



Research article

Biogas and bio-fertilizer production potential of abattoir waste: implication in sustainable waste management in Shashemene City, Ethiopia

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HIGHLIGHTS

- The average number of cattle slaughtered was 37 cattle per day, and 13,505 cattle per year.
- The abattoir waste generated could be about 1,887 kg/day and 688,755 kg/year.
- The slaughterhouse has a biogas production capacity of approximately 566.1 m³/day and 206,626.5 m³/year.
- This biogas plant could hypothetically generate a heating value of 3.8×10^6 kW/year and electric power of 371,927.7 kW/year.
- The installation of AD plants at SMA has the potential to reduce GHG emissions by 952.4 t CO₂ eq per year and about 43,184.9 kg of biofertilizer will be produced annually.

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ABSTRACT

Fossil fuel resources become scarce, and their combustion is a major pollutant in the environment. As a result, scientists are eager to find alternatives to fossil fuels, and biomass could be one of them. One method of turning biomass into biogas is anaerobic digestion (AD). One of the organic waste kinds used to generate biogas is abattoir waste. In developing countries, managing abattoir waste streams is a significant concern. Using these wastes to produce biogas and biofertilizers could help Ethiopia reduce its environmental hazard while also solving energy and fertilizer-related issues. Given that, the researchers in this study intend to investigate the biogas and bio-fertilizer production potential of abattoir waste in Shashemene Municipality Abattoir (SMA), Ethiopia. To this aim, the production potential of biogas, energy, biofertilizer, and Greenhouse gas (GHG) reduction was examined. The study showed about 688,755 kg (kg) per year of slaughterhouse waste is produced from 13,505 cattle, and anaerobic digestion may create approximately 206.63×10^3 m³/year of biogas. As a result, it can generate 1,018.98 Kilowatt-hour (kWh)/day and 371,927.7 kWh/year. On an annual basis, the biogas output (206.63 10³ m³) can replace the 211.8 tons of energy consumed by LPG, kerosene, charcoal, furnace oil, petrol, and diesel. Moreover, the anaerobic digester has the potential to minimize the emission of greenhouse gas (GHG) by 952.4 tons CO₂ eq per year. Furthermore, biogas has the potential to generate 43,184.9 kg of dry bio-fertilizer per year. Therefore, while biogas technology is the long-term solution for ensuring environmental safety and public health, proper disposal was one of the short-term options.

1. Introduction

1.1. Background

The abattoir is a site where animals are slaughtered for the aim of producing meat or protein for public consumption. When proper processes are not followed when producing meat, the way byproducts/wastes are handled might ultimately result in a hazard (FAO, 2010;

Mahmoud et al., 2020; Yasir et al., 2021). Recently, abattoir waste disposal is therefore extremely difficult in urban environments all over the world. Low-income countries, in particular, are experiencing rapid urbanization, which is putting enormous strain on the city's abattoir waste (Ezeoha and Ugwuishiwi, 2011). According to (Arshad et al., 2018; Chukwu, 2008), the absence and lack of properly built abattoirs, as well as a lack of legislation on the restriction and prohibition of indiscriminate and hazardous waste discharge, the inadequate ability of waste

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handlers, poor equipment efficiency, and a lack of political commitment and knowledge, are the most significant causes of inappropriate abattoir waste management. Furthermore, in developing countries, there are insufficient waste management programs (Audu et al., 2020; Fearon et al., 2014) and a well-organized policy for disposing of solid and liquid waste produced in abattoirs (Akinro et al., 2009). Solid waste is dumped without further purifying or composting, or eroded, according to (FAO, 2010).

Feces, blood, bone, hone, fat, animal trimmings, paunch content, and urine from operations, stunning or bleeding, corpse processing, and by-product processing are among the contaminants found in abattoir wastes (Aniebo et al., 2009). Abattoir wastewater, on the other hand, makes up 70–75 percent of abattoir water, resulting in increased organic matter and a substantial amount of dissolved solids in the waste (Azad-bakht et al., 2021; Roberts et al., 2009). This pollution has the potential to pollute the environment, thereby putting people's health at risk. Quality of air, crop production and productivity, water supplies, and aquatic organisms are all impacted by abattoir waste, causing health and environmental hazards (Adeyemi and Adeyemo, 2007).

Bioenergy technology has recently grown in popularity as several countries adopt biogas goals as a primary method of handling a range of organic wastes. According to (Cvetković et al., 2014), abattoir waste is a good substrate for biogas manufacturing, because it contains a large proportion of organic stuff (proteins and lipids). Besides that, financial benefits, social benefits to the climate, health, jobs, gender, and poverty reduction benefits are all included in the economic benefits of biogas technology (Amigun and Von Blottnitz, 2010). Biogas generation is a low-cost, environmentally beneficial technology (Glivin and Sekhar, 2016) that protects the environment while reducing pollutants and greenhouse gas emissions (Bi et al., 2016).

Despite the potential benefits of slaughterhouse waste, improper disposal is a serious issue in many developing countries, and untreated abattoir wastes are a major source of public health and environmental problems (Adeyemi and Adeyemo, 2007). Several scholars have looked at the biogas producing technology's potential (Athanasoulia et al., 2012; Cuetos et al., 2008; Kefalew et al., 2021; Martín-González et al., 2010). Many scholars have also demonstrated blood and rumen content were a portion of slaughterhouse wastes that could be used to generate biogas and offers many advantages in terms of managing waste, sustainable

energy, health, and the environment (Afazeli et al., 2014; Audu et al., 2020; Azadbakht et al., 2021; Mahmoud et al., 2020; Sindibu et al., 2018; Tolera and Alemu, 2020; Yasir et al., 2021). However, there are several obstacles to renewable energy generation (e.g. policy, financial, and technological issues, as well as a lack of government and public interest and a gap in the available potential study) (Arshad et al., 2018). In most abattoirs, rumen content (waste formed from the stomachs of killed cattle) and other solid wastes are dumped at adjacent authorized areas, the liquid phase of washings is allowed to run into drains, including market places and roadways in Ethiopia (Sindibu et al., 2018; Tolera and Alemu, 2020) and particularly in the study area. Moreover, no data on the quantification of abattoir waste for long-term management was available. From the viewpoint of environmental management, a lack of data about the amount of waste generated resulted in difficulty in planning for waste management (Chukwu et al., 2011). It is critical to understand the amount created daily, monthly, and annually, as well as their ability to generate bioenergy and biofertilizer, for proper management. As a result, this research aimed to study the biogas and bio-fertilizer potential of abattoir waste in SMA, Ethiopia.

2. Materials and methods

2.1. Description of the study area

The research was carried out in Shashemene city, West Arsi zone, Ethiopia. The study site is geographically located between $0^{\circ} 00' - 16^{\circ} 00' N$ and $0^{\circ} 00' - 12^{\circ} 00' E$ (Figure 1). It stretches to the Rift Valley's south-eastern escarpment. It is situated on a plateau that rises from (1,826–2,107 m) above sea level. The average maximum and lowest temperatures of $24.3^{\circ} C$ in May and $7.5^{\circ} C$ in December in the study area. Each year, the city gets an average of 1200 mm of rain. The drainage pattern is dendritic, with flow direction varying from south-east to north-west depending on elevation. The micro watersheds define the catchment regions of the major rivers that flow into Lake Shala Basin, which is 50 km north of town. The national census in 2007 reported that the population was 102, 062 people dispersed across 12, 868 ha (CSA, 2007). Shashemene is anticipated to have more than 295,898 residents by 2021, according to OUPI projections (CSA, 2007).

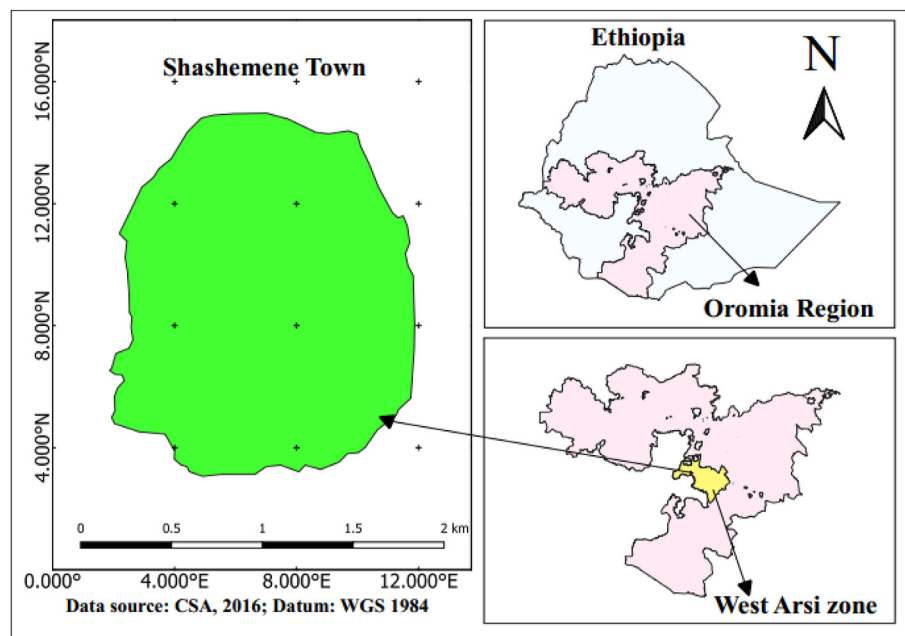


Figure 1. Location map of the study area.

2.2. Study design and approach

In the study area, cross-sectional research was undertaken. The number of cattle slaughters obtained from the survey was used to determine the volume of waste and biofertilizers created and, finally estimate the Greenhouse gas emission reduction (Table 1). This research was performed following the laws, guidelines, and ethical standards of Ethiopia, where the research was performed.

2.2.1. Waste from slaughterhouse

All slaughtered livestock was collected from March 1, 2020, to February 30, 2021, in the Shashemene City abattoir. The average number of livestock waste was calculated using their body weight, which was used by numerous scholars around the world (e.g. (Afazeli et al., 2014; Azadbakht et al., 2021; Mahmoud et al., 2020; Yasir et al., 2021)). Accordingly, the average body weight of cattle was estimated to be about 250 kg. Thus, the amount of blood available was estimated to be 8.4% of the weight of cattle (21 kg every day), while ruminal weight (kg) was estimated to be 12% of their total weight (30 kg of rumen content per day). (Afazeli et al., 2014) reported that the blood of slaughtering livestock and the rumen content could be regarded as a potential waste for the AD process. Thus, the total amount of waste generated in the study area is calculated using Eq. (1) as follows (Afazeli et al., 2014).

$$M = [E * A_M + N * (A_b + A_r)] * 365 \quad (1)$$

Where; M refers to the total annual of waste produced (kg year⁻¹); E is the total number of live cattle's; N is the total number of slaughtered cattle's; A_m is the amount of produced manure (kg day⁻¹); and A_b and A_r are the amounts of blood and rumen (kg day⁻¹) produced at slaughterhouses, respectively. In this research, only slaughtered cattle were considered and live livestock was not included (meaning zero).

2.2.2. Biogas production potential

Many scholars indicated that wastes of blood and rumen contents in abattoir were the key potential feedstock for biogas production (Abdeshahian et al., 2016; Afazeli et al., 2014; Audu et al., 2020; Azadbakht et al., 2021; Mahmoud et al., 2020; Onurbas, 2012; Yasir et al., 2021). Accordingly, the blood and rumen contents of cattle were considered for biogas production potential in this study (Figures 2,3,4,5). To determine the amount of biogas produced from blood and rumen lesions, it was

Table 1. Overall assumptions used for this study.

Assumptions	Values	Sources
Average Body weight of cattle (kg)	250	(Afazeli et al., 2014; Azadbakht et al., 2021; Mahmoud et al., 2020; Yasir et al., 2021)
Blood (kg day ⁻¹)	21	
Rumen content (kg day ⁻¹)	30	
The efficiency of biogas (m ³ kg ⁻¹ of TS) from blood	0.3–0.6	(Abdeshahian et al., 2016; Onurbas, 2012)
The efficiency of biogas (m ³ kg ⁻¹ of TS) from Rumen content	0.3–0.6	(Abdeshahian et al., 2016; Onurbas, 2012)
Dry Mass (DM) (10 ³ t/y)	15% of total waste	(Deublein and Steinhauser, 2008)
Volatile solids (VS) (10 ³ t/y)	96.7% of DM	(Ware and Power, 2016)
Heating conversion efficiency (%)	85	(Abdeshahian et al., 2016)
Lower calorific value in biogas (MJ.m ⁻³)	36	(Abdeshahian et al., 2016)
The overall efficiency of converting biogas to electricity (%)	30	(Abdeshahian et al., 2016; Benito et al., 2015; Hosseini and Wahid, 2014)
The quantity of the Energy content biogas (kWh m ⁻³)	6	(Abdeshahian et al., 2016; Hosseini and Wahid, 2014)

anticipated that all of these lesions would be converted to plant biogas without losing moisture. Biogas generation efficiency from both blood and rumen waste ranges from 0.3 to 0.6 m³ kg⁻¹ of fresh waste (Abdeshahian et al., 2016; Onurbas, 2012). Thus, 0.3 m³ kg⁻¹ of fresh waste was used for this study.

2.2.3. Electricity potential from biogas

According to (Salomon and Silva Lora, 2009), 60 % of methane biogas produced from slaughterhouses (rumen and blood) is expected.

By using a lower calorific value of 36 MJ per cubic meter of methane (36 MJ/m³) for the computation of the heating value of the methane produced, it was believed that 85 percent of the methane evolved could be converted to heat (85 percent heating conversion efficiency) in the boiler (Abdeshahian et al., 2016). The quantity of electricity that may be generated from biogas was estimated using (Eq. (2)).

$$e_{\text{biogas}} = e_{\text{biogas}} * \eta \quad (2)$$

Where e_{biogas} is the amount of produced electricity (kWh year⁻¹), E_{biogas} is the raw biogas energy that hasn't been converted (kWh year⁻¹) and the η represents the overall efficiency of the conversion of biogas to electricity (%). Depending on the electricity-producing plants, the amount η of varies. In power plants with large turbine systems and small generators, the number is 35–42 percent and 25 percent, respectively (Abdeshahian et al., 2016; Benito et al., 2015; Hosseini and Wahid, 2014).

The number was considered to be 30% in this investigation (Abdeshahian et al., 2016). Eq. (3) is used to compute the amount of E_{biogas}:

$$E_{\text{biogas}} = \text{Energy content}_{\text{biogas}} * m_{\text{biogas}} \quad (3)$$

Where Energy content_{biogas} denotes the calorific value of biogas (kWh m⁻³) and m_{biogas} denotes the quantity of biogas generated annually (m³ year⁻¹). The amount of the Energy content_{biogas} is expected as 6 kWh m⁻³ by considering the biogas calorific value as 21.5 MJ per m³ biogas (1 kWh = 3.6 MJ) (Abdeshahian et al., 2016; Hosseini and Wahid, 2014).

2.2.4. Reduction of GHGs using biogas technology

The reduction in GHGs caused by the production of biogas from abattoir waste was determined using the IPCC-developed mathematical computational method (B-sustain, 2013; Hua et al., 2020; JGCRI, 2018; Tolera and Alemu, 2020), demonstrated as GHG reduction potential of AD equivalent to the approximate of GHG emissions from dumpsites minus the approximate of GHG emissions from AD:

The following is a summary of the greenhouse emissions from dumping sites calculated using quantitative calculations (Eq. (4)):

$$\text{GHG Emission} = [((Q \times \text{DOC} \times \text{DOCF} \times \text{F1} \times 1.336) - R) \times (1 - \text{OX}) \times 25] \quad (4)$$

Where Q is the amount of slaughterhouse waste based on recorded waste (ton/kg); DOC is degradable organic carbon represented as a proportion of abattoir waste with the default value (DV) = 0.12; DOCF is the fraction of degradable organic carbon dissimilated for abattoir waste with DV = 0.7, and F1 is the fraction of methane (CH₄) produced from dumping sites, DV = 0.50; 1.336 is the rate of carbon being transformed to methane; R is the amount of methane recovered per year, measured in tons (here no recovered methane); OX is the oxidation factor (DV = 0.1 for well-managed and DV = 0 for unmanaged), and 25 is the CH₄ global warming potential used to convert the quantity of methane emitted to CO₂eq from the quantity of abattoir waste produced.

$$\text{GHG emissions}(\text{tCO}_2\text{eq}) = Q_j \times \text{EF}_j \quad (5)$$

Where t is the unit for waste either by ton or kg; CO₂eq is the CO₂ in equivalence; Q_j is the amount of waste by type j (here is only abattoir waste); EF_j is the emission factor of waste type j for biogas (DV = 0.02 kgCO₂eq).



Figure 2. Waste of rumen contents stored in the abattoir site (Kefalew, 2021).



Figure 3. Blood waste in the abattoir site (Kefalew, 2021).



Figure 4. Potential bone waste in the abattoir site (Kefalew, 2021).



Figure 5. Components of abattoir waste in the abattoir site (Kefalew, 2021).

To know the difference, the emission of GHGs from biogas production will be calculated:

$$\text{Reduction of the GHGs using biogas} = \sum \text{Equation 4} - \sum \text{Equation 5}$$

Equivalence of Biogas with expensive fossil fuels

According to energy estimates from (Amigun and Von Blottnitz, 2010) and (B-sustain, 2013), using 1 m^3 of biogas is equivalent to using 0.45 kg Liquefied Petroleum Gas (LPG); 0.6 kg kerosene (K); 3.50 kg charcoal/fire wood; 0.4 kg furnace oil (F); 0.7 kg petrol (P); and 0.5 kg diesel (D) in similar activities.

$$\text{Equivalence Biogas} = \sum \text{CFF} * \text{BV} \quad (6)$$

where CFF: Coefficient factor for above fuels; BV; the volume of produced biogas.

2.2.5. Bio-fertilizers yield (BFY) estimation

Only around 60% of VS is converted to biogas, which has biofertilizer potential. Likewise, several organic substrates demonstrated VS decreases of 40–46 percent after 80 days of AD (Schirmer et al., 2014). As a result, we employed 40% of VS to replace the dry matter that was leftover after the AD treatment. As a result, Eq. (6) was used to calculate the potential biofertilizer yield (dry) and was used by (Ngumah et al., 2013) and used by (e.g. (Audu et al., 2020; Sindibu et al., 2018; Tolera and Alemu, 2020).

$$\text{BFY} = (\text{DM} - \text{VS}) + (40\% * \text{VS}) \quad (7)$$

Where: DM = dry mass, VS = volatile solids, i.e., a portion of DM that is potentially converted to biogas. The DM percentage of fresh organic wastes is 15% for abattoir waste, according to (Deublein and Steinhauser, 2008), however, the Volatile Solids (VS) is the theoretically dry mass (DM) of abattoir waste transformed into a gas, which is 97 percent of DM (Ware and Power, 2016).

2.3. Practical applications and future research perspectives

We designed a five-year proposal for a long-term waste management system based on the findings of this investigation. It entails the construction of a biogas plant to reduce waste's environmental impact, generate bio-energy for the local population, and green public parks and other plants in the city using bio-fertilizer generated by anaerobic digestion.

3. Results and discussions

3.1. Abattoir waste generation rate

Currently, SMA provides only cattle slaughtering service, and the number of slaughtered cattle during the study period is presented in Table 2. On average, 37 cattle per day, 275 cattle per week, 1121 animals per month, and 13,505 cattle per year were slaughtered (Table 2). The number of slaughtered cattle per month ranges from 581 to 1537. This appears to be attributable to different fasting times and vacations, as well as periodic festive events throughout the year. The number of cattle slaughtered each day in SMA was lower than that reported by (Sindibu et al., 2018) for Hawassa City (63/day) (YesihakYusuf and Edward, 2015); for Elfora Kombolcha slaughterhouse (275/day), Adama slaughterhouse (200/day), and Mekele slaughterhouse (125/day); and Ethiopia Dire Dawa Abattoir (66/day) (Tolera and Alemu, 2020). Moreover, it is lower than the number of cattle slaughtered at Suleja (180), Minna (60), Lafia (45), and Karu (135) in Nigeria (Audu et al., 2020). In contrary to this, the number of cattle slaughtered per day was higher than in Harar town Abattoir (17/day), Haramaya town Abattoir (10/day), Haramaya University Enterprise Abattoir (12/day) (Tolera and Alemu, 2020). This might be owing to persons killing a higher number of cattle in their houses without informing the City abattoir office, or it could be due to beef demand and population.

The result indicated about 1,887 kg per day and 688,755 kg per year of abattoir waste was generated during meat production (Table 2). This demonstrates that it is capable of providing enough fuel for biogas technology to provide long-term energy and organic fertilizers for the community. This generation amount is less than the finding of (Sindibu et al., 2018) 2,456.04 kg/day and 885,881.6 kg/year from Hawassa City; 2,394 kg per day and 873,810 kg per year) from Mina abattoir in Nigeria (Ahaneku and Njemanze, 2015); and 14280 Cow and Buffalo per day in Golestan Slaughterhouses in Iran (Azadbakht et al., 2021). Also, it was lower than the annual waste recorded in Suleja (8.19 ton), Minna (3.05 ton), Lafia (2.25 ton), and Karu (8.41) slaughterhouses in Nigeria (Audu et al., 2020). A slightly lower generation (2,134 kg per day and 778,910 kg per year) was also reported from Temale abattoir in Ghana (Frederick et al., 2010). However, estimated waste in the present study is substantially greater than the annual waste recorded in Harar town Abattoir (224,366 kg), Haramaya town Abattoir (192,253 kg), and Haramaya University Enterprise Abattoir (174,193 kg) (Tolera and Alemu, 2020). Thus, waste estimation methods and components of wastes (e.g bone was not incorporated in this study) were the major cause for the variation. Moreover,

Table 2. Abattoir waste and volume of biogas.

Duration	Number of Cattle	Abattoir waste composition and generation (kg)			The volume of biogas produced (m ³)		
		Blood	Rumen	Total waste	Blood	Rumen	Total biogas
Day	37	777	1110	1887	233.1	333	566.1
Week	275	5775	8250	14025	1732.5	2475	4207.5
Month	1121	23541	33630	57171	7062.3	10089	17151.3
Year	13,505	283605	405150	688755	85081.5	121545	206626.5

differences in cattle slaughtering skills and community knowledge of slaughterhouse use appear to be the cause of these disparities.

Particularly, about 777 kg and 1110 kg of blood and rumen waste could be generated daily. According to (Aniebo et al., 2009), the discharge of blood into sewer lines from a single slaughtered calf is comparable to the whole sewage generated by 50 individuals on average each day. As a result, the total effluent load of sewage produced by 1850 humans per day was similar to the blood waste created per day in this study (i.e. from 37 slaughtered calves). Given the considerable volume of slaughterhouse waste generated throughout the country, including Ethiopia, neither governments' municipalities nor private-sector abattoirs have given waste management any concern.

Ethiopia has over 57 million cattle and more than 58 million sheep and goats in 2014, according to FAO statistics. In 2014, it accounted for 18 percent of Africa's total cattle population and 8.2% of the sheep and goat population. In 2010, Ethiopian beef demand was estimated to be at 421,400 metric tons (MT) (Enahoro et al., 2019). This is expected to rise to 678,500 metric tons in 2030 and 887,000 metric tons in 2050 (Enahoro et al., 2019). This means that by 2050, the number of cattle, sheep, and goats slaughtered will have nearly doubled. As a result, the amount of slaughterhouse waste created will increase, potentially providing the necessary fuel for biogas generation. As a result, the Shashemene Municipality abattoir can provide enough feedstock for biogas technology if sustainably managed.

3.2. Biogas and energy potential

One renewable energy source is a biogas digester, which can produce low-cost electricity while also being environmentally beneficial. According to Table 3, the blood of slaughtered cattle in SMA could hypothetically yield a total biogas output of 85081.5 m³/year. The rumen content determined a significant level of biogas production potential when compared to blood waste. The rumen content obtained from the meat factory has the potential to provide a total biogas capacity of 121545 m³/year, which is 30% more than the biogas generated from blood waste.

Blood and rumen methane production capacities were estimated to be 51048.9 and 72927 m³/year, respectively. Methane from blood and rumen content have also been discovered to be capable of supplying 1.6106 and 2.23106 MJ/year of heat, respectively. Table 2 reveals that the abattoir of the Shashemene Municipal has a total biogas potential of 206,626.5 m³ per year with a methane concentration of 123975.9 m³/year. This biogas total may hypothetically generate 3.8 106 kW/year of heating and 371,927.7 kW/year of electrical energy. Although digester capacities of 20–60 m³ are considered adequate for small-to-medium scale business enterprises based on the assumption that a family consumes a minimum of 0.8 m³/day (Arnott, 1985; Avery et al., 2011), the Shashemene Municipal abattoir fulfills the waste volumes required to run as small-scale business enterprises.

The annual biogas production potential recorded in this study was substantially higher than that reported by (Sindibu et al., 2018) 46, 951.72 m³/year abattoir in Hawassa City, Ethiopia, and Minna abattoir, Nigeria (45,672.64 m³) (Frederick et al., 2010) and Temale abattoir (Ghana) (40,716.72 m³) (Adzabe et al., 2005); Harar town (11,891.61 m³/year), Haramaya Town abattoir (10,189.25 m³/year), and Haramaya

Table 3. Estimation of methane content, potential heat value, and electricity generated.

Duration	Biogas (m ³)	CH ₄ (m ³)	Heating value (10 ⁴) (kWh)	Electricity (kWh)
Day	566.1	339.66	1.0	1018.98
Week	4207.5	2524.5	7.7	7573.5
Month	17151.3	10290.78	31.5	30872.34
Year	206626.5	123975.9	379.4	371927.7

kWh: Kilowatt-hour.

University Enterprise abattoirs (9,263.87 m³/year) in Eastern Ethiopia (Tolera and Alemu, 2020). However, it is lower than the annual biogas recorded in Suleja (623,000 m³), Minna (232,000 m³) and Karu (640,000 m³) in Nigeria (Audu et al., 2020); the province of Bassiknou (136.9 * 106), Tintane (134.9 * 106), Kiffa (134.5 * 106) and Aioun (125.3 * 106) m³/year (Mahmoud et al., 2020). These differences appear to be due to the difference in the cattle slaughtering capacities, type of livestock (e.g. Cattles, buffaloes, Camels, Sheep, and goats) considered in the study, variation in awareness of community toward use abattoir for slaughtering, and variation in the methods of estimation biogas production.

The Ethiopian government, non-governmental groups, and international players were urged to seek alternative renewable energy sources due to the threats posed by climate change, rising energy requirements, and expanding non-renewable energy sources, as well as growing environmental concerns. In Ethiopia's National Biogas Program (NBP), 14,500 biogas plants were planned during the first phase (2009–2013) and 20,000 biogas plants were scheduled for phase 2 (2014–2017) in 163 districts, such as the studied area. Nevertheless, approximately 8,063 and 1762 biogas plants were built during the first and second phases, respectively (Berhe et al., 2017; Mengistu et al., 2016). As a result, our findings were consistent with and backed up this strategic goal for any enterprises or organizations interested in using energy from biowaste, such as slaughterhouse waste, as a sustainable alternative to disposal.

Ethiopia's population has nearly doubled since 1990, rising from 48 million to 92 million in 2012 (WDI, 2015). (Mondal et al., 2018) predicts that by 2050, the country's population would have surpassed 134 million. In particular, the urban population, which currently accounts for 17% of the population, is anticipated to increase to 21% by 2030. As a result, overall energy consumption is expected to rise from 1358 Petajoule (PJ) in 2012 to about 2120 PJ by 2030 (2.1 percent average growth per year) (Mondal et al., 2018). Hence, introducing sustainable and renewable energy sources is critical for long-term growth. Therefore, the introduction of an anaerobic digester has the potential to boost the study area's energy supply.

3.3. Estimation of possible reduction of GHG emissions

The IPCC provided a model for computation with default values for the various coefficients, which was used to assess the potential of biogas toward GHG reduction (t CO₂ eq) (Hua et al., 2020). SMA's AD plants can minimize GHG emissions by 952.4 t CO₂ eq per year (Table 4).

The generation of biogas and biofertilizer from slaughterhouse wastes might help to reduce the use of fossil fuels and inorganic fertilizers. This

Table 4. Estimation of potential reduction of GHG emission.

Period	Estimated waste (ton)	GHG estimated from dumping (ton)	Estimated of GHGs from AD (ton)	Potential of AD reduction (ton)
Day	1.9	2.6	0.04	2.6
Week	14.0	19.7	0.28	19.4
Month	57.2	80.2	1.14	79.1
Year	688.8	966.2	13.78	952.4

will also serve as a cost-effective waste recycling strategy, reducing GHG emissions from open manure storage (Lukehurst et al., 2010). Specifically, an anaerobic digester may reduce around 966.2 tons of carbon dioxide equivalency of GHG emissions, saving about 952.4 ton CO₂eq. Based on the existing findings, an anaerobic digester may produce only around 13.78 tons of carbon dioxide equivalency of GHG when it is installed (Table 4).

The potential biogas or energy (electricity and heat) generated from the waste may be used to substitute the biomass and the costly fossil fuels (kerosene, petrol, liquefied petroleum gas (LPG), diesel, and furnace oil) and it is a “cleaner” than these fuels (Audu et al., 2020). According to the calculations, the estimated 206.63 103 m³/year of biogas is comparable to 82.6 tons of furnace oil, 92.98 tons of LPG, 103.3 tons of diesel, 123.9 tons of kerosene, 144.6 tons of petrol, and 723.2 tons of charcoal/firewood per year using same functions as in Table 5. Displacement of firewood, charcoal, and kerosene, as stated by (Ngumah et al., 2013), will reduce demand for firewood, resulting in deforestation, as well as save numerous diseases and fatalities connected to indoor environmental damage caused by these sources. As a result, the production of efficient and sustainable energy and biological fertilizer from waste recycling could be a viable alternative to the most costly conventional fossil fuels and biomass, both have substantial disadvantages.

As the country's energy security has improved, so has its greenhouse gas emissions. In 2000, carbon dioxide emissions were expected to be 5.8 million metric tons (MMT), increasing to 6.4 MMT by 2010 (Mondal et al., 2018). CO₂ emissions are expected to rise from 6.7 million metric tons in 2012 to 17.2 million metric tons by 2030, according to (Mondal et al., 2018). Between 2012 and 2030, Charcoal, oil, and LPG may comprise the majority of GHG emissions. The Ethiopian government underlined the necessity for sustainable energy development in the Growth and Transformation Plan (MoFED, 2010), the Green Economy (FDRE, 2011), and the Biomass Energy Strategy (Geissler et al., 2013). As a result, the adoption of renewable energy sources (for example, biogas technology) can help to reduce greenhouse gas emissions in the research region.

3.4. Production of biofertilizer

Biofertilizer is the remaining part of slaughterhouse waste produced from the anaerobic digester and about 43,184.9 kg of biofertilizer was estimated annually (Table 6). This potential bio-fertilizer generated can be used for crop production and productivity improvement for local farmers or used for urban greening. Biofertilizer generated from biogas

Table 5. Estimation of equivalence of biogas potentials with some fossil fuels in the same function.

Period	Biogas (m ³)	Equivalent of fuels (kg)					
		LPG*	Kerosene	Charcoal/Firewood	Furnace oil	Petrol	Diesel
Day	566.1	254.745	339.66	1981.35	226.44	396.27	283.05
Week	4207.5	1893.375	2524.5	14726.25	1683	2945.25	2103.75
Month	17151.3	7718.085	10290.78	60029.55	6860.52	12005.91	8575.65
Year	206626.5	92981.93	123975.9	723192.8	82650.6	144638.6	103313.3

* LPG = Liquid Petrol Gas.

Table 6. The bio-fertilizer potential of Shashemene Municipal Abattoir waste.

Duration/Period	Abattoir waste Generated (kg)	DM*(kg)	VS**(kg)	BFY potential (kg)
Day	1887	283.1	274.6	118.3
Week	14025	2103.8	2040.6	879.4
Month	57171	8575.7	8318.4	3584.6
Year	688755	103313.3	100213.9	43184.9

technology has the potential to improve crop production and productivity for sustainable agriculture at a low cost (Hua et al., 2020). (Veroneze et al., 2019) also indicated that anaerobic digestion has the potential to produce organic fertilizer with excellent nutritional conditions, with sufficient levels of Phosphorus, Potassium, Calcium, Magnesium, Manganese, iron, and Zinc. Furthermore, organic fertilizer reduces pollution of the environment (water sources, soil) and loss of decomposer microorganisms which are vital for soil fertility improvement. Hence, biofertilizers from biogas have the potential to raise the yield of the crop from 15% to 25%.

In another way, the income generated from the Shashemene Municipality abattoir could be an additional source of revenue for the town. Hence, the generation of sustainable organic manure from recycling abattoir waste is a potential way to achieve a circular economy and can also healthy and a cleaner environment (Chukwu et al., 2011). The aforementioned findings back up the GTP's second goal, which specifies that "any government entity should improve their internal resource utilization of income benefits to not less than 5% of their governmental budget" (NPC, 2016). In addition, when compared to other waste treatment options, AD has the potential to reduce pollutants and greenhouse gas emissions. It also aids in the reduction of global warming and the improvement and maintenance of soil health.

According to (Nikos and Jelle, 2012), the expected growth rate of total global consumption of all agricultural goods is equal to production, and worldwide production in 2050 could be 60% greater than in 2005/2007. This accounts for a 77 % increment in developing countries. As a result, overall fertilizer use could rise from 166 million tons in 2005/2007 to 263 million tons in 2050. In particular, by 2050, developing countries would account for over 70% of global fertilizer usage (Nikos and Jelle, 2012). Thus, organic fertilizer produced from renewable sources (e.g biogas) is environmentally friendly and low cost. Thus, it has the potential to meet the needs of fertilizers to improve agricultural production and productivity.

4. Conclusion

The potential of abattoir waste for the production of biogas and bio-fertilizer from abattoir waste were analyzed and presented. This study showed that SMA created a large amount of abattoir waste, which was directly released into water sources and the surrounding ecology without any management system. As a result, installing biogas (anaerobic digestion) may provide a large amount of biofertilizer yield and energy while also lowering GHG emissions. Anaerobic digestion can help to reduce GHG emissions and inorganic fertilizer use by providing an

effective waste recycling technique. Furthermore, as a way of long-term management, it can assure environmental safety and public health. As a result, although biogas technology is the long-term answer to ensure environmental safety and public health, appropriate disposal is a short-term solution.

Declarations

Author contribution statement

Tamiru Kefalew: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Misgana Lami: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data associated with this study has been deposited at Kefalew et al. (2021), "Data input", Mendeley Data, V1, doi: 10.17632/2xkj3sf598.1.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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