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Resource Recovery Potential of Limuru Municipality Abattoir Waste

Mbugua J. K[1*], Waswa A. G[2], Mbui D. N[3]

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ABSTRACT

Municipalities are entrusted with solid waste management to avoid rapid fill-up of landfills, provide apt sustainable solid waste management solutions, and mitigate greenhouse gas emissions. Slaughterhouses are major contributors to environmental degradation, water pollution and global warming. In the current study, the waste generated from animal slaughter houses in Limuru was calculated, the potential of Limuru municipality slaughterhouse waste to generate biogas and bio-electricity and organic bio-fertilizer investigated and the waste greenhouse gases emission potential was also computed. Inadequate information on abattoir resource recovery and utilization formed the need for this cross-sectional study conducted from January to March 2024. Four selected slaughter houses in Limuru municipality, Kenya, were selected; namely Limuru, Bahati, Makutano and Ngecha. Aniebo mathematical computation models were used to determine the amount of slaughterhouse from the number of animals processed. The results exhibited that 1739.479 tonnes of abattoir waste is generated annually. Anaerobic digestion produced 92.1924 m^3 of biogas annually as per the Rao model. This translated to electricity production potential of 49.3229 kWh p.a and heat production potential of 71.4484 kWh p.a as a form of resource recovery. There was 549.0512 m^3 reduction of greenhouse gases using biogas technology which translated to positive impact on environmental safety, public health and GHG emission reduction.

INTRODUCTION

Waste from slaughterhouses includes a variety of contaminants, including animal feces, blood, bone, fat, animal trimmings, paunch content and urine from operations and in the form of solid, liquid and gases (Adeyemo *et al.*, 2002). If abattoir wastes are not properly managed and controlled, they may negatively impact the nation's economy, public health, animal health, and environment. Abattoirs, especially those based in developing countries, are always faced with setbacks in disposal, handling and treatment of their wastes efficiently (Adesola *et al.*, 2024). This has always resulted in contamination of soils, water, air threatening public health and greenhouse gases emissions (Rojie *et al.*, 2008). Good production and hygiene procedures, together with appropriate waste disposal mechanisms are critical to reducing the adverse effects of slaughterhouse wastes. Methods for safe disposal, treatment, and processing include burial, composting, rendering, incineration, anaerobic digestion, and blood processing can be harnessed and public health risks and environmental pollution mitigated (Tamenech & Tamirat, 2017).

Methane (CH_4) is an important greenhouse gas because of its absorbs radiation from the sun based on its chemical structure. Its components remain in the environment for hundreds or thousands of years, making it a Short-Lived Climate Pollutant (SLCP) with a 12-year half-life. With a projected 0.3% rise in 2016 to a total of 9.2 Gt CO_2 eq, CH_4 is the second most potent anthropogenic GHG in terms of global warming potential (GWP) (Olivier *et al.*, 2017). Methane is responsible for at least 25% of global warming because it is very good at trapping solar heat (Climate and Clean Air Coalition, 2012). As a result, it adversely affects ambient air quality and makes a substantial contribution to climate change. Enteric fermentation in ruminant animals is responsible for over 70% of agricultural CH_4 emissions (Jackson *et al.*, 2020).

Slaughterhouses generate vast amounts of biological waste, much of which is unused. (Khan *et al.*, 2023). Utilizing plants to produce industrial byproducts such as fats and oils, such as lard and tallow (Chakraborty *et al.*, 2014), fertilizers made from organic compost (Darch *et al.*, 2019), biogas through the production of methane (Ware & Power, 2016), and animal feed as meat powder (Ragályi & Kádár, 2012) is the most common method of reusing livestock waste.

Therefore, this work was carried out to assess the tonnage of abattoir waste generated by slaughterhouses in Limuru municipality, Kenya, on a daily basis, assess its bio-energy and bio-fertilizer potential and estimate the green houses gases emissions, so as to develop policies on slaughterhouse waste sustainable management.

MATERIALS AND METHODS

Sampling

Cross-sectional study design was used with an approach of simple random sampling done at four slaughterhouses located in: Limuru, Bahati, Ndeiya and Ngecha Wards within Limuru municipality in Kenya. The area of study is depicted in figure 1.

[1] Limuru Municipality, Kiambu County P.O. BOX 2344-00900, Kiambu, Kenya
[2] Department of Physical Science, South Eastern Kenya University, P.O. Box 170-90200 Kitui, Kenya
[3] Department of Chemistry, University of Nairobi, P.O Box 30197-00100 Nairobi, Kenya
[*] Corresponding author's e-mail: domjamkam@gmail.com

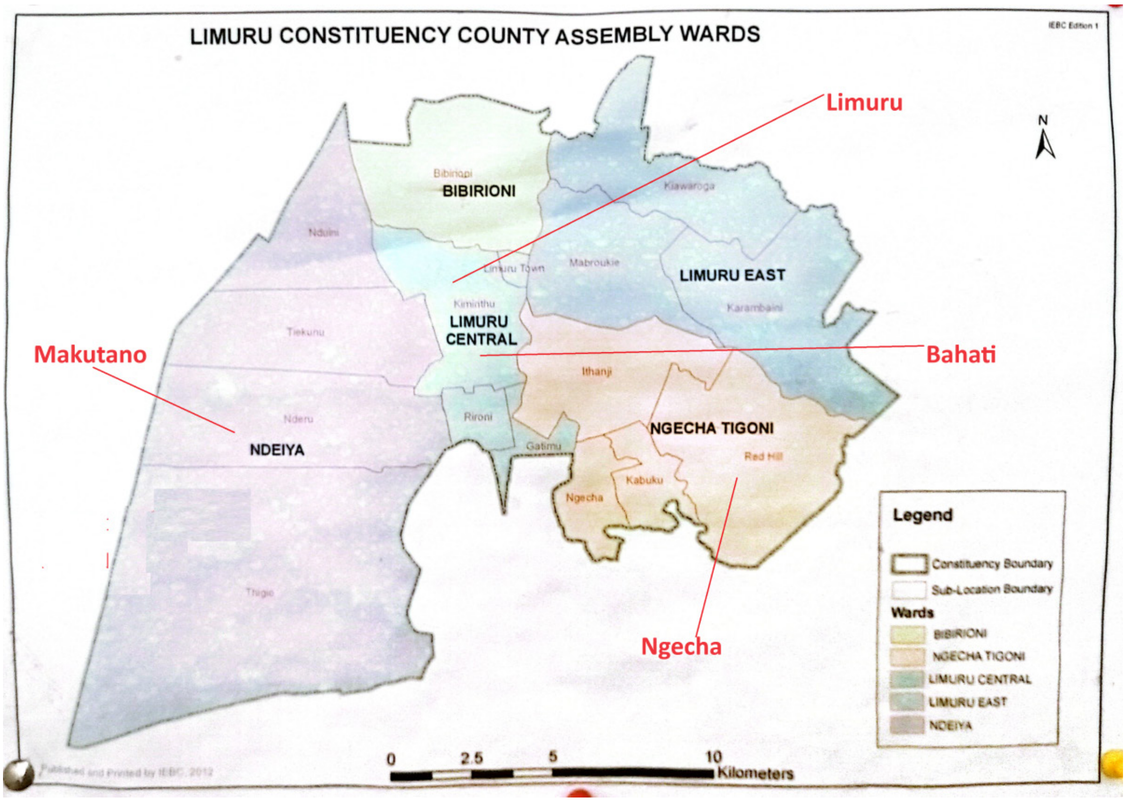

Figure 1: A map of slaughterhouses in Limuru municipality

Limuru is one of the municipalities in Kiambu County. The population was about 159,314 people according to the 2019 census (Kenya National Bureau of Statistics (KNBS), 2020). This urban community is located roughly 30 kilometers northwest of Nairobi at coordinates of 1°06'28.0"S and 36°38'34.0"E.

Data on Number of Animals Slaughtered

The quantity of animals slaughtered in the four slaughterhouses in Limuru municipality was recorded daily for three months and the mean ± standard deviation reported.

Economics of Slaughterhouse Wastes

For abattoir waste generation, a mathematical model by Aniebo *et al.* (2009) was applied (Equation 1).

$$\text{Total waste} = \sum (BLw+Bnw+Icw+Tw)*N \quad (1)$$

where BLw is the blood waste, Bnw is the bone waste, Icw is the intestinal content waste, and Tw is the tissue waste, all measured in kg; N is the number of slaughtered livestock.

Estimation of Biogas Production from Abattoir Waste

The Rao *et al.* (2000) model was used to compute biogas generation. The model suggests that 1 Kg of abattoir waste produce 0.053m^3 of syngas. Therefore, the volume of biogas produced (VBP) can be estimated using equation 2:

$$VBP=AWG*0.053m^3\,kg^{(-1)} \quad (2)$$

Where AWG is the total waste generated.

Estimation of Energy from Biogas

Ngumah *et al.* (2013) state that the calorific value (high heating value) of the methane concentration in biogas determines its energy potential. According to Rohstoffe (2012), biogas has an average calorific value of 21-23.5 MJ/m^3 (around 22.0 MJ/m^3). Kilowatt hours (kWh) are commonly used to denote energy, and 3.6 MJ is equivalent to 1 kWh. 1 m^3 of biogas has an energy potential of 6.1 kWh if the 22.0 MJ/m^3 of biogas is converted to kWh. Biogas's energy (heat and electricity) potential was determined using the energy conversion techniques developed by Banks (2009). These methods demonstrated that biogas has a 35% conversion efficiency to electricity, meaning that 1m^3 of biogas has a potential for producing 2.14 kWh of electricity (i.e., its energy potential of 6.1kWh × 0.35). Consequently, the formula in equation 3 can be used to determine the electricity production potential (EPP), or kWh:

$$EPP=VBPm*2.14kWh \quad (3)$$

Furthermore, according to Banks (2009), biogas has a 50% conversion efficiency to heat energy, meaning that 1 m^3 of biogas has a 3.1 kWh heat production potential (i.e., 6:1 kWh × 0.5 energy potential). Equation 4 provides an estimate of the heat production potential (HPP), expressed in kWh:

$$HPP=VBP*3.1kWh \quad (4)$$

Greenhouse Gas Reduction through Biogas Technology

According to mathematical calculations based on (B-sustain, 2013, IPCC, 2000, JGCRI, 2018), the greenhouse gas emissions from disposal sites are summarized as follows:

$GHGemission=[((QX \times DOC \times DOCF \times F1 \times 1.336)-R) * (1-OX)]*25$ (5)

F1 is the methane fraction produced from carbon to methane; R is the recovered methane over the year, expressed in kg or tons; QX is the amount of slaughterhouse waste stated in tons/kg from waste records; DOC is the degradable organic carbon represented as a proportion of abattoir waste (default value (DV) = 0:12); DOCF is the fraction of degradable organic carbon dissimilated for the abattoir waste (DV = 0:7); In order to convert the amount of methane released to CO2eq from the amount of abattoir waste generated (equation 6), the oxidation factor (OX) is employed (DV = 0:1 for well-managed and DV = 0 for unmanaged); and the CH_4 global warming potential is 25.

$GHGemissions(tCO2eq)=Qj \times EFj$ (6)

where Qj is the amount of trash by type j (only abattoir waste is considered here), EFj is the biogas emission factor for waste type j (0.02 kg CO2eq), t is the unit of waste, either in tons or kilograms, and CO2eq is the CO2 equivalent. The difference between equations 5 and 6 (equation 7) will be used to estimate the GHG emissions from the production of biogas.

ReductionoftheGHGsusingbiogas= ∑Equation5-∑ Equation6 (7)

Equivalence of Biogas in Fossil Fuels (equation 8)

Blottnitz (2010) and B-Sustain (2013) energy estimation states that using 1 m^3 of biogas is equivalent to using 0.45 kg of LPG, 0.6 kg of kerosene, 3.50 kg of charcoal or firewood, 0.4 kg of furnace oil, 0.7 kg of gasoline, and 0.5 kg of diesel for the same activities.

Equivalence=∑ CFF*N (8)

Where CFF is each of above coefficient factor; N is the volume of biogas produced (i.e., from Equation (2)).

Cost Estimate for Biogas Energy

The amount of energy generated was calculated by comparing it to the Ethiopian Electric Power Corporation/EEPC (2018) cost (equation 9); that is, the minimum cost (tariff) of 1kWh of heat or electricity is 0.021USD (2.71 KShs).

Cost=(Equation5*2.71KShs)+(Equation6*2.71KShs) (9)

Methods for Estimating Biofertilizer Yield Potential

The percentage of organic waste's dry mass (DM) that is not converted to biogas is the basis for the coefficients used to estimate biofertilizer yields (Ngumah *et al.*, 2013). The coefficient proportion of the dry mass (DM) and volatile solid (VS) components of slaughterhouse waste was used in this study to calculate the amount of biofertilizer. For slaughterhouse waste, the DM percentage of fresh organic wastes was set at 15%, and the theoretically dry mass (DM) of abattoir waste converted to gas (dry mass minus mineral content) is known as the volatile solid (VS), which was calculated by multiplying the DM of abattoir waste by 85%. DM and VS were determined for this study using the following formulas (equations 10 and 11):

DM=AWG*0.15(15"\%") (10)

VS=DM*0.85(85"\%") (11)

Biofertilizer production from slaughterhouse waste was evaluated using the coefficient fraction model of the dry mass (DM) part developed by Deublien and Steinhauser (2008), and the biofertilizer yield (BFY) of abattoir waste was computed using DM and VS as inputs. However, according to Burke (2000), 60% of VS is the actual proportion converted to biogas, with the remaining 40% factored into the BFY estimate. Consequently, the potential of BFY was deduced as follows:

BFY=(DM-VS)+(40"\%"*VS) (12)

Calculating the Cost of Producing Biofertilizer

As per the average retail prices in Kenya, 50 kg of UREA and DAP fertilizers cost at about Ksh 3500 to Ksh.5500 respectively. In comparison, similar quantities of biofertilizers could have a cost multiplier factor of almost 30-40.

CostofBFY=50kgofBFY*US$28.6 ((KSh.4000))/Kg (13)

Data Analysis

Minitab, Version 17/19, was used to enter the data for analysis. Numerical data was analyzed using descriptive statistics, including frequency (F), range, mean (M), total, percentage, and standard deviation (SD).

RESULTS AND DISCUSSIONS

This study in Limuru municipality collected the number of slaughtered animals (cattle, goats, pigs, and sheep)

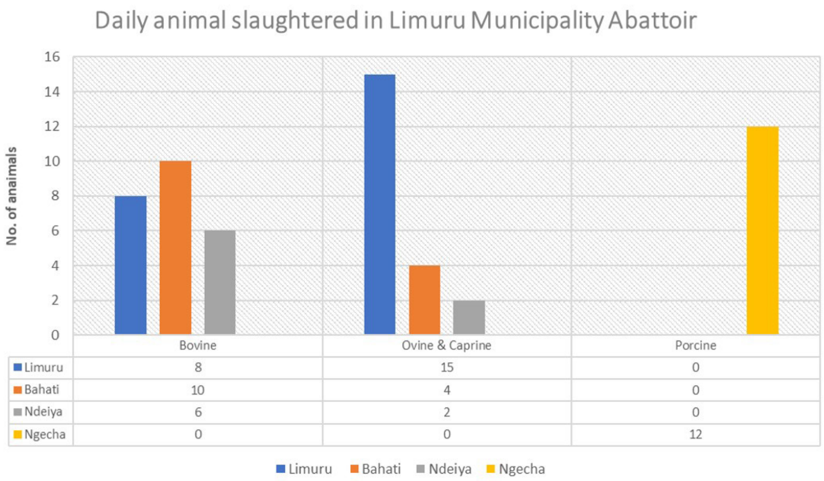

Figure 2: Number of animal slaughtered daily in different abattoir

daily from January 1, 2024, to March 31, 2024, from the four registered abattoirs, as represented in Figure 2. The number approximated 20,805 animals annually. Only Ngecha slaughterhouse slaughters pigs, while the other three slaughter bovine, ovine, and caprine animals.

The specific and total waste generated from bovine, ovine and caprine and porcine is shown in table 1 as calculated using equation 1 as described by Aniebo *et al.*, 2009 mathematical model. The waste ranges from blood, rumen matter, bones among other form of waste as shown in figure 3.

Figure 3: Slaughterhouse wastes from Limuru abattoir

On estimate, 12.6 kg of blood waste, 8.0 kilogram of intestinal content waste, 6.4 kg of tissue waste, and 11.8 kg of bone debris (a total of 38.8) might be produced by one cow. Likewise, a single goat or sheep that has been killed may yield 0.72 kilogram of blood waste and 1.25 kg of digestive content waste.

The study demonstrated that an annual total waste of 1739.479 ton was generated in Limuru municipality. The proportions depended on the number and type of livestock slaughtered, whereby 76.8 % of the total waste originated from bovines, with Bahati abattoir contributing the most. This would suggest that a significant amount of abattoir waste is produced throughout the public or privately run slaughterhouses in comparison to other towns. This necessitates the study of resource recovery from the enormous amounts of waste and environmental considerations at their disposal.

Table 1: Animal wastes per slaughterhouse in Limuru municipality

Name of slaughter house	Livestock slaughtered			Blood waste (ton)			Bone waste (ton)			Intestinal content (ton)			Tissue waste (ton)			Total waste (ton)		
	Bovine	Ovine/ Caprine	Porcine	Bovine	Ovine/ Caprine	Porcine	Bovine	Ovine/ Caprine	Porcine	Bovine	Ovine/ Caprine	Porcine	Bovine	Ovine/ Caprine	Porcine	Bovine	Ovine/ Caprine	Porcine
Limuru	2.92	5.475	0.00	36.79	3.942	0.00	34.46	11.28	0.00	23.36	6.84	0.00	18.69	4.38	0.00	113.29	26.44	0.00
Bahati	3.65	1.46	0.00	45.99	1.0512	0.00	43.07	3.01	0.00	29.20	1.83	0.00	23.36	1.17	0.00	141.62	7.05	0.00
Makutano	2.19	0.73	0.00	27.59	0.5256	0.00	25.84	1.50	0.00	17.52	0.91	0.00	14.02	0.584	0.00	84.97	3.53	0.00
Ngecha	0.00	0.00	12.00	0.00	0.00	8.64	0.00	0.00	31.2	0.00	0.00	15.00	0.00	0.00	9.60	0.00	0.00	57.96

According to Montford and Wotherspoon (2021), slaughterhouses produce billions of tons of biological waste each year, both liquid and solid.

The quantity of animals slaughtered and the method used for treating them determine how much garbage is produced. The Kikuyu municipality's Dagorretti slaughterhouse, for instance Each of its around 15 slaughterhouses generate 4,000 L of wastewater and four tons of solid waste daily on average (Odera *et al.*, 2018). A unit that slaughtered 200 cows and 400 sheep daily on average produced 16,000 kg of solid waste and 40 m^3 of wastewater, according to a study by Kabeyi and Olanrewaju (2022). The investigation found that the biogas digestor does not process 53,200 kg of the slaughterhouse's total solid and liquid waste, with only 2,800 kg being used in biogas generation.

Depending on the animal's sex, load weight, collecting method, fat percentage, and living topographic area, the yield % of animal abattoir wastes might vary greatly (Kupusovic *et al.*, 2007). The waste from slaughterhouses can be handled in a number of ways. Incineration (heat destruction technology), burial, and controlled landfilling (dumping byproducts into the landfill site) are the primary disposal methods that are still in use today (Yagout, 2003, Chen *et al.*, 2008). Hence, there is a greater need for studies on the resource recovery potential of abattoir wastes in the generation of biogas and biofertilizers. This is mainly so in reference to the management of the abattoir solid and liquid wastes. Solid wastes account for 3% of worldwide GHG emissions (Ilmasa *et al.*, (2018).

Among these solid wastes, animal byproducts are well-known GHG emitters. The life cycle assessment study also found that vegetarian meals had a 40% lower environmental effect than meat-containing meals in terms of indices such as carbon footprint, resource usage, water use, and health implications. (Ernstoff *et al.*, 2019). Furthermore, because many slaughterhouses are located in city centers, traditional waste disposal methods such as application to agricultural land are no longer viable due to increased transit distances. Direct discharge of contaminated degradable waste into the sewerage system before treatment is generally unacceptable owing to the resultant environmental and ecological issues and the possibility of clogging in wastewater pipe systems. Water, waste treatment, and electricity expenditures account for approximately 20% to 30% of total slaughtering costs. Resource recovery process from abattoir waste could also greatly contribute to greenhouse gas emission management. Methane (CH_4) emissions from manure, untreated organic waste, and wastewater, as well as fuel consumption for processing (such as drying and evaporation), are the two main sources of greenhouse gas emissions from slaughterhouses. Anaerobic lagoons are a regularly used treatment system that reduces the nutritional content of waste while producing methane as a byproduct. Existing abattoirs must have a strategy to decrease the emission of ozone-depleting gases. In addition to various treatment techniques, recycling and re-use strategies for organic waste and adequate storage capacity should be put in place to limit CH_4 emissions brought on by the (uncontrolled) disposal of untreated waste (Degate *et al.*, 2001).

IPCC and GWP coefficient factors were applied in estimation of global warming gases emitted from the dumping sites of these meat processing places (Figure 2). An annual reduction of 549.0512 m^3 greenhouse gas was determined, translating to a positive impact on the environment (Table 2).

In addition, the Rao model established that 92.1924 m^3 of annual biogas was generated from abattoirs in Limuru municipality, translating to 49.3229 kWh and 71.4484 kWh of electricity production and heat production potential respectively, indicating that this could viably be scaled up across other municipalities within the country for complementary energy production from abattoir wastes (Table 2).

In terms of biofertilizer yield potential estimation, the residual abattoir wastes were viable for improving soil quality and optimizing crop yield. The microbes degrade complex organic matter into simpler form thereby enriching the soils (Mbugua *et al.*, 2022). Annual yield of 110.8115 tons of biofertilizer was obtained with over 90 % originating from bovines. Scaled production of this biofertilizer could eventually lead to competitive retail market costings in which the small-scale farmers can afford. Cost benefit analysis regarding chemical fertilizer effects on the environment could also advantage the production of biofertilizer.

Table 2: Biogas and energy production from Limuru municipality abattoirs

Name of slaughter house	Total waste (ton)			VBP (m^3)			EPP (kWh)			HPP (kWh)			GHG emission (Eq5)			GHG emission ($tC0_2eq$)		
	Bovine	Ovine/Caorine	Porcine	Bovine	Ovine/Caorine	Porcine	Bovine	Ovine/Caorine	Porcine	Bovine	Ovine/Caorine	Porcine	Bovine	Ovine/Caorine	Porcine	Bovine	Ovine/Caorine	Porcine
Limuru	113.29	26.44		6.005	1.402	0.00	12.85	2.999	0.00	18.61	4.344	0.00	143.0	33.39	0.00	2.27	0.528	0.00
Bahati	141.62	7.052		7.506	0.374	0.00	16.06	0.799	0.00	23.27	1.158	0.00	178.8	8.903	0.00	2.84	0.141	0.00
Makutano	84.97	3.526		4.503	0.187	0.00	9.638	0.399	0.00	13.96	0.579	0.00	107.3	4.452	0.00	1.70	0.070	0.00
Ngecha	0.00	0.00		0.00	0.00	57.96	0.00	0.00	3.07	0.00	0.00	6.573	0.00	0.00	9.52	0.00	0.00	73.17

CONCLUSION

Anaerobic digestion of organic matter leads to emission of GHG; carbon dioxide and methane (Mitchie, 2022). The calculated GHG emissions from the slaughterhouses per slaughtered animal is shown in table 2. Using equation 5, an average GHG emission of 143.03 and 15.311 from bovine and ovine/caprine was computed, respectively. Further, the carbon dioxide equivalent from bovine and caprine was 2.27 and 0.692 tCO2eq. According to the United Nations Framework Convention on Climate Change (UNFCCC), a tonne of animal waste produces over 100 cubic metres of biogas has a concentration of 65 per cent methane (CH_4) and 35 per cent carbon dioxide (CO2), both of which are among the five notorious greenhouse gases contributing to global warming (UNFCCC, 2015).

Conclusion

The study showed that the four selected abattoirs generated a significant amount of abattoir waste which could pose a challenge on disposal and effects on the environment. With the increasing number of abattoirs across other municipalities within the county, scale of abattoir wastes is expected to increase, leading the more GHG emissions, hence effective and efficient abattoir resource recovery and utilization as done through production of biogas and biofertilizer will be quite essential in managing the wastes and enhancing environmental safety and public health. The calculations showed that 1739.479 tonnes of abattoir waste is generated annually. Anaerobic digestion produced 92.1924 m^3 of biogas annually as per the Rao model. This translated to electricity production potential of 49.3229 kWh p.a and heat production potential of 71.4484 kWh p.a as a form of resource recovery. There was 549.0512 m^3 reduction of greenhouse gases using biogas technology which translates to GHG emissions reduction.

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