Original Research Article

Mitigating Climate Change through energy recovery at Dandora Wastewater Treatment Plant, Nairobi County, Kenya.

ABSTRACT

The world is experiencing an increase in the rate of greenhouse gases emissions accumulating in the atmosphere due to natural and anthropogenic causes. These gasses absorb and emits radiation within the thermal infrared range thus contributing to the Green House effect. The building up of greenhouse gasses beyond the natural acceptable levels can change the earth's climate thus contributing to climate change. To mitigate climate change, there is need to cease the increase of greenhouse gases either by not adding them into the air and or increasing the earths' ability to withdraw them out of air. This study looked into mitigating climate change through energy recovery at Dandora wastewater treatment plant in Nairobi. The study employed both primary and secondary data. Operational data on the raw sewer chemical oxygen demand and biological oxygen demand levels was collected from the plant between 2007 and 2013. MS excel was used to analyze the data in order to cipher the trends of biological oxygen demand & chemical oxygen demand loadings and removals and thus estimation of biogas and methane likely to be generated and energy recovery thereof. The relationship between these two variables were tested through a Correlation coefficient test. The two-level computations estimated the daily biogas generation at the treatment plant as 2738m3. The study estimates methane generated to be equivalent to 68398MJ/Day of energy. Considering the calorific value of LPG of 46MJ/kg, this is equivalent to 495 cylinders daily serving 2974 households daily. The findings indicate that recovery of energy from the Plant mitigates climate change through reduction of emissions by 16 tCO2-e per day. The energy recovered had a positive correlation with the emission reduction at a high value of r= 0.99. The study concludes that energy recovery from wastewater treatment plant reduces emission thus mitigates climate change.

Keywords: Climate change; greenhouse gas, energy recovery, global warming

1. INTRODUCTION

The world is experiencing an elevated rate of greenhouse gases (GHGs) brought about by natural and anthropogenic causes. These greenhouse gases blanket the earth, trapping suns heat in the atmosphere and increasing temperatures making it warm, a phenomenon referred to as the greenhouse effect. When the greenhouse gasses build beyond the natural acceptable levels, they can alter the earth's climate thus having negative effects on natural ecosystems as well as on human health.

This study focuses on Methane as a greenhouse gas. The waste sector (Anaerobic waste treatment and main sewer) contributed approximately 9% of total global CH_4 emissions in 2006 (US EPA 2006). Furthermore, the Green House Gas emissions factsheet of 2017 by USAID estimated emissions from agricultural sector as 62.8%, energy sector as 31.2%, industrial processes sector as 4.6%, and lastly waste sector (1.4%) (USAID, 2017). Anaerobic wastewater treatment plant is the main human sources of methane gas which is the focus of my study.

The treatment and technology employed in a wastewater treatment plant dictates the type of greenhouse gas emitted therein. (Letting *et al*, 1999). Effluents from wastewater treatment plants generates methane (CH_4) when treated anaerobically. Biological decomposition of organic matter and pollutants is one of the well-developed methods of environmental conservation through remedial specialty in handling wastes and wastewater (J.H Reith *et all*, 2003). Biogas is the by-product of anaerobic digestion; biogas is a gaseous fuel that is made up of about 60% methane and 40% carbon dioxide (J.H Reith *et al*, 2003). Methane when purified, can serve as an alternative energy source (Lord and Gregory, 2010). These greenhouse gases if not collected and recycled will prevent the emission of heat from the earth back into the space. This results in increased temperatures on the Earth's surface and creating global warming. Due to multidimensional applicability of carbon footprints, there is a huge scope to apply it in the context of Wastewater Treatment Plants in terms of emission control, energy generation, and, credits for bio energy (Snip and Keesman, 2009).

This study focused on climate change mitigation through energy recovery from a waste water treatment plant. Energy will be recovered through utilization of methane produced from the effluent waste. Methane produced can be utilized for domestic use as green energy instead of the other non-renewable energy sources; but most captivatingly, it will go a long way in ensuring that the greenhouse effect is kept to a minimal.

Sewage management or effluent waste management continues to be a big issue in Kenya, polluting environmental mediums like the air, land and water sources. For instance, given today's technological development, these effluents can be treated anaerobically and this yields biogas that creates energy (Alexander, 1998). In Kenya, the application of anaerobic digestion has been applied in treating sewage in major towns including the Dandora Waste Water Treatment Plant (DWWTP) in Nairobi. It is evident that DWWTP is one among the largest such treatment plants in Kenya Specifically, due to high population density in Nairobi County, the increasing levels of urbanization, and the enormous amount of waste that is produced in both solid and liquid forms (Gebbie, 2013).

The total average industrial and domestic effluent waste inflow at the DWWTP may rise to about 250,000 m^3 per day in the year 2025 (Gebbie, 2013). This rapid increase in the average effluent inflow at DWWTP is directly proportional to the overall increase in biogas production. Methane in biogas is one of the potent atmospheric pollutants and it's estimated that its global warming potential (GWP) is 21 times more than that of carbon dioxide (CO_2) (Waluszewski,2010). Biogas generated at this facility has not undergone any measurement and is released to the atmosphere without being harnessed leading to emission of greenhouse gases and air pollution. For this reason, this study aims to contribute towards the reduction of climate change impacts through energy recovery at DWWTP. The energy generated can be utilised at the community using it for heating as well as cooking purposes.

2. MATERIAL AND METHODS

2.1 The Study Area

This research was conducted at Dandora Wastewater Treatment Plant (DWWTP). DWWTP is located 30km to the East of Nairobi Central Business, at latitude $1^0 14^1$S and longitude 37^0 15^1E (Figure 1). It is designed to treat about 120,000m^3 of sewage per day (80% of Nairobi's wastewater). The map below shows pictorial view of the treatment works site.

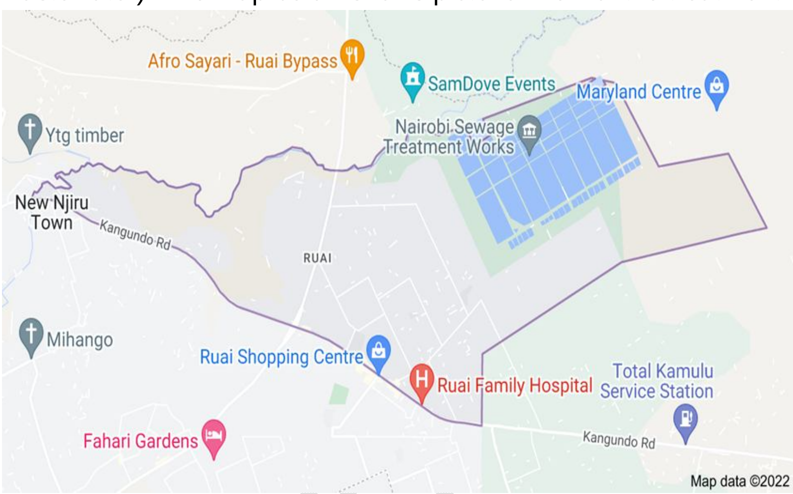

Figure 1: Map of DWWTP (Source: Meteorological Department)

The arrangement of the ponds is shown in

Figure 2 below;
Figure 2: Layout of DWWTP(Source: Google Earth, 2013)

2.2 Data collection and type

The study employed both primary and secondary data. Operational (secondary) data on the raw sewer in mg/l, COD and BOD levels was collected from DWWTP which has been documented between 2007 and 2013. These years were settled on since the data was more consistent than all the other years. Additional primary data was collected in 2013 to confirm the consistency of operational data obtained from DWWTP. This synthesised data was then analysed in excel sheet to calculate the BOD loading and removal rates, total methane generated, thus energy equivalent and the emission reduction equivalent using the formulas given in the subsequent sub sections. The entire study was structured into tasks that were performed during the proposed study period as summarised below to achieve study objective;

2.3 Data Analysis and presentation

Data was analyzed by use of MS excel. The results were presented in tables, bar charts and pie charts together with a summarised explanation in relation to the literature.

Correlation analysis was used to test relationship between the quantitative variables. In this case biogas generated, energy equivalent and emission reduction estimates.

Pearson correlation coefficient was then used to test the relationship between the two variables.

2.4 Research Design

Correlation design was used to discover the relationship between biogas converted to energy and climate change abatement. Correlation research design was chosen since it helps in prediction of future occurrences.

3. RESULTS AND DISCUSSION

3.1 To quantify amount of biogas generated at Dandora wastewater Treatment Plant

To determine the quantity of biogas produced in the anaerobic ponds, a relationship between BOD_5 removals across anaerobic treatment lagoons as a function of volumetric loading rate, i.e., g BOD_5/m^3d was developed.

The plant was found to be generating approximately $2736m^3$/day of methane at the calculated flow of $83648m^3$ daily.

Table 1: Daily methane generated for the period 2007-2013

Month	Methane generated(m^3/day)
July	1668
August	3527
September	1825
October	1631
November	3821
December	5121
Jan	4453
Feb	1862
Mar	3009
April	2251
May	3137
June	2916
Average	**2736**

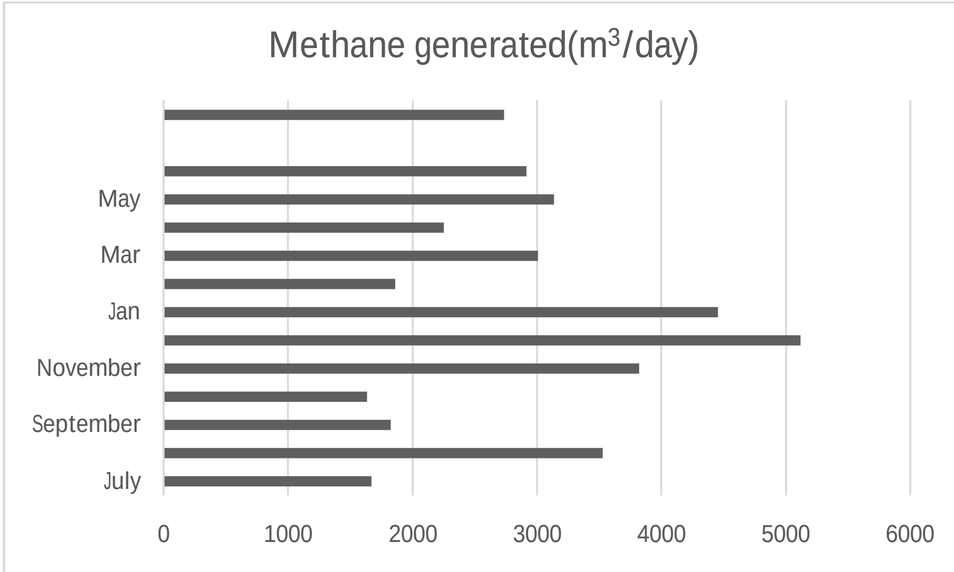

Figure 3: Methane generated(m3/day)

3.2 To determine energy recovered by converting biogas to energy. / To find out the number of typical households that can be sustainable supported by the recovered energy.

The amount of energy that can be produced from methane was computed as;

Energy value of biogas generated (MJ/d) = Biogas generated per pond (m^3/day) X Fuel value of biogas (MJ/m^3).

Computation is based on the following assumptions (IPCC, 2006) that:

(i) Heat value of biogas is 25 MJ/m^3
(ii) DWWTP does not have any steam demand or absorption chillers and hence waste heat will be diffused into the atmosphere

Energy value of biogas generated (MJ/d) = Biogas generated per pond (m^3/day) X Fuel value of biogas (MJ/m^3)

Energy value of biogas generated (MJ/d) = 2736 (m^3/day) X 25 (MJ/m^3)

Energy value of biogas generated (MJ/d) = 68398 MJ/day

3600MJ = 1MWh

68398MJ = 18MWh daily =

Research from Burton and the Electric Power Research Institute (EPRI) in the US shows that anaerobic digestion with biogas utilization can produce about 525 KWh of electricity for every million gallons (3785m^3) of wastewater treated at the plant (Ashlynn et al (2010). Using the same argument, DWWTP treating about 83643m^3 of domestic and industrial waste daily would generates roughly about 12MWh and at full capacity when treating 160,000m^3 daily would generate about 22.1MWh. These two figures relatively compare to my calculation of 18MWh.

To estimate the number of households that can be served by the amount of energy generated, the following were the assumptions made;

- Most households within Ruai are dependent on 3kg LPG gas for cooking
- Calorific Value of LPG gas cylinder is 46.1MJ/kg (Edward, 2001)
- Total no. of households in the project area is 22755 (Kenya Population and Housing Census, 2019.)

The total energy that can be generated at DWWTP is estimated at 68,398MJ/day, and considering Calorific Value of LPG of 46MJ/kg, this is equivalent to 495 cylinders daily which can serve about 2974 households daily.

Economic value of 3kg cylinders can be estimated by 495*800/= which is equivalent to saving Kshs. 396,000 daily.

Ashlynn et al (2010) reiterates that Wastewater treatment plants with treatment capacities of less than 5 million gallons per day (18,900m^3) do not produce enough biogas to make electricity generation feasible or cost-effective (Ashlynn *et al*, 2010). Based on this, it can be argued that Dandora generating about 83,643m^3 per day can generate enough biogas to make energy or electricity generation feasible and cost effective.

3.3 To estimate emission reduction potential of converting biogas to energy

The following formulae was used in the computation of Emission Reduction Equivalent:

To determine a preliminary estimate of the emission reductions for this project; the baseline (fossil fuel) and project emissions was determined.

Potential Emissions Reductions ($tCO_{2\text{-}e}$) = Total Baseline Emissions ($tCO_{2\text{-}e}$) - Total Project Emissions ($tCO_{2\text{-}e}$).

The following assumptions was incorporated into the baseline and project GHG emission calculations for annual carbon dioxide equivalent emissions (tCO_2) for this Project.

- An Emission Factor for HFO of 0.896 tCO_2/MWh has been adopted as per the 'CO_2 Emissions from Fuel Combustion' 2012 edition published by the International Energy Agency;
- An Emission Factor for biogas captured (methane only) of 0.0174$tCO_{2\text{-}e}$/MWh based on 4.8$kgCO_{2\text{-}e}$/GJ (Australian National Greenhouse and Energy Reporting Act 2007).

For this calculation, the electricity generation for the baseline scenario is supplied by generators using Heavy Fuel Oil (HFO), with an Emissions Factor (EF) of 0.896 t CO_2/MWh[1]. For this analysis, the biogas capture and combustion at the DESTP as calculated earlier generates about 18MWh per day, thereby displacing 18MWh per day of HFO-generated electricity each year. The baseline emissions are therefore approximated as:

Total Baseline Emissions ($tCO_{2\text{-}e}$) = Electricity Generation x EF

= 18 MWh x 0.896 $tCO_{2\text{-}e}$/MWh

= 16.1280 $tCO_{2\text{-}e}$ per day

Total Project Emissions ($tCO_{2\text{-}e}$) = Electricity Generation x EF

18 x 0.0174 $tCO_{2\text{-}e}$/MWh

= 0.3132 $tCO_{2\text{-}e}$ per day

The GHG emission reductions attributed to this Project therefore the difference between the baseline and project emissions:

Potential Emissions Reductions ($tCO_{2\text{-}e}$)

[1] Source: International Energy Agency, 'CO_2 Emissions from Fuel Combustion, 2012 edition.

= Total Baseline Emissions (tCO_{2-e}) - Total Project Emissions (tCO_{2-e})

= 16.1280 tCO_{2-e} per day - 0.3132 tCO_{2-e} per day

= approx. 16 tCO_{2-e} per day

According to Greenhouse Gas Equivalencies calculator by EPA, 2023[2]; the figure 16 tCO_{2-e} per day is equivalent to carbon sequestered by 240 tree seedlings grown for 10 years or equivalent to CO_2 emissions from 1633 gallons of gasoline consumed this emphasizes on the significance of this amount of emission reduction in combating climate change.

Correlation coefficient

The following formula was used to calculate the relationship between the two variables that is energy recovered and emission reductions.

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2]\,[n\Sigma y^2 - (\Sigma y)^2]}}$$

Table 2: Correlation coefficient parameters

Energy Generated (y)	Methane Reduction	XY	X^2	Y^2
111325	27	3024643	12393255625	738
46544	11	528703	2166320664	129
75219	18	1380832	5657860352	337
56263	14	772550	3165468906	189
78425	19	1501059	6150480625	366
72894	18	1296789	5313498789	316
41688	10	424131	1737847656	104
88163	22	1896953	7772626406	463
45631	11	508175	2082210977	124
40781	10	405891	1663110352	99
95513	23	2226430	9122637656	543
128019	31	3999778	16388800352	976

[2](https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results)

880463	**215**	**17965935**	**73614118359**	**4385**

Based on the above the ***r* = 0.99**

The study's results on the correlation analysis between energy generated and emission reduction equivalent, showed a high value of ***r* = 0.99** with a positive slope as shown below;

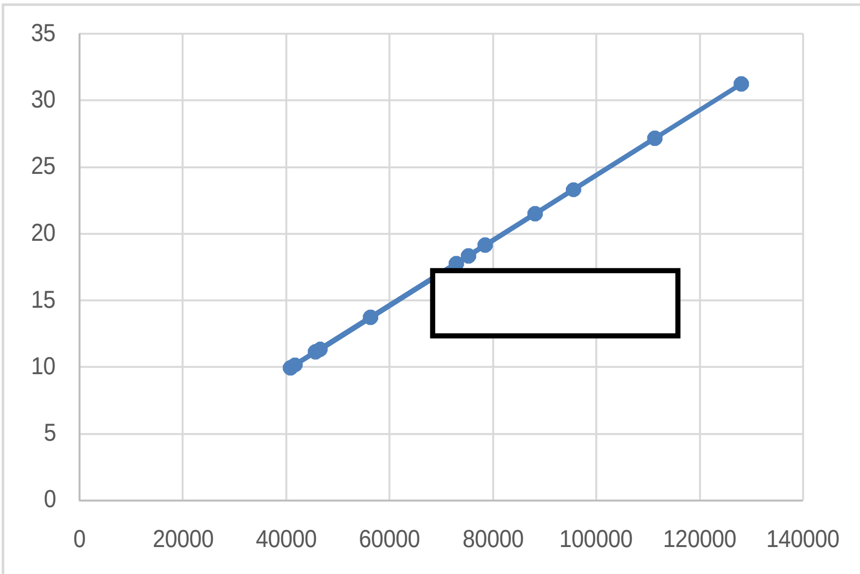

Figure 4: Correlation between biogas converted to energy and emission reduction

This confirms that energy recovery from Dandora Wastewater treatment plant is significant in mitigating climate change and thus rejects my null hypothesis that Conversion of Biogas to energy doesn't have significant effect on emission reduction.

4. CONCLUSION

4.1 Conclusion

The study concludes that recovery of energy from waste water treatment plant can help in combating climate change.

This confirms that energy recovery from Dandora Wastewater treatment plant is significant in mitigating climate change.

In their last submission of Nationally Determined Contributions of 2020, Kenya is undertaking an ambitious mitigation contribution towards meeting the Paris Agreement of 2015 by abating her GHG emissions by 32% by 2030 relative to the Business As Usual

(BAU) scenario of 143Mt CO2eq. As per our estimations, this project will help reduce GHGs emissions by at least **16 $tCO_{2\text{-}e}$ per day**. These findings give an impetus to the government of Kenya and other relevant stakeholders to develop green energy from methane generated at the treatment plant thereby reducing GHGs emitted to the atmosphere in line with Kenya's NDC commitment to abating the climate change menace.

4.2 Recommendation

- This project can be one among many projects in the waste sector that Kenya can implement to meet its National Determined Contributions (NDC) as per Paris Agreement of 2015 that is abate climate change by 32% against Business As Usual of 143M $tCO_{2\text{-}e}$ by 2030.
- Harnessing methane should be encouraged as an alternative green energy for use by the local community around the treatment plant.

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