CH_4/CO_2}(tCO_2 e/yr) = CH_4_{\text{emis}} \times GWP_{CH_4}\]

where, \(E_{CH_4/CO_2}\) represents equivalent emission of \(CO_2\), \(GWP_{CH_4}\) is global warming potential of \(CH_4\).

Electricity baseline emissions;

3\[CH_4_{\text{UASSF}}(kg/yr) = (COD_{\text{inf}} \times R_{COD}) \times B_0 \times MCF\]

where, \(CH_4_{\text{UASSF}}\) is capture by UASSF, \(R_{COD}\) represents the removal rate of COD in anaerobic system.

3\[Q_{CH_4}(TJ/yr) = CH_4_{\text{UASSF}} \times CV_{CH_4} \times CH_4\]

where, \(Q_{CH_4}\) is thermal energy that can be produced by the \(CH_4_{\text{UASSF}}\), \(CV_{CH_4}\) represents calorific value of \(CH_4\) and \(CH_4\) refers to the thermal efficiency of \(CH_4\) combustion.

3\[E_{oil/CO_2}(tCO_2 e/yr) = Q_{CH_4} \times CEF\]

where, \(E_{oil/CO_2}\) represents equivalent \(CO_2\) emission of fossil fuel without project activity, CEF is \(CO_2\) emission factor of the fossil fuel.

The IPCC guideline provides the default value of \(R_{COD}\) is 0.8, MCF for UASSF is 1.0, \(CV_{CH_4}\) is \(5.5 \times 10^{-5}\), \(CH_4\) is 0.8 and CEF is taken as 77.37.

\(N_2O\) emissions from aerobic lagoons discharge;

3\[N_{ef}(kg/yr) = TN_{ef} \times \text{Capacity} \times \text{Time}\]

where, \(N_{ef}\) is nitrogen of effluent discharged to aquatic environments per year, \(TN_{ef}\) is total nitrogen concentration of effluent.

3\[N_2O_{\text{emis}}(kg/yr) = N_{ef} \times EF_{ef} \times F_{N_2O-N/N_2O}\]

where, \(N_2O_{\text{emis}}\) represents yearly \(N_2O\) emissions, \(EF_{ef}\) is emission factor for \(N_2O\) emissions from discharged to wastewater and \(F_{N_2O-N/N_2O}\) refers to the conversion factor from \(N_2O\)-N to \(N_2O\).

3\[E_{N_2O/CO_2}(tCO_2 e/yr) = N_2O_{\text{emis}} \times GWP_{N_2O}\]

where, \(E_{N_2O/CO_2}\) is \(CO_2\) equivalent emission of \(N_2O\) and \(GWP_{N_2O}\) is global warming potential of \(N_2O\).

The IPCC guidelines provide a default value of 0.005 for \(EF_{ef}\) \(F_{N_2O-N/N_2O}\) is usually taken to be 44/28 and \(GWP_{N_2O}\) is 0.296.

2.2.2. Project emission calculation. The project emissions primarily include the MBR system's \(CH_4\) emissions and stack release in the power generation system and the MBR system's \(N_2O\) emissions as well as its effluents. The project emissions were measured as following equations:
CH$_4$ emissions from the MBR system;

\[ CH_{4_{emis}}(kg/yr) = COD_{inf} \times (1 - R_{COD}) \times B_0 \times MCF \]  

(10)

where, the CH$_4$ emis is the CH$_4$ emissions from the MBR system, COD$_{inf}$ is anaerobic lagoons’s influent COD, B$_0$ refers to the maximum CH$_4$ producing capacity, MCF is correction factor of CH$_4$ and R$_{COD}$ is COD removal rate of anaerobic system. The IPCC guideline provides default value of 0.21 for B$_0$ and MCF is 0.5.

Stack emissions from energy generation;

\[ E_{CH_4/CO_2}(tCO_2e/yr) = CH_{4_{UASSF}} \times LR_{CH_4} \times GWP_{CH_4} \]  

(11)

where, LR$_{CH_4}$ is CH$_4$ loss rate due to incomplete combustion in boiler, E$_{CH_4/CO_2}$ represents CO$_2$ equivalent emission; GWP$_{CH_4}$ is global warming potential of CH$_4$. The IPCC guidelines provide a default value of 0.002 for LR$_{CH_4}$ and GWP$_{CH_4}$ is 0.023.

N$_2$O emissions from MBR discharge;

\[ N_{ef}(kg/yr) = TN_{ef} \times Capacity \times Time \]  

(12)

where, N$_{ef}$ is the nitrogen in the discharge effluent to aquatic environment per year and TN$_{ef}$ is effluent’s total nitrogen.

\[ N_{2O_{emis}}(kg/yr) = N_{ef} \times EF_{ef} \times F_{N_2O-N/N_2O} \]  

(13)

where, N$_{2O_{emis}}$ represents yearly N$_2$O emissions, EF$_{ef}$ is N$_2$O emissions factor from discharged to wastewater and F$_{N_2O-N/N_2O}$ refers to the conversion factor from N$_2$O-N to N$_2$O.

\[ E_{N_2O/CO_2}(tCO_2e/yr) = N_{2O_{emis}} \times GWP_{N_2O} \]  

(14)

where, E$_{N_2O/CO_2}$ is CO$_2$ equivalent emission of N$_2$O and GWP$_{N_2O}$ is global warming potential of N$_2$O. The IPCC guideline provides a default value of 0.005 for EF$_{ef}$ F$_{N_2O-N/N_2O}$ is usually taken to be 44/28 and GWP$_{N_2O}$ is 0.296.

N$_2$O emissions from MBR system;

\[ N_{inf}(kg/yr) = TN_{inf} \times Capacity \times Time \]  

(15)

where, N$_{inf}$ is the nitrogen of discharge influent of MBR system and TN$_{inf}$ is influent’s total nitrogen.

\[ N_{2O_{emis}}(kg/yr) = N_{ef} \times EF_{ef} \times F_{N_2O-N/N_2O} \times P_{TN/N_2O} \]  

(16)

where, N$_{2O_{emis}}$ represents direct N$_2$O emissions, EF$_{ef}$ is N$_2$O emissions factor from discharged to wastewater, F$_{N_2O-N/N_2O}$ refers to the conversion factor from N$_2$O-N to N$_2$O, P$_{TN/N_2O}$ is represents percentage of TN transformed to N$_2$O emission from leachate treatment. The default value for EF$_{ef}$ is 0.005, F$_{N_2O-N/N_2O}$ is usually taken to be 44/28 and P$_{TN/N_2O}$ is 0.0531.
2.3. Economic benefit sustainability of greenhouse gases
The economic benefit of the carbon credit reduction was determined based on 2006 IPCC Guidelines on National Greenhouse Gas Inventories and the Clean Development Mechanism (CDM). The carbon credit revenue of greenhouse gas was calculated by using following equations:

\[
Emission\ \text{reduction} = \text{CO}_2\ \text{reduction equivalent in baseline emission} - \text{CO}_2\ \text{reduction equivalent in project emission} \quad (17)
\]

\[
\text{Carbon credit} = Emission\ \text{reduction} \times \text{cost carbon}(RM35/tonnes) \quad (18)
\]

3. Results and discussion
3.1. Greenhouse gases emission from leachate treatment plant
As the result presented in table 2, the total baseline emissions is 488.42 tCO\(_2\)e/yr, which is equivalent to concentration of 3.515 \times 10^{12} ppm. These total amounts are contributed by the methane emission from open lagoons (195.43 tCO\(_2\)e/yr), carbon dioxide from electricity (51.06 tCO\(_2\)e/yr) and the nitrous oxide from lagoon discharge (241.93 tCO\(_2\)e/yr). Besides, as for the total project emission is calculated to be 255.21 tCO\(_2\)e/yr and the total concentration of project emission is 9.125 \times 10^{11} ppm. These total amounts are contributed by the methane emission from MBR system (16.36 tCO\(_2\)e/yr), methane emission from stack emission (0.008 tCO\(_2\)e/yr), nitrous oxide from MBR discharge (203.69 tCO\(_2\)e/yr) and the nitrous oxide from MBR system (35.15 tCO\(_2\)e/yr). The CO\(_2\) emission reduction from the greenhouse gas emission in leachate treatment plant is equivalent to 233.2 tCO\(_2\)e/yr, which is equivalent to 2.603 \times 10^{12} ppm.

Table 2. Concentration of Greenhouse Gas Emission From Baseline Emission and Project Emission in Leachate Treatment Plant.

| Item               | Emission source                        | Equivalent Emissions ( tCO\(_2\)e/yr) | Calculated From Equation |
|--------------------|----------------------------------------|--------------------------------------|--------------------------|
| Baseline Emissions | Methane Emissions from open lagoons    | 195.43                               | 1 - 3                    |
|                    | Carbon Dioxide from electricity        | 51.06                                | 4 - 6                    |
|                    | Nitrous Oxide from lagoon discharge    | 241.93                               | 7 - 9                    |
|                    | Total                                 | 488.42                               |                          |
| Project Emissions  | Methane Emissions from MBR system      | 16.36                                | 10                       |
|                    | Methane Emissions from Stack Emission | 0.008                                | 11                       |
|                    | Nitrous Oxide from MBR discharge       | 203.69                               | 12 - 14                  |
|                    | Nitrous Oxide from MBR system          | 35.15                                | 15 - 16                  |
|                    | Total                                 | 255.21                               |                          |
| Emission Reduction | Baseline emission - Project Emission   | 233.21                               | 17 - 18                  |

3.2. Potential economic benefit of greenhouse gas emission
The economic benefits of greenhouse gas emissions in leachate treatment plant are shown in table 3 below. The greenhouse gas emissions in leachate treatment plant can be converted into the profit by implementing the Clean Development Mechanism. As data shown in table 3, the greenhouse gas
emission has contributes to a reduction in carbon emissions by 233.21 tonnes/yr, which could attract the carbon credit of RM 8,162.35 based on RM35/tonnes of CO₂ [7]. In year 2022, the greenhouse gas emission is estimated could attract the carbon credit of RM 11,660.5 based on RM 50/tonnes of CO₂ [7]. The results of calculation indicate that the treatment plant with leachate can bring direct economic benefits to the local. In addition, it can effectively reduce the greenhouse gas emissions from the leachate treatment plant that can help protect the ecological benefits.

**Table 3. Economic benefits of greenhouse gas emission.**

| Parameters                          | Value  |
|-------------------------------------|--------|
| Equivalent CO₂ reduction emission (tonnes) | 233.21 |
| Revenue from carbon credit (RM)      | 8,162.35 |

4. Conclusion

The energy recovery at the leachate treatment plant, carbon credits can be gained in the leachate treatment plant by implementing a CDM project. The CDM project's sustainable practices program is capable of handling high-strength wastewater, which yields much more carbon credits than other conventional systems. Based on the results of the greenhouse gas emission in leachate treatment plant, the total emission reduction is calculated to be 233.21 tCO₂e/yr, which can provide carbon revenue of RM 8,162.35 based on RM35/tonnes of CO₂. Results also showed emission from baseline calculation contributed more emissions compare to project emission. This is due to removal of lagoon ammonia through biological nitrification in MBBR system. An ambitious control of greenhouse gases in landfills are urgently required to overcome methane emissions from the leachate treatment plant that could be contributed to increasingly critical environmental issues for the local governments. Firstly, implementation of CDM is classified as a control of addressing environmental and climate change problems. They are in a good match, which contributes to sustainable development. Besides, increase the amount of appropriate landfill gas collection systems and the quantity of landfill waste recycling will effectively control the CH₄ emissions.

References

[1] Agamuthu P, Khidzir K and Fauziah M S H 2009 Waste Manage Res 27 625-33
[2] Aziz S Q, Aziz H A, Yusoff M S, Bashir M J K and Umar M 2010 J Environ Manage 91 2608-14
[3] Ngoc U N and Schintzer H 2009 Waste Manage 2(9) 1982-95
[4] Wan A and Kadir W R 2001 A comparative analysis of Malaysia and the UK (London: Addison-Wesley Publishing Company Inc.)
[5] Intergovernmental Panel on Climate Change (IPCC) 1996 IPCC Guidelines for National Greenhouse Gas Inventories 3 Reference Manual
[6] Shin H C, Park J W, Kim H S and Shin E S 2005 Energ Policy 33 1261-70
[7] Ricke K L and Caldeira K 2014 Environ. Res. Lett. 9 124002