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Evaluation of potential feedstocks for sustainable biogas production in Ghana: Quantification, energy generation, and CO₂ abatement

Richard Arthur¹*, Martina Francisca Baidoo², Gabriel Osei³, Linda Boamah⁴ and Samuel Kwofie⁵

Abstract: This study aimed at evaluating the potential biogas production from four main sources, in terms of the volume of methane for energy production and the equivalent avoidable carbon dioxide emissions in 2020 through to 2030. It was based on the projection of methane production from common livestock and poultry manure, possible landfills, wastewater treatment plants, and palm oil mill effluent. This paper uses sound and reliable methodology to estimate the biogas potential of these major resources, which could lead to significant achievement in environmental sustainability via biogas generation and carbon dioxide emission reduction. The results showed that a total of 690.7 million m³ and 848.74 7 million m³ of methane could be obtained from all the sources considered in 2020 and in 2030, respectively, which translates to about 1.84 TWhₑₘ and 2.28 TWhₑₘ. It also meant that a total carbon dioxide equivalent emission of 12.36 million tCO₂-eq and 15.82 million tCO₂-

eq could be avoided in 2020 and 2030, respectively. The results of this study therefore, show the remarkable contribution that biogas technology can make, as well as serve as an immediate technical information for policies makers.

ABOUT THE AUTHOR
The authors are focused on research related to environmental sustainability, through renewable energy application, innovative techniques in biomass conversion, and climate protection. The diverse backgrounds of the authors bring the various benefits and related applications in the various fields to bare. The authors’ work seeks to emphasize the importance of application of sustainable approaches for environmental sustainability. Specifically, it highlights the impact of the application of proper solid and liquid waste management techniques, biogas production from livestock manure, and agro-processing residues, to sustainably managing the environment. This study particularly looked at the biogas potential, energy generation, and carbon dioxide reduction potential of these sources, with emphasis on the associated contribution to Ghana’s renewable energy target.

PUBLIC INTEREST STATEMENT
The identification and use of renewable energy resources is critical when finding long-term solutions to achieve environmental sustainability. However, the extent of the contribution from these resources should be linked to the major socio-economic lifestyle of a particular country. Several technologies are known to successfully convert these resources. However, in many cases, the potentials of some of these identified resources are largely unknown. The biogas potential of four sources were estimated and projected to determine the bioenergy potential in Ghana for 2020 through to 2030. Furthermore, the carbon dioxide emission reduction potential was also determined. With the importance attached to the benefits of using sustainable approaches set by the country to meets its renewable energy and climate change obligations, this paper highlights the importance of focusing on these resources by using best practices to achieve the set goals.
government agencies, and potential investors on the development of biogas technology in Ghana. Significant achievements can be made when comprehensive attempts are made so as to provide sustainable energy by integrating and improving livestock rearing, application of comprehensive solid and liquid waste management system and usage of best practices for managing agro-processing residues, which are integral part of the socio-economic activities in Ghana.

**Subjects**: Environmental Management; Renewable Energy; Climate Protection

**Keywords**: Biogas potential; livestock manure; palm oil mill effluent; landfills; wastewater; carbon dioxide emission reduction

1. Introduction

Access to energy is one of the most important strategic considerations when developing schemes for sustainable development. The overall economic growth of a country is also tied to the substantial role played by the energy sector. Furthermore, the issues regarding energy is strongly linked to human development as well as the environment (Amigun et al., 2011; Uahunamure et al., 2019). Ghana is endowed with abundant renewable energy resources, and the country is fully aware of the relationship between access to energy and development of a low-carbon economy.

In attempting to protecting the environment, biogas technology has been identified as one of the renewable resources to consider (Energy Commission, 2019a). Similar to other Sub-Saharan African countries, Ghana largely depends on fossil fuel sources and large hydroelectric for electricity generation, and woodfuel as the primary fuel for domestic use (Arthur, Baidoo, Antwi et al., 2011; Kemausuor et al., 2011; Sakah et al., 2017). Biogas is particularly a strong candidate for domestic use, as it is also known to address issues related to indoor air pollution, and also known to be an environmentally sustainable energy resource, as its production creates almost a closed-nutrient cycle. Some of the nitrogen is lost with the gas produced, otherwise it would have been a perfect closed-nutrient cycle.

Furthermore, effluent from biogas production can be successfully applied as bio-fertiliser. There is also global interest in biogas due to the significant role it plays in climate change adaptation attempts and reduction of greenhouse gas effects (Budzianowski, 2012; 2011; Iglinski et al., 2015). In fact, the World Biogas Association estimates that biogas is among the most effective industry in this respect, as it can contribute to the achievement of 9 out of the 17 Sustainable Development Goals (Bartoli et al., 2019).

For Ghana to meet its total energy target of 22,091 ktoe in 2030, based on Accelerated Economic Growth scenario(Energy Commission, 2019b), supplementation of the national energy supply with renewable energy, would also require development of its biogas sector, for example, through best practices in solid and liquid waste management. This could provide direct and indirect realisation of the benefits of biogas technology. Recovery of biogas from agricultural residues, such as manure, and agro-processing residues are also generally known to be cost-effective greenhouse gases (GHG) mitigation approaches in the agricultural sector. Therefore, agriculture being one of the key development sectors in Ghana (Table 1), could be a major focal point to support the development of biogas technology.

Wastewater and Organic Fraction of Municipal Solid Waste (OFMSW) can be transformed through methane generation for electricity production. There are several examples about the potential use of biogas production for electricity generation: 1.1 TWh/year from landfill in Portugal, 0.162 TWh/year from anaerobic digestion of agricultural residues, animal manure, vinasse, wastewater treatment sludge, and municipal solid waste in Uruguay,8.27 GWh/year
from animal manure in Malaysia, 34.4 TWh/year from cattle, pig and poultry manure (Dos Santos et al., 2018) and 8.2 TWh/year from domestic wastewater in West Africa (Rupf et al., 2016). Therefore, these potential sources could also be harnessed to support the renewable energy sector in Ghana.

Therefore, this paper aims to present the projected estimates and analysis of the biogas production potential from four possible sources in Ghana, by estimating the electricity generation potential and the possible CO2 emission reduction for 2020 through to 2030. The year 2030 was chosen because there is a Renewable Energy Master Plan (REMP) for Ghana to address the attendant effects of such short-term planning of the overall development of the renewable energy sector by 2030. In this paper, the four possible sources covered are the anaerobic digestion of manure from common livestock and poultry, wastewater sanitary facilities, organic fraction of municipal solid wastes through engineered landfills, and palm oil mill effluent generated from the palm oil production industry. The goal is to identify areas of possible development to boost the overall renewable energy mix through biogas technology, while meeting climate change mitigation obligations. The approach used in this paper is fundamental and generally applicable in similar socio-economic and environmental conditions.

2. Materials and methods

2.1. Estimation of potential methane production from livestock and poultry manure

The potential methane production from the manure of cattle, pig, sheep, goat and chicken was considered in this study. Data related to the selected livestock and poultry produced between 2007 and 2017 obtained from FAO were used. The northern part of Ghana is considered to be the natural livestock region due to the lower tsetsefly population as compared with the humid southern regions of the country (Nin-Pratt & McBride, 2014). Furthermore, the increase in the production of goats and sheep in recent decades may be because they exhibit high feed conversion efficiency compared with pig, cattle, and poultry (Peacock, 2005).

It is not possible to collect all the manure generated by livestock and poultry due to the different rearing management systems used in Ghana. Livestock and poultry reared using the open-ranged system are more likely to feed on grass or straw, which tend to cause an increase in the production of methane due to the possibly high production of acetate than propionate, leading to high methanogenic activities (Hassanat & Bencharak, 2013). The quality and quantity of feed affect methane production and emission from ruminants (Bencharak et al., 2001; Hopkins & Del Prado, 2007). Therefore, there are opportunities to harness the methane emission from intensive and semi-intensive management systems, where the feed can be manipulated or supplemented to achieve high methane production from the manure.
Table 2. Selected livestock production data for Ghana (head) (FAO, 2019)

| Livestock | 2007       | 2008       | 2009       | 2010       | 2011       | 2012       | 2013       | 2014       | 2015       | 2016       | 2017       |
|-----------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Cattle    | 1,373,000  | 1,392,000  | 1,438,000  | 1,454,000  | 1,498,000  | 1,543,000  | 1,590,000  | 1,657,000  | 1,734,000  | 1,734,000  | 1,763,984  |
| Pig       | 491,000    | 506,000    | 521,000    | 536,000    | 568,000    | 602,000    | 638,000    | 682,000    | 730,000    | 730,000    | 741,500    |
| Sheep     | 3,420,000  | 3,529,000  | 3,642,000  | 3,759,000  | 3,887,000  | 4,019,000  | 4,156,000  | 4,335,000  | 4,522,000  | 4,522,000  | 4,611,831  |
| Goat      | 4,196,000  | 4,405,000  | 4,625,000  | 4,855,000  | 5,137,000  | 5,435,000  | 5,751,000  | 6,044,000  | 6,352,000  | 6,352,000  | 6,400,000  |
| Chicken   | 37,038,000 | 39,816,000 | 43,320,000 | 47,752,000 | 52,575,000 | 57,885,000 | 63,732,000 | 68,511,000 | 71,594,000 | 71,594,000 | 74,478,000 |
Based on the livestock production data (Table 2), the potential methane production and utilisation from the livestock manure were estimated using the information provided in Tables 3 and 4 and further projected from 2020 to 2030. This was based on the assumption that the manure from the livestock and poultry would be collected and transferred into biodigesters. The biogas produced could be used for cooking, lighting, and electricity production (Table 4). The theoretical energy production from these appliances was also calculated to estimate the amount of firewood that could be offset, especially for cooking.

Equation (1) was used to estimate the theoretical methane potential of the manure from the selected livestock and poultry

\[ ME_{PL(i)} = \frac{N_t(i) \times M_{CE} \times 365 \times M_{YF(i)} \times DM(i) \times B_{Y(i)}}{10^6} \]  

(1)

Where: \( ME_{PL(i)} \) is the methane potential of selected livestock (i) in Nm³/year; \( N_t(i) \) is the total number of selected livestock (i) (Table 2); \( M_{CE} \) is the manure collection efficiency %; \( M_{YF(i)} \) is the percentage of methane in biogas, %; \( B_{Y(i)} \) is the biogas yield factor of selected livestock manure in m³/kg; i is the selected livestock; DM (i) is the dry matter of selected manure. Using Equation (1), the projected methane potential of the livestock manure was estimated using the data presented in Tables 2 and 3. The minimum values of the dry matter (DM) and the minimum values of the biogas yields of the manure were used (Table 3). The theoretical energy equivalent of methane was taken as, 1 m³ methane = 10 kWh(Suhartini et al., 2019).

The actual proportion of methane in biogas varies and could lay in a range of 55–65% (Abbasi et al., 2012), due to different composition of substrates, biological consortia, and fermentation conditions of the digester. In view of this, it was assumed that methane content of the biogas produced from the livestock manure is 60%. Also, the collection efficiency of the manure from the livestock depends on the livestock management(Powell et al., 2005). A study carried out in four peri-urban livestock keeping regions in Ghana, showed that about 1.5% of livestock farmers practice extensive management systems or open range, whereas 39.4% and 59.1% practice semi-intensive and intensive system of management, respectively (Turkson, 2008). Therefore, if it is assumed that all the manure produced under intensive system is collected (100%), and only 50%
of the manure is collected under semi-intensive system, while none of the manure produced under
extensive system of livestock management are collected, then, using the above data, the overall
manure collection efficiency could be estimated to be about 80%. Additionally, using global
warming potential (GWP) of methane relative to carbon dioxide of 25 kg CO₂/kg CH₄ (Ryu, 2010)
and using methane density of 0.716 kg/m³ (UNFCCC, 2003), the equivalent GHG emission that
could be avoided was also calculated.

2.2. Estimation of potential methane from landfill sites
The waste generation rates depend on the population and the gross domestic product (GDP) espe-
cially in developing countries (Troshcinetz & Mihelcic, 2009). Furthermore, increasing population
and improving economic parameters also influence the quality of waste generated (Ayodele et al., 2018).
Municipal Solid Waste (MSW) management is still at the stage where only the effective collection
of MSW away from the streets into disposal sites are considered accomplished, which still eludes many
municipalities in developing countries (Aboyade, 2004). Moreover, MSW are highly heterogeneous in
nature and have viable characteristics (Owusu-Nimo et al., 2019), with much of the waste generated
from households (55–80%), markets (10–30%) and institutions, inter alia (Douti et al., 2017). In this
study, it is assumed that the landfills would be engineered for biogas recovery. To calculate the
potential methane production from the possible landfills, the quantity of MSW expected to be
generated between 2020 and 2030 was estimated. Also, the composition of the MSW obtained and
the volume of waste generated annually was calculated using Equation (2).

\[ V_C(i) = \frac{J \times P_{op(i)} \times 365 \times E_{wvc}}{1000} \]  

(2)

Where: \( V_C(i) \) is the volume of waste generated for the projected year (ton/year); \( J \) is the national
average MSW generated per capita (kg/person/day) = 0.51 kg/person/day (EPA, 2017) \( P_{op(i)} \) is the
projected population over the given period; 365 is the number of days in a year; \( E_{wvc} \) is the municipal
waste collection efficiency. The MSW collection efficiency in Ghana varies from city to city ranging
from 70 to 82 % in the major cities as of 2014 (EPA, 2017). An average of 78% based on the collection
efficiencies in the major cities, was used for the calculation. The projected populated, \( P_{op(i)} \) was
calculated using Equation (3) for a particular year, \( i \), from (Ayodele et al., 2018).

\[ P_{op(i)} = P_b \times (1 + r)^i \]  

(3)

Where: \( P_b \) is the initial estimated population (32.2 million in 2020, estimated based on data from
worldBank (2019)); \( r \) is the population growth rate (2.18%, 2016 est. (Ghana Statistical Service,
2019)). Not all the wastes generated is expected to be sent to landfill sites, as some of them would
be disposed of unlawfully. The total volume of waste deposited at landfill sites can be calculated
by considering the proportion of waste sent to the landfill sites. Currently, only 10% of the solid
waste generated is properly disposed throughout the country by incineration and land filling
(Ofori-Boateng et al., 2013). This is probably due to the limited number of engineered sanitary landfill
sites being 5, against 172 dumps currently in Ghana (EPA, 2017). However, the total volume of
waste expected to be at landfill sites for a given year can be calculated using Equation (4).

\[ V_T(i) = V_C(i) \times F_D \]  

(4)

Where: \( V_T (i) \) is the total amount of waste at landfill sites for a given year (ton/year); \( V_C (i) \) is the
total amount of waste generated (ton/year); \( F_D \) proportion of municipal solid waste sent to landfill
sites (%). For these calculations, \( F_D \) of 50 and 60% of the MSW were assumed and considered
based on the situation in Brazil- a developing country (Dos Santos et al., 2018) and Sub-Saharan
African countries (Ayodele et al., 2018; Rupf et al., 2016).

The average factors for production of biogas from moderately and highly degradable wastes in
landfills were used in this study (Dos Santos et al., 2018). The average values of the production
potential of methane (\( M_J \) for highly and moderately degradable wastes used are 170 m³/ton of
waste and 262.5 m³/ton of waste, respectively. Furthermore, the biogas collection efficiency of
55.5% was also assumed (Dos Santos et al., 2018). Subsequently, the biogas from potential landfills was calculated based on Equation (5).

$$M_T(i) = M_i \times V_T(i) \times C_{eff}$$

(5)

Where: $M_T(i)$ is the total methane to be produced annually in the landfills (m$^3$/year); $M_i$ is the methane production factor m$^3$/ton of MSW, $V_T(i)$ is the total amount of waste at landfill sites for a given year (ton/year), $C_{eff}$ is the biogas collection efficiency.

The methane recovered from landfills could use internal combustion engines for the power production. Therefore, the annual electrical energy and the potential power production from the landfill sites were calculated using Equations (6) and (7), respectively.

$$E_M(i) = \frac{M_T(i) \times P_{eff} \times LHV_{CH4} \times CF}{3.6 \times 10^6}$$

(6)

Where: $E_M(i)$ is the annual electrical energy production potential (GWh/year) $P_{eff}$ is the efficiency of the internal combustion engines, typically 35% for such systems (Hadidi & Omer, 2017); $LHV_{CH4}$ is the lower heating value for methane, 35.5 MJ/m$^3$; CF capacity factor of the plant, 0.8 (Dos Santos et al., 2018); $3.6 \times 10^6$ is the factor unit conversion.

$$P_{(i)} = \frac{E_M(i)}{OP_{h}}$$

(7)

Where: $P_{(i)}$ is the annual potential power production (MW/year); $OP_{h}$ is the annual operation hours of the plant, 8760 h/year (best case scenario). This was chosen because the plants are expected to operate throughout the year, as long as the MSW generated would be sent to the landfill sites.

Avoidable equivalent CO$_2$ was calculated by assuming that the potential methane from the landfill sites would have been released directly into the atmosphere instead of it being recovered. Therefore, GWP of methane relative to carbon dioxide of 25kgCO$_2$/kgCH$_4$ (Ryu, 2010), was used. Only the emission of methane was considered, although GHG is composed of other gases such as nitrous oxide (N$_2$O), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The mass of potential methane emission was calculated by using methane density of 0.716 kg/m$^3$ (UNFCCC, 2003).

Apart from the direct biogas recovery from engineering landfill sites, another option could be to separate the organic fraction of the municipal solid waste (OFMSW) from the entire waste and conveying them to biodigesters, while the residual waste could be burnt via waste-to-energy systems for power generation.

2.3. Estimation of methane from potential wastewater treatment plants

Wastewater treatment plants are major potential source of methane for power production. In this case, the biogas can be produced from the anaerobic digestion of the effluent treatment in anaerobic reactors or anaerobic digestion of sludge from the treatment (Dos Santos et al., 2018). Currently, wastewater treatment is very limited in Ghana and only 5% of urban settlements are served with wastewater treatment plants (EPA, 2017). It therefore suggests that, there is a huge potential to generate methane when wastewater treatment facilities are constructed in the various urban areas of the country coupled with significant potential avoidable GHG emissions.

Presently, there are different types of sanitation facilities in Ghana. These include flush systems to a septic tank, pit latrine with slab, Kumasi Ventilated Improved Pit (KVIP) and bucket/pan (very small percentage of the population use it, although it has been banned). The public sanitation facilities are also in the form of KVIP, where patrons pay a fee to use. In the urban areas about 38.6% of population use flush systems and KVIP, whereas in the rural areas, only 10.5% use flush systems and KVIP (EPA, 2017). In Ghana, the proportion of the population living in urban and rural areas are 54% and 46%, respectively. Wastewater from household flush systems to a septic tank and shared
sanitation facility could be transported to a wastewater treatment plant for anaerobic digestion. It is also possible that the wastewater from the shared sanitation facility could be anaerobically digested on-site in community-scale biodigesters. The population with these improved sanitation facilities was chosen exclusively to derive this estimated methane. The methane potential of the wastewater was calculated using Equation 8, modified from Rupf et al. (2016).

\[ M_{\text{ww}} = \sum_{i=\text{urban, rural}} (U_i \times T_i \times B_o \times \text{MCF}) \times (P_{\text{op}} \times \text{BOD} \times 365) \]  

Where: \( M_{\text{ww}} \) is the methane production potential from wastewater (kg/year); \( U_i \) is the fraction of the population that are either urban or rural; \( T_i \) is the fraction of the urban or rural population that have access to improved sanitation; \( P_{\text{op}} \) is the population calculated using Equation (3); \( \text{BOD} \) is the biological oxygen demand in a given year; \( B_o \) is the maximum methane-producing capacity, and \( \text{MCF} \) is the methane correction factor, which is an indicator of the degree to which a treatment system is anaerobic. The average kg BOD per person per day, and \( B_o \) values for Sub-Saharan Africa being 0.037 kg/pp/day and 0.6 kg CH\(_4\)/kg BOD, respectively were used (Rupf et al., 2016), due to unavailable-specific data for Ghana. The MCF value for anaerobic reactors of 0.8 (Arthur & Glover, 2012; Rupf et al., 2016).

### 2.4. Estimation of methane from palm oil mill effluent

The palm oil industry in Ghana is a strong contributor to the economy (Arthur & Glover, 2012). The average production of fresh oil Palm fruit bunches is 15 Mt/ha, which is slightly lower than the global average of 18 Mt/ha (MASDAR, 2011). The relatively low national yield compared with the global average may be due to climatic and soil conditions. Total crude palm oil production in Ghana increased from 341,675.10 Mt in 2006 to 545,702.48 Mt in 2015 (Table 5), indicating an increase of about 60% in 9 years. The increase in production can be attributed to the medium-scale mills, small-scale mills and other private holdings. In 2015, the Oil palm companies (GOPDC, TOPP, BOPP, NOPL and AMEEN) contributed only 14.6% of the total production.

Wet process of palm oil milling is the most common and typical method used for extracting palm oil in Ghana. During the process of crude palm oil (CPO) extraction through the wet process, high quantities of water are utilized (Arthur & Glover, 2012). Furthermore, the CPO extraction process produces significant amount of high-energy value by-products such as liquid effluent with high organic content known as palm oil mill effluent (POME), empty fresh fruit bunches (FFB), fibres, and shells. Palm oil mill produces residues equivalent to almost three times the amount of oil produced by biomass on a mass basis (Arrieta et al., 2007). POME is non-toxic because no chemical is used in the processing, but as it is a highly polluted agro-processing wastewater, it can cause severe land and water pollution due to the high levels of organic loading, high temperature and low pH (Table 6) (Ahmad et al., 2003; Lam & Lee, 2011; Singh et al., 2011).

This, on the other hand, present a huge opportunity for methane recovery and supplementation of the energy requirement for the palm oil industry. Table 7 shows the typical characteristics of POME from a palm oil-producing industry. In this study, the estimation of maximum biomethane from POME was based on the methodology developed in the 2006 IPCC Volume 5 guidelines for National Greenhouse Gas Inventories, specifically for industrial wastewater (Arthur & Glover, 2012; Eggleston et al., 2006). The volume of methane from the POME was estimated using Equation (9).

\[ M_{\text{POME}} = \frac{Q_{\text{CPO}} \times D_{\text{OG}} \times V_{\text{ww}} \times \text{EF}_{\text{CODR}} \times M_{\text{C}}}{\rho \times 10^6} \]  

Where: \( M_{\text{POME}} \) is the potential methane production from POME (million m\(^3\) CH\(_4\)/year); \( Q_{\text{CPO}} \) is the quantity of CPO (tonnes/year); \( D_{\text{OG}} \) is the degradable organic component (kg COD/m\(^3\) POME); \( V_{\text{ww}} \) is the wastewater produced (m\(^3\) POME/tonne CPO); \( \text{EF}_{\text{CODR}} \) is the efficiency of COD removal by
| Company           | 2006   | 2007    | 2008    | 2009    | 2010    | 2011    | 2012    | 2013    | 2014    | 2015    |
|-------------------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| GOPDC\(^a\)       | 28,743.10 | 17,842.70 | 18,055.68 | 20,143.00 | 18,960.54 | 18,045.80 | 17,131.05 | 16,216.30 | 17,027.12 | 17,476.16 |
| BOPP\(^b\)       | 16,485.00 | 15,305.00 | 14,960.18 | 14,124.00 | 14,232.57 | 13,916.82 | 13,601.07 | 17,554.00 | 17,817.31 | 18,173.66 |
| TOPP\(^c\)        | 20,348.00 | 14,797.10 | 14,249.66 | 13,733.00 | 14,544.40 | 13,627.94 | 12,711.48 | 11,795.02 | 11,971.95 | 12,930.16 |
| NGL (NOPL)\(^d\) | 7,019.00 | 7,721.00 | 8,492.83 | 12,775.00 | 11,812.93 | 12,856.74 | 13,900.55 | 14,944.36 | 15,168.53 | 15,579.07 |
| AMEEN\(^e\)      | 9,805.00 | 10,785.50 | 11,863.68 | 11,0000.00 | 12,589.86 | 13,314.50 | 14,039.14 | 14,763.78 | 14,985.24 | 15,284.94 |
| MSM\(^f\)        | 8,387.00 | 9,225.70 | 10,148.07 | 10,836.00 | 11,584.66 | 12,357.44 | 13,130.22 | 13,903.00 | 14,598.15 | 15,345.05 |
| SS and OPH\(^g\) | 250,888.00 | 275,976.80 | 303,572.32 | 316,222.00 | 342,012.51 | 364,279.77 | 386,547.04 | 408,814.30 | 429,255.02 | 450,913.43 |
| **TOTAL**         | 341,675.10 | 351,653.80 | 381,342.42 | 402,473.00 | 425,737.47 | 448,399.01 | 471,060.55 | 497,990.76 | 520,823.32 | 545,702.47 |

\(^a\) GOPDC: Ghana Oil Palm Development Company.
\(^b\) BOPP: Benso Oil Palm Plantation.
\(^c\) TOPP: Twifo Oil Palm Plantation.
\(^d\) NOPL: National Oil Palm Limited.
\(^e\) AMEEN: Ameen Sangaari Industries Limited.
\(^f\) MSM: Medium-Scale Mills
\(^g\) SS and OPH: Small-Scale Mills and Other Private Holdings
Table 6. Typical POME characteristics

| Parameter | Value (mg/l) | Reference |
|-----------|-------------|-----------|
| BOD       | 25000       | (Wu et al., 2009) |
| TSS       | 19020       | (Wu et al., 2009) |
| TS        | 43,636      | (Wu et al., 2009) |
| Alkalinity (CaCO₃-equiv.) | 50–150 | (Wu et al., 2009) |
| TVFA (CH₃COOH) | 300–500 | (Khemkhao et al., 2011) |
| COD       | 55000–60000 | (Khemkhao et al., 2011) |
| COD       | 80000–95000 | (Khemkhao et al., 2011) |
| Temperature | 70–80 °C | (Abdurrahman et al., 2011) |
| pH        | 4–5         | (Ahmad et al., 2003; Singh et al., 2011) |

*aAll parameters are in mg/l except temperature and pH.
*bBOD: biochemical oxygen demand.
*cTSS: total-suspended solids.
*dTS: total solids.
*eTVFA: total volatile fatty acids.
*fCOD: chemical oxygen demand.

Table 7. Input parameters for estimating methane potential from the POME produced in Ghana

| Input parameter | Value | Reference |
|----------------|-------|-----------|
| Q₃₀°C | Table 7 (tonnes/year) | (SRID, 2016) |
| D₀₆₅ | 55 kg COD/m³ POME | (Khemkhao et al., 2011) |
| Vᵩₚₚ | 3.86 m³ POME/tonne CPO | (Arthur & Glover, 2012) |
| EF₉₀₀ | 0.807 | (Yacob et al., 2005) |
| M₀ | 0.25 kg CH₄/kg COD | (Lam & Lee, 2011) |

*aValues in Table 7 representing the quantity of CPO, where used.
*bAssuming COD in POME input to anaerobic digestion is 55,000 mg/l.

anaerobic digestion; M₀ is the maximum methane-producing capacity (kg CH₄/kg COD); ρₘ is the density of methane = 0.716 kg/m³ (UNFCCC, 2003).

The energy potential of the POME was estimated using the methane-producing capacity (kg CH₄/ kg COD) shown in Table 7.

3. Results and discussion

This study had focussed on the evaluation of the methane and electricity potential of four major sources as well as the avoidable GHG emissions, specifically CO₂-eq CO₂ abatement potential in 2020 and through to 2030. Thus, manure from livestock and poultry, faecal sludge for wastewater treatment, methane recovery from engineered landfills and from POME.

The study further highlights other benefits of generating biogas from livestock and poultry manure with domestic biogas plants. It also considered the possibility of producing biogas from solid and liquid waste treatment through municipal or full-scale systems across the country, using the specific waste production pe capita. It also considered the option of augmenting the energy needs of the palm oil production industry via anaerobic digestion of the POME, at the same time minimising the detrimental effects of indiscriminate disposal into nearby water bodies.
The results of this study was of particular interest because, domestic biogas digesters predominantly used in developing countries are highly efficient for livestock manure (Tauseef et al., 2013), although they could also be used for other substrates as well; however, in those cases, they are not that efficient (Abbasi & Abbasi, 2010). Some of the common biogas digester designs mostly used in developing countries include floating drum (KVIC, IARI, ASTRA, Botswana, Jwala models), fixed dome (Chinese Puxin, Janata and Deebandhu models), hybrid and balloon digester (Arthur, Baidoo, Antwi et al., 2011; Arthur, Baidoo, Brew-Hammond et al., 2011; Tauseef et al., 2013). A survey conducted indicated that about 80% of the biogas digester designs in Ghana are based on the fixed dome design (Arthur, Baidoo, Brew-Hammond et al., 2011; Bensah, 2010). Based on the historic livestock and poultry production data between 2007 and 2017 (Table 2), the methane production projections for 2020 and 2030 were calculated and have been presented in Table 8. These projections were done, first by estimating the methane potential (million m³) from of the manure of the selected livestock and poultry using Equations (11)–(15), which were developed based on the actual livestock and poultry production levels in Table 2.

Cattle: \[ \text{ME}_{\text{cattle}} = 1.380 \times (\text{year} - 2007) + 42.059, \quad (R^2 = 0.9791) \]  
(11)

Pig: \[ \text{ME}_{\text{pig}} = 0.399 \times (\text{year} - 2007) + 6.196, \quad (R^2 = 0.9712) \]  
(12)

Goat: \[ \text{ME}_{\text{goat}} = 0.688 \times (\text{year} - 2007) + 11.051, \quad (R^2 = 0.9796) \]  
(13)

Sheep: \[ \text{ME}_{\text{sheep}} = 0.357 \times (\text{year} - 2007) + 9.176, \quad (R^2 = 0.9895) \]  
(14)

Chicken: \[ \text{ME}_{\text{chicken}} = 3.742 \times (\text{year} - 2007) + 29.585, \quad (R^2 = 0.9788) \]  
(15)

The annual projected methane potential from the cattle and sheep manure is expected to increase at an average rate of 2% from 2020 until 2030 based on the BaU scenario, whereas that of pig and goat would both increase by 3% and that of chicken would also increase by 4%. The total theoretical energy potential from the livestock and poultry manure is expected to be 1834 GWh and 2492 GWh in 2020 and 2030, respectively. The corresponding electric and thermal energy production potential from methane from the manure for this period has been presented in Table 8.

These estimations were based on the conversion efficiencies of the biogas stove and biogas-fuelled engines (Table 4). Chicken are expected to contribute the highest amount of methane, making up about 42.7% of the production in 2020 and 47.9% by 2030, due to high production rate, which could translate into high methane production potential. This presents a huge opportunity for poultry farmers in the country. Moreover, the theoretical total thermal energy that could be generated from the methane through biogas stoves, for example, for domestic or commercial cooking, is about 1008.7 GWh in 2020, and could increase to 1307.7 GWh in 2030 (Table 8).

It is generally admitted that there is persistence high demand for wood-fuel, particularly in rural households, which threatens forest resources, which consequently increase the carbon footprint of the country. Residential firewood demand in urban and rural households for 2020 and 2030 have been shown in Table 9. Based on the estimated energy potential from methane generated from livestock and poultry manure, and assuming that 1 KTOE is equivalent to 11.6 GWh of energy, then it would be possible to replace 6.6 and 6.9% of the firewood demand for household cooking or thermal energy (GWhth) in 2020 and 2030, respectively, through the methane from livestock and poultry manure.

The equivalent amount of wood fuel can be calculated assuming that 1 kg of firewood produces 4.5 kWhth of thermal energy (Kossmann, Pönnitz, et al., 1999). That means potentially, thermal energy from methane generated from livestock manure could replace 224,156 tonnes and 304,600 tonnes of
Table 8. Methane and electric energy production potential, as well as avoidable GHG emissions from Livestock and poultry manure for 2020 and 2030

| Livestock | Projected Methane Potential (10^6 m^3) | Emissions avoided (Million tCO_2-eq.) | Electrical energy production from biogas stoves (GWh_{el}) | Thermal energy production from biogas stoves (GWh_{th}) | Projected Methane Potential (10^6 m^3) | Emissions avoided (Million tCO_2-eq.) | Electrical energy production from biogas stoves (GWh_{el}) | Thermal energy production from biogas stoves (GWh_{th}) |
|-----------|--------------------------------------|---------------------------------------|----------------------------------------------------------|------------------------------------------------------|--------------------------------------|---------------------------------------|----------------------------------------------------------|------------------------------------------------------|
|           | 2020                                 | 2030                                  |                                                          |                                                      |                                      |                                      |                                                          |                                                      |
| Chicken   | 78.2                                 | 1.40                                  | 187.7                                                    | 430.1                                                | 115.6                                 | 2.07                                  | 277.7                                                    | 117.0                                                |
| Cattle    | 60                                   | 1.07                                  | 144.0                                                    | 330.0                                                | 73.8                                  | 1.32                                  | 117.0                                                    | 406.0                                                |
| Goat      | 19.9                                 | 0.36                                  | 48.0                                                     | 110                                                  | 19.2                                  | 0.48                                  | 64.6                                                     | 147.9                                                |
| Sheep     | 13.8                                 | 0.25                                  | 33.1                                                     | 75.9                                                 | 17.4                                  | 0.31                                  | 41.8                                                     | 95.7                                                 |
| Pig       | 11.4                                 | 0.20                                  | 27.4                                                     | 62.7                                                 | 15.4                                  | 0.28                                  | 36.9                                                     | 84.7                                                 |
| Total     | 183.3                                | 3.28                                  | 440.2                                                    | 1008.7                                               | 241.4                                 | 4.46                                  | 538.0                                                    | 1370.7                                               |
firewood in 2020 and 2030, respectively. The firewood savings would be significant because the three-stone stove commonly used has conversion efficiency of only 12% (Arthur & Baidoo, 2011), which also generates smoke and has the tendency to cause respiratory diseases, especially in poorly ventilated areas of utilisation.

Therefore, generating biogas with livestock or poultry manure is one major approach to increase access to modern and clean energy, while driving the environmental sustainability agenda. This could augment government efforts at minimizing the use of firewood to reduce forest degradation, reduce CO₂ emission and as well as minimizing the workload on women, especially searching firewood and other health-related problems.

With about 3 billion people globally still cooking with solid fuels, most of the people living in rural areas are susceptible to diseases related to indoor air pollution. It is estimated that about 3.8 million people edie prematurely every year from diseases attributed to the household indoor air pollution (WHO, 2018). Thus, it is noteworthy that, a total avoidable GHG emissions from the livestock manure could be 3.28 and 4.66 million tCO₂-eq. in 2020 and 2030, respectively (Table 8), where more than 46.4% could be through chicken manure alone.

The energy demand projections of “The Strategic National Energy Plan” of Ghana (SNEP 2030) recommends the promotion and adaptation of improved cook-stoves, with fuel savings of 15% (EnergyCommission, 2019b). However, conscious consideration of energy from biogas systems for domestic use, could increase government efforts at increasing access to modern energy.

There is a policy to address some challenges in the livestock industry in Ghana (Arthur & Baidoo, 2011). The policy seeks to address the following: competition with animal produce that are imported, absence of adequate disease control, poor animal nutrition, and insufficient supply of water for the livestock during the dry season. Productivity of the livestock could still be improved through the use of efficient appropriate technologies coupled with best practices, which could increase the availability of the manure for conversion into biomethane. It has also been proposed that there is a need for investment into research and extension in developing and disseminating relevant integrated crop-livestock management practices to boost crop and livestock production (Asante et al., 2017). Hence, it is possible to harness the methane through anaerobic degradation in biogas plants in households or commercial livestock rearing facilities or farms to meet the energy demand.

The organic fraction of municipal solid waste (OFMSW) through anaerobic digestion, have been recognized as a viable option for methane generation for sustainable utilisation (Mittal et al., 2019). The estimation in this work showed that, the MSW is expected to increase from 4.7 million tonnes in 2020 to 5.9 million tonnes by 2030 (Figure 1). Thus, engineered landfills in different municipalities could generate methane for power production and avoid direct GHG emissions. The calculated results of the different scenarios considered with respect to the proportion of the MSW sent to landfills and their degradability, have been presented in (Table 3). It has also been shown that the potential methane of 277.87 million m³ could be generated by 2030,
assuming 50% of the MSW would be sent to the landfill and are moderately degradable (Table 10). This could produce about 767.23 GWh with a corresponding avoidable GHG emission of about 4.974 million tonnes of CO$_2$-eq. However, the best case in these estimations, also for 2030, where the efficiency of the collection and disposal of the MSW to landfill could be 60% and with the assumption that the waste is in the highly degradable category, have also been presented. In this regard, there would be about 85% increase in the potential methane production with equivalent electrical energy production of 1421.64 GWh and 9.216 million tonnes of CO$_2$-eq abatement.

The efficiency of the waste transported to the landfill could be substantially improved when adequate structures, such as provision of collection bins, as well as strategic waste transportation routines are followed. However, the degree of degradability could only be influenced by the type of waste generated, which may be linked to the lifestyle or the economic circumstances. Some studies indicate that while the waste generation in Sub-Saharan cities is clearly linked to the GDP of the country, no direct links were evident with the waste composition (Couth & Trois, 2011; Rupf et al., 2016).

Additionally, if all the sewage generated in households and communities through the improved sanitation facilities are transferred to wastewater treatment sites, there is a theoretical potential to produce about 150.26 GWh/yr of electrical energy in 2020 which could increase to 186.42 GWh/yr in 2030 (Table 11). There is also significant reduction of GHG emission through this approach, at the same time, waste management targets could be met.

The methane potential from the POME in 2006 was estimated to be about 30.44 million m$^3$ CH$_4$, and increased to about 32.64 million m$^3$ CH$_4$ in 2015 based on the quantity of CPO produced during that period, where the Small-scale and Other Private Holdings (SS and OPH), which form the majority of the palm oil producers in Ghana, contributed about 73 and 83% of the methane potential in 2006 and 2015, respectively. The total methane of POME generated by palm oil industry from 2006 to 2015 has been shown in Figure 2, based on the historical CPO produced during that period (Table 5). The CPO production levels varied among the companies, making it difficult to reasonably predict the methane production potential from the companies alone. Nevertheless, with the significant production of CPO from the SS and OPH (more than 70%) in the palm oil production industry, prediction of the methane potential from the total CPO produced can be made with reasonable accuracy. The consistent increment in POME generation could be ascribed to the increment in the number of cottage industries contrary to the well-established companies and the MSM because their operation
Table 10. Energetic potential of methane and CO₂ emissions avoidance of possible landfills

| Year | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|------|------|------|------|------|------|------|------|------|------|------|------|
| MSW at Landfill, 50% | | | | | | | | | | | |
| Moderately degradable | Methane, M₁ (10⁶ m³/year) | 223.96 | 228.85 | 233.84 | 238.94 | 244.15 | 249.47 | 254.91 | 260.46 | 266.14 | 271.94 | 277.87 |
| Power (MW) | 70.59 | 72.13 | 73.71 | 75.31 | 76.95 | 78.63 | 80.35 | 82.10 | 83.89 | 85.72 | 87.58 |
| Electrical Energy (GWh/yr) | 618.40 | 631.88 | 645.66 | 659.73 | 674.11 | 688.81 | 703.83 | 719.17 | 734.85 | 750.87 | 767.23 |
| Emissions avoided (Million tCO₂-eq./year) | 4.009 | 4.096 | 4.186 | 4.277 | 4.370 | 4.466 | 4.563 | 4.662 | 4.764 | 4.868 | 4.974 |
| Highly degradable | Methane, M₁ (10⁶ m³/year) | 345.83 | 353.37 | 361.08 | 368.95 | 376.99 | 385.21 | 393.61 | 402.19 | 410.95 | 419.91 | 429.07 |
| Power (MW) | 109.00 | 111.38 | 113.81 | 116.29 | 118.83 | 121.42 | 124.06 | 126.77 | 129.53 | 132.35 | 135.24 |
| Electrical Energy (GWh/yr) | 954.88 | 975.70 | 996.97 | 1018.70 | 1040.91 | 1063.60 | 1086.79 | 1110.48 | 1134.69 | 1159.43 | 1184.70 |
| Emissions avoided (Million tCO₂-eq./year) | 6.190 | 6.325 | 6.463 | 6.604 | 6.748 | 6.895 | 7.045 | 7.199 | 7.356 | 7.516 | 7.680 |

(Continued)
|                      | Year | 2020  | 2021  | 2022  | 2023  | 2024  | 2025  | 2026  | 2027  | 2028  | 2029  | 2030  |
|----------------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| **MSW at Landfill, 60%** |      |       |       |       |       |       |       |       |       |       |       |       |
| Moderately degradable |     |       |       |       |       |       |       |       |       |       |       |       |
| Methane, \( \text{M}_1 \) \((10^6 \text{ m}^3/\text{year})\) | 268.76 | 274.62 | 280.61 | 286.72 | 292.97 | 299.36 | 305.89 | 312.56 | 319.37 | 326.33 | 333.45 |
| Power (MW)            | 84.71 | 86.56 | 88.45 | 90.37 | 92.34 | 94.36 | 96.41 | 98.52 | 100.66 | 102.86 | 105.10 |
| Electrical Energy (GWh\(_\text{el}\)/year) | 742.08 | 758.26 | 774.79 | 791.68 | 808.94 | 826.57 | 844.59 | 863.00 | 881.82 | 901.86 | 920.68 |
| Emissions avoided (Million tCO\(_2\)-eq./year) | 4.810 | 4.915 | 5.022 | 5.132 | 5.244 | 5.358 | 5.475 | 5.594 | 5.716 | 5.841 | 5.969 |
| Highly degradable    |      |       |       |       |       |       |       |       |       |       |       |       |
| Methane, \( \text{M}_1 \) \((10^6 \text{ m}^3/\text{year})\) | 414.92 | 424.05 | 433.29 | 442.74 | 452.39 | 462.25 | 472.33 | 482.62 | 493.14 | 503.89 | 514.88 |
| Power (MW)            | 130.81 | 133.66 | 136.57 | 139.55 | 142.59 | 145.70 | 148.88 | 152.12 | 155.44 | 158.83 | 162.29 |
| Electrical Energy (GWh\(_\text{el}\)/year) | 1145.86 | 1170.84 | 1196.36 | 1222.44 | 1249.09 | 1276.32 | 1304.15 | 1332.58 | 1361.63 | 1391.31 | 1421.64 |
| Emissions avoided (MtCO\(_2\)-eq./year) | 7.428 | 7.590 | 7.756 | 7.925 | 8.098 | 8.274 | 8.455 | 8.639 | 8.827 | 9.019 | 9.216 |

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would require considerable investments to expand based on their production levels. The methane production potential from the CPO from 2006 to 2015 can be represented by Equation (10).

\[
\text{MP}_{\text{POME}} = 1.39 \times (\text{year} - 2006) + 18.60 \left( R^2 = 0.9975 \right) \tag{10}
\]

Where \( \text{MP}_{\text{POME}} \) is the projected methane production potential from POME, (million \( m^3 \) CH\(_4\)/year).

The \( R^2 \) of 0.9975 was based on the total production of CPO, including the well-established companies. It is worth noting that the high level of predictability (\( R^2 \)) was due to the existing trend of the SS and OPH. The \( R^2 \) value of the SS and OPH alone is 0.9986, indicating even a much higher accuracy with the prediction of the methane production potential from that group.
If it is assumed that the trend of CPO production would increase at the same rate to 2020 and further to 2030, then the potential methane production can be estimated to be 38.08 million m³ CH₄ and 51.96 million m³ CH₄, respectively. Consequently, the theoretical electrical energy potential could be 101.72 GWhₑ and 138.85 GWhₑ in 2020 and 2030, respectively. Untapped methane from the POME can possibly, altogether, add to climate change. Using a GWP of 25 kg CO₂/kgCH₄ (Ryu, 2010), it can be estimated that POME from the palm oil industry could generate about 681 thousand tCO₂-eq and 930 thousand tCO₂-eq in 2020 and 2030, respectively. Consequently, a total of about 8.8 million tCO₂-eq. could be avoided between 2020 and 2030, with significant amount coming from the SS ad OPH group. The companies in the palm oil industry in Ghana are well established with advanced technologies used in the processing of palm (Arthur & Glover, 2012), therefore it is possible to generate the methane POME produced and avoid GHG emission. These companies for the most part, utilise the palm kernel shells and fibre fuel for the manufacturing plant activities. Furthermore, the substantial amount of energy from methane could be utilised to ensure that non-renewable fuel utilisation is minimised while meeting their energy demand.

The significant levels of BOD and COD in POME makes it hazardous to discharge directly into the environment (Wu et al., 2009). The SS and OPH group, which form the majority of the palm oil industry in Ghana, and produce substantial amount of POME, is likely to dispose it directly into the environment compared with the MSM and the companies. The SS and OPH group tend to use crude techniques for the processing. Therefore, if the methane is not harnessed, the POME, which contains high organic content, will pollute water bodies located near the processing areas and make them unsafe for other purposes. This unsustainable practice will eventually affect communities along these water bodies, who depend on them for other socio-economic activities. On the other hand, the application of the digestate produced the anaerobic digestion of the POME as bio-fertiliser to replace fossil-based fertilisers, could increase the yield of the annual palm oil production level extending the benefits of biotechnology even further. The SS and OPH through their cooperatives, could use their platform to educate their members and overall benefits of integrating biogas technology into their practices.

The REMP of Ghana identified challenges in adapting or developing specific projects and also proposed several strategies to improve or promote the technologies. However, one of the biggest limitations is lack of funds for domestic biogas systems. A huge support is needed in the area of providing financial support, especially development of low-cost domestic digesters. The analysis of Figure 3 showed that the total volume of methane expected to be generated is about 691 million m³ in 2020 and to increase to 876 million m³, where the major contribution (60 %) is expected from

![Figure 3. Projected volume of methane available from landfills, livestock manure, wastewater and POME in Ghana for 2020 and 2030.](image-url)
landfills alone, followed by livestock manure. It is obvious that harnessing this potential is challenging due to logistical issues with respect to waste management practices. Co-digestion and dry anaerobic digestion could also be viable options in areas where there is unavailable feedstock or water scarcity (Mittal et al., 2018).

Therefore, the type of technology and size should be adapted to suit the conditions of the locality to ensure continuous operation of the biogas systems. That notwithstanding, the findings of this study demonstrate outstanding potential of renewable energy resources and a positive direction for the development of Ghana's biogas matrix. When this methane is successfully tapped, it would translate into significant electrical energy production (Figure 4) and corresponding CO₂ emission abatement (Figure 5). The 62% of the available energy potential (1421.64 GWhₑ by 2030) in landfills (Figure 4) should drive the government to focus on ensuring the possibility of engaging independent power producers (IPPs) to invest in electricity generation from landfills.

![Figure 4. Projected electrical energy potential from methane available from landfills, livestock manure, wastewater and POME in Ghana for 2020 and 2030.](image)

![Figure 5. Projected CO₂-eq. abatement potential from methane available from landfills, livestock manure, wastewater and POME in Ghana for 2020 and 2030.](image)
Even though Ghana’s energy mix is currently clean, with about 43.2% installed capacity coming from hydropower in 2015, with a corresponding grid emission factor of 0.33 tCO₂/MWh in the same year (Energy Commission, 2019a), the results in this paper show that there are still opportunities to improve it even further. Currently, most of the renewable energy interventions in the country are either being carried out as pilot projects or on short term planning cycle basis.

The benefit of the advancement of biogas power plants in the landfills and wastewater treatment facilities has the tendency to make municipalities more economically attractive and environmentally friendly, which can possibly improve other external economies. Although the methane contribution from POME is minor compared with the others (Figure 2), it is noteworthy, that in most of the rural areas, agriculture, and small-scale agro-processing industry are the major economic activities. Therefore, integrating biogas technology into the industry cannot be overlooked.

Also, majority of the people engaged in these economic activities belong to the low-income households. Consequently, the key barrier to the deployment of biogas plants for processing agro-processing residues, for example, would require flexible financial schemes to support the deployment of the technology. For example, biogas system installation cost barrier can also be reduced by providing low-cost credits like interest-free loans or subsidized loans or cheap technology such as biogas plants that are used in some developing countries (Mittal et al., 2018). Thus, a strong collaboration between research institutions/technical universities and biogas service providers is required for the development of low-cost systems and improvement of existing technologies for households and agro-processing industries. Identification of major challenges in the sector would also need continuous education and research to boost the development of the industry. Development of these renewable energy resources would significantly reduce the overreliance of fossil fuel sources for power generation and contribute to the development of other sectors of the economy. The findings of this study also highlight the connection between palm oil production, which is a major agro-processing industry in Ghana, the challenges posed by the existing practice of the palm oil production industry and the possibility of transforming the entire process into an environmentally and economically sustainable process.

4. Conclusion
This study aimed to evaluate of the methane, electricity, and avoidable GHG emissions, specifically CO₂-eq CO₂ abatement potential of four major sources in 2020 and projected through to 2030. The potential sources considered were the manure from livestock, faecal sludge for wastewater treatment systems, municipal solid waste in engineered landfill for biogas recovery and POME from the palm oil industry. From the results, it was established that generating biogas from these sources has the potential to contribute significantly to electricity production and CO₂ reduction potential. These four sources have the potential to produced 2284.91 GWh/yr by 2030, which corresponds to 15.82 million tCO₂-equivalent savings. Besides these, the study also highlighted the significant diverse benefits from the use these sources as feedstock for biogas generation.

There is abundance of resources available for biogas production in Ghana. Therefore, it is possible to increase the share of the renewable energy in the national energy mix by developing a clear roadmap to include a long-term promotion of biogas technology by involving all the necessary stakeholders at all stages.

One of the pathways in achieving this is by focusing on developing strategies, as identified in the REMP, to harness the biogas potential from livestock manure, landfills, waste water treatment and residues from agro-processing industries such as POMEs. The production of the biogas from the identified resources for electricity generation at utility-scale, or heating in households, would lead to the reduction in the reliance on fossil fuels, reducing the CO₂ emissions to augment attempts at meeting GHG emission targets. Furthermore, integration of biogas technology into the livestock farming in Ghana would significantly improve the livelihood of majority of the workforce in the agriculture. By recognizing biogas as an economic tool, it will, in addition to being renewable energy resource, improve the waste treatment status in communities and improve other external
economies. As a tool for environmental sustainability, there could be significant reduction on the impact on climate change vulnerability parameters and reduce Ghana’s GHG emissions. The results of this study could also serve as first-hand information for policy makers, government agencies, and the private sector on the general outlook of the biogas potential of these resources.

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