African Biodigester Component

Assessment of the Potential for Small-scale and Medium-scale Biodigesters in Kenya

SEE – Clean Cooking
African Biodigester Component

Co-financed by:

Ministry of Foreign Affairs

Ministry of Foreign Affairs of Denmark
DANIDA | International Development Cooperation

Coordinated by:

Netherlands Enterprise Agency

In partnership with:

endev

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a federal enterprise and supports the German Federal Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices in Eschborn:

Global Project - 'Energizing Development', Kenya (OE 3000)
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Acknowledgements

This publication presents the potential for small-scale and medium-scale biodigestion in Kenya. This report was developed by Eng. Peter Gichohi, an independent energy consultant for the African Biodigester Component in Kenya under the overall supervision of Florent Eveillé, African Biodigester Component manager in Kenya. Among the colleagues who provided valuable inputs, the authors would like to thank Evelyne Munihu and Mark Rotich for their careful reading, editing and suggestions.

Funded by the Dutch Ministry of Foreign Affairs (DGIS), the Danish International Development Agency (DANIDA) and the European Union (EU), the African Biogas Component (ABC) in Kenya aims at facilitating a shift of the biodigester market from its pioneering to the expansion phase where 20,017 small and 250 medium-sized biodigesters will be constructed/installed. This will be achieved by means of a well-balanced mix of demand-side, supply side, financing and enabling environment interventions, geared at boosting demand and supporting small scale and medium scale biodigester companies in acquiring more clients. The component is implemented by a consortium between GIZ and SNV (the Netherlands Development Organisation) in cooperation with the Africa Bioenergy Programs Limited (ABPL - ex-Kenya Biogas Programme).

Alongside the construction or installation of 20,017 small-sized (0 to 50m^3) biodigesters in Kenya, the ABC project will support the construction or installation of 250 medium-sized (50 to 500m^3) biodigesters in Kenya. The ranges defining the small and medium scale segments as per the Kenyan standards will be applied.

Unfortunately, standards defining the medium-scale segment have not been published yet. Therefore, the project has adopted a pragmatic approach of defining the medium-scale according to the amount of feedstock to feed a specific plant capacity. The specific target groups for the medium-scale segment include:

- Large livestock farms (≥30 cows, >100 pigs (fully confined) or >2,000 birds (poultry))
- Boarding schools that raise cattle/pigs (≥30 cows or >100 pigs fully confined)
- Agro-processing industries such as coffee wet mills, flower farms, slaughterhouses, slaughter slabs, poultry farms with over 2,000 birds, prisons, sisal farms and municipal wastewater management.
- Small food processing industry and other facilities with bio-degradable waste, such as dairies, meat and fish processing, fruit and vegetable operations, breweries, distilleries, manufacturers of baked goods and candies, sugar industry

The purpose of the report is to determine the feedstock available for small-scale (0 to 50 m^3) and medium scale (50 to 500m^3) biodigesters in Kenya. The results of this study will support market intelligence for biodigester companies in Kenya. For this, the project needs the most accurate and updated information on biodigester potential in Kenya.

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List of abbreviations and acronyms

ABC	African Biodigester Component
AC	Alternating Current
AD	Anaerobic Digester
BCE	Biogas Construction Entrepreneur
BOD	Biological Oxygen Demand
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
DC	Direct Current
DM	Dry Matter
DTF	Decentralized Treatment Facility
EMCA	Environment Management and Coordination Act
(M)FI	(Micro)Financial Institutions
GDP	Gross Domestic Product
GHG	Green House Gas
Ha	Hectare
KAM	Kenya Association of Manufacturers
KDB	Kenya Dairy Board
Kg	Kilogram
KNBS	Kenya National Bureau of Statistics
kV	Kilo Volt
kVA	Kilo Volt Ampere
kW	Kilo Watt
kWh	Kilo Watt Hour
L	Litre
LPG	Liquefied Petroleum Gas
M^3	Cubic Meters
mg	Milligram
NEMA	National Environment Management Authority
VS	Volatile Solids
WASCO	Water and Sewerage Companies
WWTP	Wastewater Treatment Plant
Yr	Year

Executive summary

The main purpose of the study was to estimate the potential for the installation of small-scale (0 to 50m^3) and medium-scale (50 to 500m^3) biodigesters in Kenya.

The study used a mix of quantitative and qualitative methods:

- The authors performed a literature review to obtain data from related sector publications as well as from national census data from 2019 (KNBS, 2019) which provided comprehensive data on the livestock sector in Kenya. The census data provided the number and type of animal per county and sub-county as well as the number of livestock households per county. Other sources use were specialised studies for each sub-sector which provided valuable data and information.
- Following the literature review, a questionnaire was established and shared with county energy and agriculture officials to refine the data obtained through statistics. The information obtained was supplemented by direct interviews of these key informants during field visits. The visits also provided opportunities to compile data and information from potential sites for both small scale and medium scale biodigesters.
- Case studies of medium-scale clients without a biodigester are presented in the study. Technico-economic parameters of potential and existing medium-scale biodigester have been established to compare different business case for medium-scale biodigesters in Kenya. These business cases will feed in a tool to establish the economic viability of medium scale biodigester projects in Kenya.
- After data collection, the authors triangulated the information collected and held a consultation with county authorities to confirm the information provided.

Scientific Innovation and Relevance

Before initiating this study, stakeholders were referring to a potential for biodigester installation based on the number of dairy farmers. According to (FAO and GIZ, 2019): “there are about 1.8 million dairy farms - 70-80% are smallholdings (3–10 cows) with mostly intensive system (zero-grazing), 10–20% are medium scale (10–50 cows) and 10–15% are large scale (more than 50 cows).” Based on the number of dairy farms, the potential was estimated between 1 to 2 million biodigesters.

Our approach is innovative as it considers different levels of potential. The potential of the different bioenergy sources to be used for energy can be categorised as theoretical, technical, economic and realisable potential (see Figure 1).

The theoretical potential of renewable energy is derived from the physical supply of renewable energy sources (all phytomass and zoomass) and represents a theoretical upper limit of the available energy supply.

Generally, only a small percentage of this potential can be tapped due to insurmountable technical, ecological, structural and administrative restrictions. The technical potential, however, refers to the percentage of theoretical potential that can be used given current technical possibilities. Calculating the technical potential considers the available utilisation technologies, their efficiency, availability of sites (including the impact of competing uses), as well as “insurmountable” structural, ecological (e.g., nature conservation areas) and other non-technical restrictions.

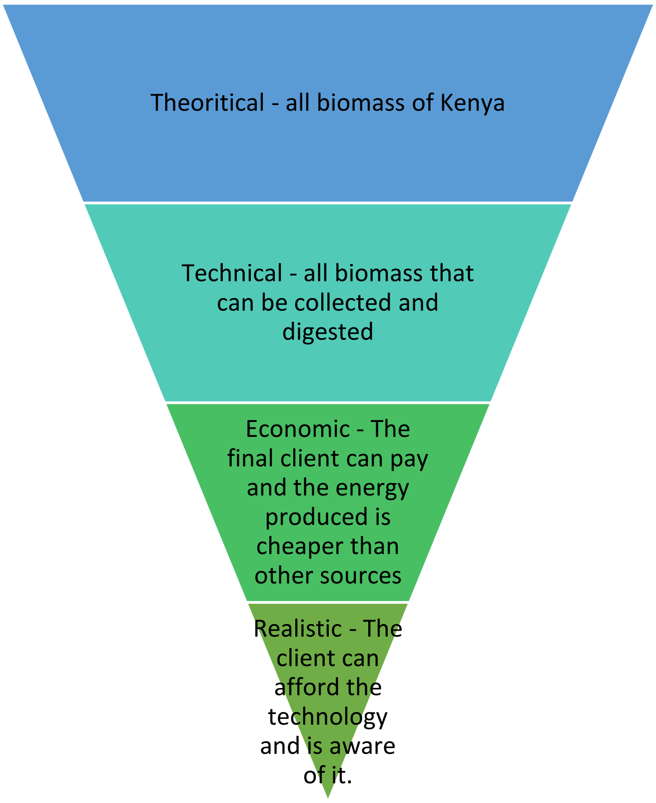

Figure 1 - Definition of the different potential levels - © GIZ

The economic potential of an option of using biomass refers to the percentage of the technical potential that can be used economically. It represents the number of clients for both market segments that can afford the biodigester technology. This affordability considers adapted financial instruments (loans, guarantee and revenues from the voluntary carbon market) as well as the financial and technical instruments developed by development partners. The economic potential for using renewable energy sources is also affected by the opportunity costs of other energy systems (charcoal, wood, kerosene, LPG, electricity for cooking, solar off-grid, grid and kerosene for lighting and powering). It shall also include the cost of nutrients used in agriculture in the model.

Realizable potential is a percentage of the economic potential constituted of potential biodigesters clients that are aware of the technology and that can be supported by the development partners. This work is of relevance for biodigester companies in Kenya as they can adapt their last-mile distribution channels to areas with high and medium potential as determined by all the stakeholders involved in the process. For national and local authorities, it also helps them to plan their support interventions for biogas in areas with the highest potential.

Preliminary results and conclusions

Biogas has a huge potential for development in Kenya as the technology is known specially in dairy farming. The main barrier for adoption is usually the up-front and investment required by biogas companies. By indicating sub-counties with the highest potential, the African Biodigester Component (ABC) helps biogas companies to de-risk their activities as they could invest in sales and marketing as well as extending their last mile distribution channels in areas with an existing pool of potential customers. The potential has been divided into small-scale (0 to 50m^3) and medium scale (50 to 500m^3) biodigesters. According to the feedback received from biodigester companies, potential clients for small scale biodigesters can qualify if they have at least 2 cows, 15 pigs or 500 chicken. The potential for small scale biodigester has been divided between the dairy, the pig and the poultry sub-sectors. As these animals are generally kept in stables and generate enough manure for biodigesters.

The main purpose of the study was to obtain data and information that inform the potential of small scale and medium scale biodigesters in Kenya. This report presents a review of the livestock distribution in counties as well as other sectors that generate biodegradable waste.

Small-scale biodigester (0 to 50m³) potential

According to the feedback received from biodigester companies, potential clients for small scale biodigesters can qualify if they have at least 2 cows, 15 pigs or 500 chicken.

Dairy sector

The core of the biodigester potential in Kenya is from exotic dairy cows kept in stables. There are 939,916 households rearing 2,209,980 exotic dairy cows in Kenya. The average number of cows per household is 2.35. In counties with a significant population of exotic dairy cattle (more than 40,000 heads), the counties of Narok (4.72 heads/household), West Pokot (4.5), Baringo (3.55), Uasin Gishu (3.16), Trans Nzoia (2.59), Nakuru (2.56) and Bomet (2.52) have the highest potential as the number of head per household is higher than nationally (2.35). The number of households in counties with more than 2 exotic cattle per household is 539,960. According to (GoK, 2020), there were 4,573,871 dairy cows in Kenya across 939.916 households. It is important to notice that the number of dairy cows, greatly differ between (KNBS, 2019) and (GoK, 2020). (GoK, 2020) mention that 28% of these cows are under an intensive system and 51% under a semi-intensive system. These two systems represent the highest potential for biogas. Together, they represent 742,534 households with 4.9 cows per household.

The number of zero grazing units is a key factor to determine the biodigestion potential. Unfortunately, only 11 out of the 47 Kenyan counties have provided this information. Kisii county is leading with 18,062 zero grazing units followed by Kiambu with 12,601 units, Taita Taveta (10,704), Nyandarua (6,795), Kitui (6,413), Kakamega (3,054), Laikipia (2,683), Busia (2,398), Bomet (862), Machakos (674) and Vihiga (200). Together, they represent a potential of 66,269 units.

Pig sector

The total pig population in Kenya is 442,761 which are owned by 110,383 households. There are in average 4.01 pigs per household. In counties with significant pig population (more than 5,000 pigs), Kajiado county has the highest pig per household ratio (18.14) followed by Machakos (12.92), Uasin Gichu (10.78), Nairobi (10.35), Nakuru (9.94), Kiambu (8.73), Kirinyaga (6.60), Nyeri (6.59), Embu (5.34) and Murang'a (4.41). The number of households in counties with more than 4 pigs per household is 37,130 in Kenya. The number of households in counties with more than 15 pig per household is 902.

Poultry sector

The total chicken population is 38,816,238 heads. It is a mix of indigenous chicken, exotic layers and exotic broilers. The chickens are reared by 3,611,678 households for a chicken ratio of 10,75 per household. In counties with significant poultry population (more than 800,000 chicken), Nairobi has the highest chicken per household ratio (39.01 birds per household) followed by Kiambu (33.12), Kajiado (21.39), Kilifi (14.12), Nakuru (13.07), Murang'a (12.10), Machakos (11.77) and Uasin Gishu (11.66). In total 873,502 households have more than 10,75 chicken in Kenya. It was not possible to identify a county with 500 chicken per household on average which would define potential clients from this feedstock.

Medium scale biodigester (50 to 500m³) potential

Commercial farms

Farms with sufficient feedstock for a medium scale biodigester of $50m^3$ are farms with at least 30 zero-grazing dairy cows, 100 pigs and 2,000 chicken in cages. While most of the dairy farms in Kenya will qualify for a small scale biodigester, a few of them with more than 30 dairy cows in zero grazing would qualify for a medium scale biodigester. During the data collection, it was determined that there are at least 21 commercial dairy farms in Kiambu, 11 in Busia, 8 in Bomet, 6 in Uasin Gishu, 3 in Garissa, 2 in Vihiga and Taita Taveta. According to (FAO and GIZ, 2019) the number of large-scale dairy farms (more than 50 cows) is 10% of the total number of households with exotic dairy cattle which represents 93,900 farms.

Similarly, there are a few commercial pig farms that were identified to have more than 100 pigs during the study compared to the potential. These farms are in Kiambu (40), Busia (4), Taita Taveta (3) and Vihiga (1). If we use the same approach for commercial dairy farmers (10% of the total dairy households) to estimate the number of commercial pig farmers, we estimate the presence of 11,038 commercial pig farms in Kenya.

In total, our sample represents 101 potential clients for medium scale biodigesters with a theoretical potential of 104,938 farms. The sample data is not exhaustive as it was collected through the 15 Key Informant Interviews and site visits. The potential of medium scale biodigester from commercial farm manure is underestimated and will be redefined with information from the Kenya Dairy Board.

Sisal sector

Biogas potential is available in the leading 10 sisal estates. Among them only Kilifi plantations has implemented a biodigester utilizing both sisal pulp and cow dung.

Sisal is a plant that is grown to produce a fibre used in the textile industry. Kenya is the third largest global producer with 22,800 tonnes per year (FAOStat, 2020). Biogas potential is available for the leading 10 sisal estates (GTZ, 2010). Among them, only the Kilifi plantations has implemented a biodigester utilizing both sisal pulp and cow dung. The total mean biogas potential is estimated for the 10 estates at $503{,}106.42m^3$/year or $138m^3$ per day per estate or 923kWh of electricity per day. This will be the equivalent of a biodigester with $400m^3$ capacity for each of the 9 estate without a biodigester.

Water services sector

Water services providers have a huge wastewater resource that is responsible for gaseous emissions at sewerage works treatment sites. A new approach in wastewater management has been the implementation of Decentralized Treatment Facilities (DTFs). These facilities are compact and can partly fit the description of medium scale biodigesters. These have been identified to provide the opportunity to harness biogas potential for such new sites.

In Kenya, a new approach in wastewater management has been the implementation of Decentralized Treatment Facilities (DTFs). These facilities are compact and manage wastewater volume that can serve as input for anaerobic digestion (AD). Anaerobic digestion in wastewater treatment plant has the following advantage: water is already present at site, the energy produced can contribute significantly to the energy autonomy of the plant. The main disadvantage is that the biogas harnessed from municipal wastewater is lower than from animal manure (IEA, 2015). Data was collected for 7 wastewater treatment plants in Kenya.

Based on (IEA, 2015), the net biodigester volume has been determined as follow:

$$\text{Net digester volume } [m^3] = \text{Hydraulic retention time [days]} \times \text{ Feedstock input } [m^3/\text{day}]$$

The hydraulic retention time is set at 20 days. The largest potential in DTF is from Isiolo (36,000m^3 biodigester), Narok (10,000m^3 biodigester), Murang’a (3,806 m^3), Nyahururu (1,681 m^3), Nanyuki 1,194 m^3), Vihiga and Laikipia (1,000 m^3 each). However, these volumes represent a theoretical sizing. Introducing AD in Kenyan DTF will require a smaller pilot first qualifying for a medium scale biodigester (100 to 200 m^3) or several ones implemented in series.

Prisons

The study has presented a list of 13 prisons that have installed medium scale biodigesters and another list of 15 prisons that have the potential to implement them. These biodigesters are however sewage based and not relying on livestock.

The study presents a list of 13 prisons that have installed medium scale biodigesters and another list of 17 prisons that have the potential to implement them. The prison with the largest potential is in Naivasha (589m^3) followed by Nakuru (388m^3), Eldoret and Nyeri (310m^3 each), Thika (217 m^3), Narok (209 m^3), Kakamega and Langata (202m^3 each), Bungoma (171m^3), Kitale, Machakos, Manyani, Shimo la Tewa and Malindi (each 155m^3), Mwea (140m^3), Kapsabet (78m^3) and Vihiga (39 m^3).

Coffee sector

The study presents data on coffee production in counties. In 2020/21, the coffee sub-sector recorded low production performance of 34,512 tons (AFA, 2021) compared to 44,987 ton in 2018-2019. Coffee is produced, harvested and processed in Kenya. A potential feedstock for biogas is at the milling stage where the coffee cherry is transformed into clean coffee. To obtain clean coffee, millers need to remove the pulp, the mucilage and the parchment. Every 7 ton of coffee cherry processed at the wet mill yields 1.6 ton of pulp, 0.4 ton of mucilage, 5 ton of parchment and 1 ton of clean coffee. Pulp and mucilage are removed at the 577 cooperatives doing pulping wet mill while the parchment is removed at the 22 parchment mills. Wet milling has the advantage of involving water in the process. According to (GTZ, 2010) coffee pulp and mucilage have a Volatile Solid content of 93% Dry Matter and a biogas potential of 390m^3/ton Volatile Solid.

It is important to note that the feedstock is present at the mill only during the two harvest periods: the fly crop in May to July and the main crop in September to December. From January to March, there is no coffee waste available at the mill. Out of the 577 wet mills in Kenya, 56 have biogas potential below the size of the smallest domestic system in Kenya (4 m^3), 205 will qualify for a domestic biodigester (4 to 50 m^3), 255 for a medium scale biodigester (50 to 500 m^3) and 61 for an industrial biodigester (500 to 10,000 m^3). The largest potential is found in Kirinyaga (11,195 m^3 biogas / day from 16 plants), Nyeri (6,470 m^3 biogas / day from 24 plants), Kericho (4,893 m^3 biogas / day from 81 plants), Murang'a (4,537 m^3 biogas / day from 43 plants) and Bungoma (3,650 m^3 biogas / day from 49 plants).

Flower sector

Case studies have been presented showing wet and dry biodigesters for flowers wastes. These models can be applied at different scales in different farms to produce biogas and fertilizer.

There are about 220 flower farms in Kenya, about 70 of them are located around Lake Naivasha. The volume of exported cut flowers was 176,372 tons in 2021 (ITC, TradeMap, 2021) for an area of 3,850 ha of flower production (AFA, 2020). Cut flowers produce two types of waste: the foliage and the fresh stems. Foliage is more digestible than fresh stems due to a lower ligneous content. Stems are also covered with wax for preservation during transport. A 42-hectare farm is producing 2.8 tons of foliage waste per day.

A 25 hectares flower farm (Simbi Roses) has a 200 m^3 biodigester to run a biogas-fuelled generator of 55kW 2-3 hours a day to power water pumps at the dam and fertigation station. The Bohemian Flowers farm has installed a 326 m^3 biodigesters based on ten 10 x 20 feet containers. The biodigester treats 1.4 tons of waste per day to run a 20kW generator and to compress biogas used in the farm kitchen. We estimate that the average size of flower farms in Kenya is 17.5 ha. This average farm will produce 1.17t/day of foliage waste all year long which could feed a 140m^3 biodigester. To our knowledge, there are four biodigesters installed at flower farms in Kenya: Simbi Roses in Thika running a 69kVA generator, PJ Dave Flowers running a 125kVA generator, the 2MW biogas power plant commissioned at Gorge Farm in Naivasha feeding the Kenyan grid and the Bohemian Flowers farm in Naivasha with a 20kW capacity. Therefore, the potential at flower farms in Kenya is 216 medium-scale biodigesters (140 m^3).

Slaughterhouses

The study also contains information related to the monthly production of 160 slaughterhouses and 26 slaughtering slabs throughout the country. Based on the number and type of animal slaughtered per month from (Kabeyi, Moses & Olanrewaju, Oludolapo, 2021) and (Pagés Díaz, Jhosané, 2015), the number of potential small-scale (108), medium-scale (18) and industrial scale (1) plants were estimated.

Biogas purification and bottling

The effort by Kekonyoike slaughterhouse to bottle biogas for sale was shelved because the gas stored was not sufficient for the competitive cooking gas market. Car tyres and ordinary LPG gas cylinders turned out not to be the ideal packages for biogas. Olivado in Murang’a county has installed a commercial scale purification and bottling facility. Biogas is purified to biomethane with a methane content of 97%. Bottled biogas is intended for running vehicles in farm operations. The bulk of the biogas (without biomethane upgrade) runs two generators for processing operations.

At Bohemian flowers, a simpler bottling installation compresses biogas at 60 bars to cylinders for local cooking. At this site only H_2S is cleaned out of the gas.

Biodigestion Potential in Kenya

The study shows that the potential for small scale biodigesters is 743,749 units from exotic dairy cows (99%), pig farms, coffee wet mill and slaughterhouses and slaughter slabs. It was not possible to estimate the number of farms with at least 2,000 chicken in cages.

The potential for medium scale biodigesters in Kenya is estimated at 105,520 units. Our sample is composed of 684 units from coffee wet mills (46%), flower farms (32%), commercial dairy farms (8%), commercial pig farms (7%), slaughterhouses (3%) prisons (2%), sisal and wastewater treatment plants (1% respectively). The theoretical number of commercial dairy and pig farms was estimated at 104,938 farms. Through this study, it was not possible to estimate the number of commercial chicken farms which could have sufficient chicken manure to feed in a $50m^3$ biodigester i.e., chicken farms with at least 2,000 chicken in cages.

In theory, all the 7 WWTP, 1 prison, 1 slaughterhouse and 61 wet mills could qualify for an industrial biodigester (more than $500m^3$). Experience with industrial biodigesters (more than 500 m^3) is limited to two projects in Kenya: the 2MW biogas power plant at Gorge Farm and the two biodigesters of $1,900m^3$ at the Olivado farm in Murang'a. Therefore, potential industrial size systems were included in the medium-scale biodigester potential.

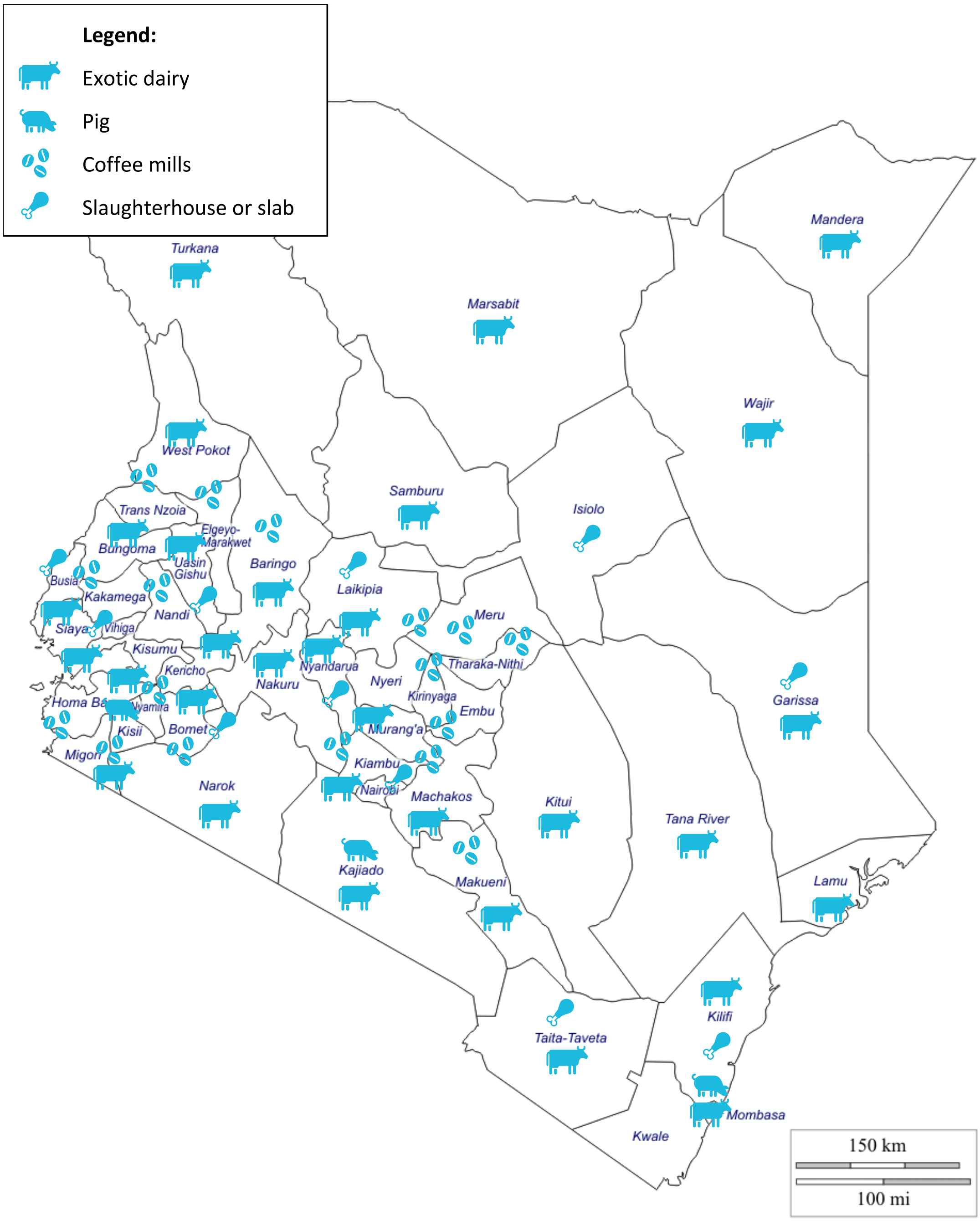

Figure 2 - County distribution of small-scale biodigester (0 to 50m³) potential in Kenya - © GIZ

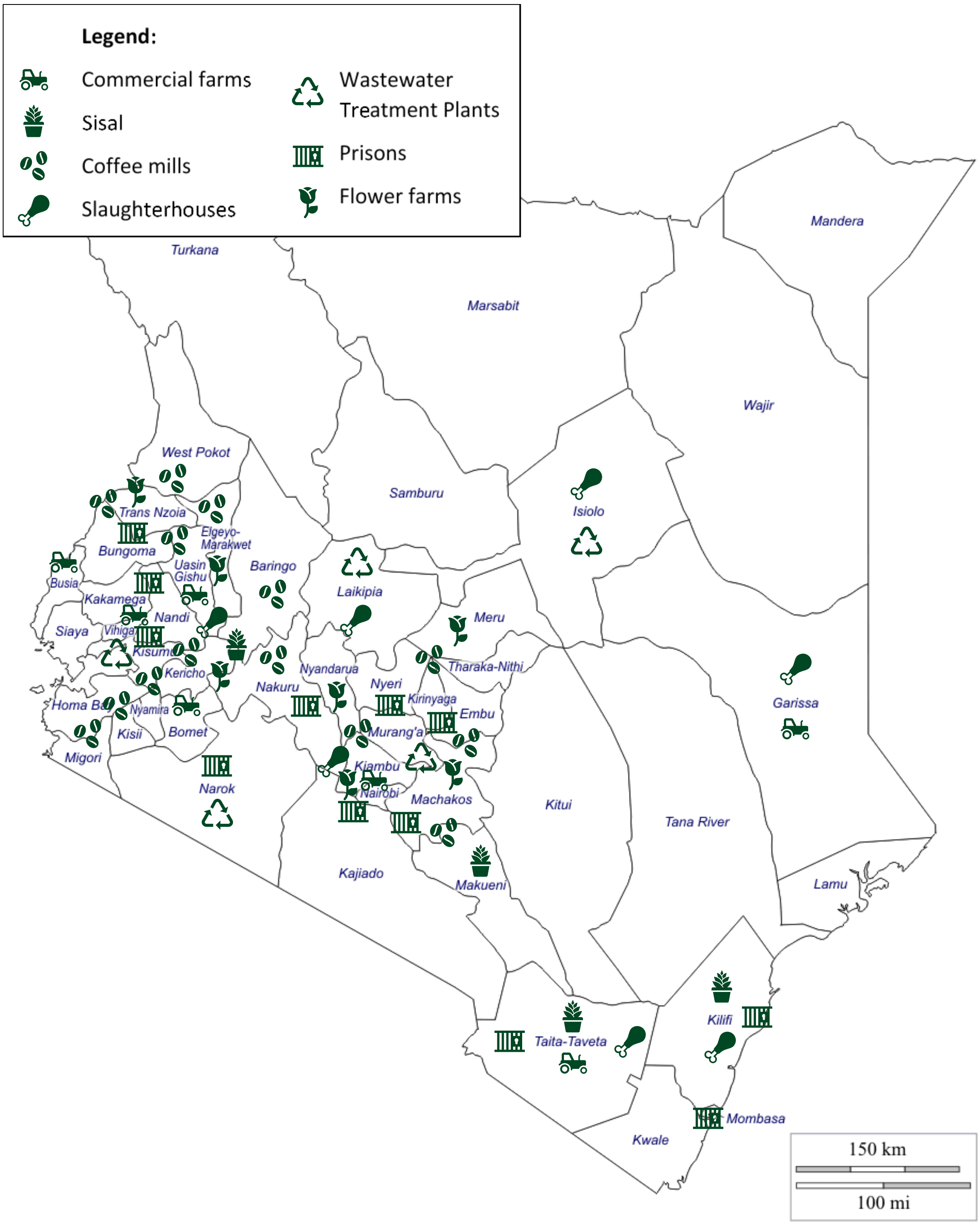

Figure 3 - County distribution of medium-scale biodigester (50 to 500m^3) potential in Kenya - © GIZ

Recommendations

This study relied on existing data on livestock population and other production volumes from different sectors. It is recommended that more studies are undertaken to address waste generation in each sector that generates biodegradable waste.

The study has established that the number of zero-grazing units is not comprehensively documented in all counties. It is recommended that records for such zero grazing units be developed through a comprehensive field survey at least for the 12 focus counties of the project. Such records should include the numbers of cattle in each zero-grazing unit as well as the number of zero-grazing units, and it should cover all other livestock categories such as at least pigs and chicken, sheep and goats.

Field visits have encountered one biodigester not performing optimally. Another one is undersized, and it is receiving already digested effluent. A Decentralised Treatment Facility (DTF) emits methane to the atmosphere since biogas capture is not integrated. It is recommended that refresher training for service providers to be undertaken regularly to update their skills in all areas of biodigester construction.

During the field visit, the authors noted a general lack of understanding of the potential to generate biogas from other non-cow dung biodegradable materials. It is recommended that biodegradable waste producers be capacitated on the potential of their waste resources and the concept of circularity in their production processes.

It was found that one institution which was operating two biodigesters has abandoned the one that was using cow dung as feedstock. This was occasioned by the decision to sell the cows. The biodigester (bio-latrine) that was using human waste is still in operation since 1994. It is recommended that for institutions, proposed biodigesters should integrate the use of wastewater since this will always be available. Sustenance of livestock in institutions is always subject to management decision especially if the biodigesters fail to generate biogas volumes sufficient to reduce the energy bill of the institutions.

Methodology

Data sources

The main source of secondary data was identified to be available publications and relevant reports. The custodians of this data are key players in the biogas sector:

1 County officials in energy, livestock, education, water etc.
2 Kenya National Bureau of Statistics (KNBS)
3 Private sector actors in agro processing, dairy, etc
4 Biodigester enterprises
5 Other organizations such as the Ministry of Energy (MoE) and the Rural Electrification and Renewable Energy Corporation (REREC)

Data collection through a questionnaire

A questionnaire was prepared to inquire on statistical data and information which broadly presents the feedstock base for each county. Only the already existing data in county records was taken into account. Data and information are presented at the sub-county level in the following areas:

- Population of exotic dairy cattle in sub-counties
- Number of zero-grazing units in sub-counties
- Number of sheep and goats in sub-counties
- Farms owning more than 30 dairy cows in zero-grazing units and more than 100 pigs
- Slaughter slabs and slaughterhouses and their monthly kills in sub-counties
- Social Institutions owning livestock in the county
- Agro-processing sites and type of agro-processing

The data and information required for filling the questionnaire was spread out in different county departments: the departments of agriculture, livestock, education and value addition in some counties where it exists. The questionnaire was completed by the department of Energy which brought together different data and information from the other departments.

Data collection through direct interviews

Direct interviews were undertaken during field visits to some of the counties with focus counties forming most counties visited. The table below is a list of the counties that were visited.

Table 1 - List of visited counties

No	County	No	County	No	County
1	Kiambu	6	Nakuru	11	Nandi
2	Murang‘a	7	Laikipia	12	Kakamega
3	Taita Taveta	8	Nyandarua	13	Meru
4	Makueni	9	Narok	14	Isiolo
5	Vihiga	10	Bomet	15	Nyeri

During county visits, three types of interviews were organised: (i) at potential sites, (ii) at sites with operating biodigesters and (iii) with service providers.

Case studies of operational sites

Case studies are presented for medium scale biodigesters to present business models and different options for utilising biogas. Such options include but not limited to:

- Biogas for heating in a hospital
- Biogas CHP in flower farms
- Bioslurry usage
- Biogas purification and bottling.
- Prisons sites

Data gaps

Data and information gaps arose in some ways that hindered revelation of a County's potential in some areas. This was through missing data e.g., from partially filled questionnaire or non-responsive counties that failed to return the questionnaire. Under these circumstances, livestock data available from KNBS 2019 Census for the unresponsive counties has been used. However, data not included in the census on number of zero grazing units, slaughterhouses, agro-processing sites, coffee wet mills, prisons etc… form an integral part of the report.

Key potential indicator

One of the key parameters that influence the volume of biogas production is the total feedstock volume. This is the average amount of material added to the biodigester each day. Availability of feedstock in specific counties is the main indicator for the biodigester potential.

The feedstock for small scale and medium scale biodigesters is mostly agricultural solid wastes produced from farming activities. Every stage and phase of the agricultural-food chain can generate significant solid and liquid wastes. It should also be mentioned that while production processes are keen on the quantities of commercial products, they generate most of them do not know the amount of waste they produce. The potential is further enhanced by the ease of collection of such waste for the biodigester.
The key waste production sectors relevant to this study include the followings:

- Animal production
- Food and meat processing
- Agro processing
- Horticultural production
- Institutions

Animal production wastes—these are the liquid and solid wastes arising from the rearing of livestock such as cows, pigs, chicken etc. For biogas production, the ease of collection of the waste is the main parameter to determine the potential. Biogas companies will favour livestock in stables such as exotic dairy cows, pigs and chicken in cages over sheep and goats. The presence of dairy cattle with zero-grazing units and feed lots for other cattle are attractive features that influence the ease of marketing biodigesters. This study has therefore collected county data on population of livestock as the basis for the volume of waste required for biodigesters. This is further qualified by presenting the number of zero-grazing units for counties where such data was available.

To inform the market for medium scale digesters, the location of farms with more than 30 dairy cows and those with more than 100 pigs have been identified by some county authorities.

Meat processing wastes—these are the wastes produced from the processing of animal products for human consumption, such as abattoir or slaughterhouses/slaughter slabs. Data has been collected on the location of slaughterhouses and slaughter slabs and their throughput.

Agro processing wastes—these are solid and liquid wastes generated in processing of fruits and other agricultural produce. The type of agro processing and location in counties was identified specially sisal and coffee wet mills.

Horticultural solid wastes— these are wastes generated in fruit and flower farms arising from the grading of the farm products as they are packed for the market. The most significant in this category is the flower sector which is renowned for extensive green houses in some counties. Data on the location of a significant number of flower farms and their sizes is presented.

Institutional wastes—these are waste generated in institutions such as schools, hospitals, universities, prisons and colleges. Wherever there are such institutions, there will always be large volumes of solid waste and wastewaters generated therein. While solid waste may require effort to collect and segregate, in some institutions, there exists infrastructure to collect and convey wastewaters to treatment sites. Such treatment sites are ideal for medium scale biodigesters depending on the size of the institution. This study also presents the potential from some waste water treatment plants across the country.

Determination of sector feedstock and biogas potential

To determine the potential for biogas, for a specific site or a production sector or a county information is required on:

- The volume and quantity of feedstock available.
- The type of feedstock to determine the biogas yield.

Sector feedstock

So far there has not been any systematic research on the volume and quantities of waste generated in various productive sectors. There are however a few mentions of estimates in related studies such as energy or environmental audit reports, general statistics etc. The production sectors have maintained accurate records of the commercial products they generate as they are the reason for their operations. However, waste volume and type are not yet of significant concern and such waste is simply disposed at no or low cost.

During field visits, interviews, were held at some representative production sites as listed below:

- Bomet: two zero-grazing farms with 2 biodigesters and 42 cows
- Isiolo: one slaughterhouse and one Waste Water Treatment Plant (WWTP)
- Kakamega County: A farm with 26,000 chicken and 500 pigs, that can qualify for an industrial biodigester of about 1,000m^3
- Kiambu: one zero-grazing farms with 2 cows, one farm with 200l (150-200kg/day) of pig dung, produced by about 70 pigs.
- Laikipia: one fruit and livestock farm and one WWTP
- Makueni: one fruit processing factory
- Meru: two farms with 400 pigs and 7 cows
- Nakuru: one flower farm with operational biogas power plant and biogas bottling
- Nandi: one milk processing plant, one farm with 90 free ranging cows, one training institute with 260 students
- Narok: two WWTP and one prison
- Nyandarua: one farm with 7 cows and one slaughterhouse
- Vihiga: one WWTP and one prison

From all the above sites, only the WWTPs have data and information on the volume of waste they manage as their core business is to manage arising wastewater. For all the others, they could only estimate the volume and quantities of waste produced. Waste producers do not have reliable data on waste generation. Government line ministries and related departments have no such records either. However, in some specific cases key informant interviews led to the generation of rough estimates on volume of waste: in Narok prison and Kiambu coffee wet mill.

Biogas potential

Biogas calculation tools were used for determining the biogas production potential. The tools helps to estimate the key performance parameters of a biogas plant, such as potential biogas production, electricity and heat output on the basis of the input feedstock.

The tools also give information on potential revenue and investment requirements, preliminary mass balance, GHG reduction and more. Some of these tools are available from:

- Biogas World Media Inc [BiogasWorld]
- Renergon GmbH [Renergon]

The potential for some sectors such as sisal and coffee has been estimated from data obtained in the literature review.

Dairy sector

Overview of the economic contribution of the dairy sub-sector

Milk production from the Kenya dairy sector has maintained a steady growth from 591.4 million litres annually in 2017 to 801.1 million litres in 2021 (Economic Survey 2022). The sub-sector contribution to various socioeconomic dimensions is summarized in table below:

Table 2 - Dairy sector contribution to various socioeconomic dimensions (Source: Kippra, 2020).

Indicator	Estimated value
Value of dairy contribution to overall GDP (%)	4
Value of dairy contribution to agricultural GDP (%)	12
Value of dairy contribution to the livestock GDP (%)	44
Number of lactating dairy cattle (million)	4.50
Annual milk production from all livestock (million litres)	4.75
Total annual milk production cows (billion litres)	3.56
Per capita consumption of milk per year (litres)	121
Amount of formally marketed milk per year (million litres)	600
Number of smallholder dairy farmers (million)	1.8
Number of indirect jobs created annually	750,000
Number of direct jobs created annually	500,000

The Kenyan dairy sector is transitioning from subsistence to greater commercialization, from low investment into capital-intensive and skilled enterprises, and from fragmentation to consolidation towards a sophisticated supply chain involving many actors and offering a wide range of milk and dairy products. This is a trend that is likely to enhance the uptake of biodigesters as the farmers become more aware of the need to become self-reliant on energy and fertilizer and to manage farm waste.

Characterization of grade dairy cattle owning households

Different dairy cattle grazing models exist in Kenya, impacting the type and size of biodigesters to be promoted. They can be differentiated between (i) zero-grazing or stall feeding, (ii) semi-intensive (combined grazing and stall-feeding) and (iii) extensive, free grazing or free range.

Zero-grazing dairy farming

In zero-grazing systems, animals are confined in stalls and feed there. There is minimum movement of cows because they are not allowed to graze. Several dairy farmers in Kenya practice this model attributable to the various advantages accruing from the practice. Issues like shortage of pasture, low productivity of dairy cows, calibration of fodder, disease management are mitigated in this system. (Oxfarm, 2022)

Figure 4: Dairy cattle in a zero-grazing model in Meru county. © GIZ – Peter Gichohi

The model offers a great advantage in operation and maintenance of biodigesters: cow dung is channelled with wash water and urine to the biodigester. This reduces the workload that would otherwise be required to collect the dung from grazing fields.

Semi-intensive dairy farming

This model of dairy cattle keeping uses a combination of partial zero-grazing and partial free grazing. It is characterized by having a stall from where the animals are fed during prescribed periods of the day and grazing area where the animals can forage on natural vegetation freely. In this model, the operation of a biodigester is subject to the volume of waste available in the stall. There is a better chance of waste collection if the stall has concreted floor.

Extensive dairy farming

The essence of open range is the free grazing of cattle on land where the cattle browse on grass and vegetation freely. Often, at the end of the day, the cattle are brought home for milking and shelter. In this model the operation of a biodigester presents great challenges not only due to the limitations of recovering dung but also since most of the night shelters are not concreted, water demand is often higher as all urine is lost through seepage. It is recommended to build a concrete slab for the night shelter to ease dung and urine collection.

Characterization of county grazing models

(FAO, 2017) has characterised the dairy cattle models in dairy producing counties of Kenya.

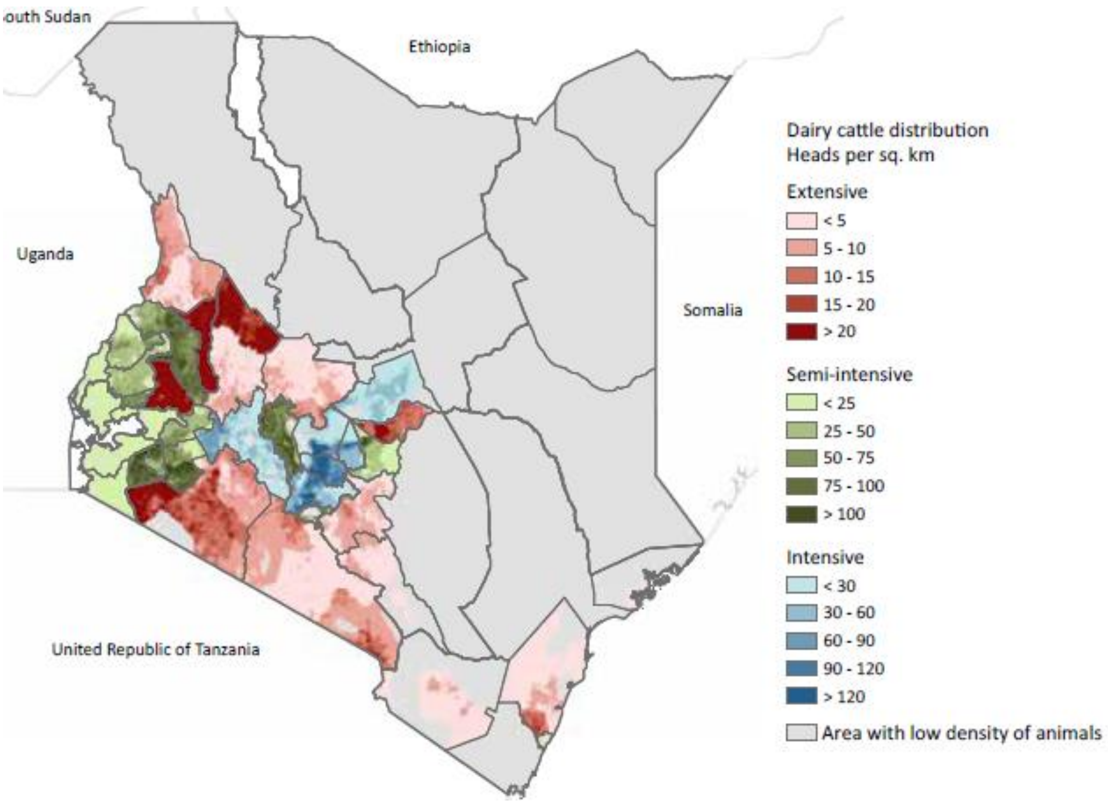

Figure 5 - Dairy cattle production systems distribution (Source: FAO, 2017).

Through field interviews, the study has found that household characteristics by grade dairy cattle production systems in counties is not a common occurrence. Two studies have however been done for such characterization. These are for Vihiga sub county, (Ongadi and al 2007**)** and central Kenya (Embu East sub county and Igembe South sub county) **(**Dr. Mugambi and al 2014). The objectives of these studies were to describe the farm household characteristics and objectives of grade dairy cattle owning households within the mixed small scale farming systems of Vihiga sub county and central Kenya (Embu and Meru counties) respectively.

In the Embu East and Igembe South study, over 95% of the dairy farmers zero-grazed their animals and they owned land sizes averaging two acres. Seventy-one percent (71.1%) of the farmers had between 2 and 5 animals. In Vihiga, intensive production systems (Zero grazing) and combined grazing and stall-feeding were found to be the main models of grade dairy cattle production systems comprising 45.8% and 34.3% respectively. The remaining 19.9% practiced open grazing combined with some feeding.

Due to the small land sizes per household and the need to satisfy households' requirements for food, grade dairy cattle owning households have adopted the intensive production systems. Semi-intensive production is practiced by households with larger land sizes in some counties. The figure below is one such household in Nyandarua county where average holding size per household is 3.5 ha. The eight dairy cows spend the night in the stables on the left.

Figure 6: Daily cattle in semi-intensive grazing model. Field photo-Nyandarua county © GIZ – Peter Gichohi.

With the projected population growth and the predominant cultural practices on inheritance, the average acreage per household will continue to decrease due to subdivisions (Nyandarua County, 2018) and zero grazing is expected to increase.

Figure 7: Zero grazing unit in Kiambu county-Gatundu North sub county – © GIZ – Peter Gichohi.

Comparatively, in Kiambu county, the average mean holding size of land is approximately 0.045 hectares on small scale. The small land holdings are mostly found in upper parts of Gatundu North, Gatundu South, Kiambaa, Limuru and Kikuyu sub counties (Kiambu County, 2018). Due to the small land holdings, intensive zero grazing is the common model practiced.

The table below shows the distribution of exotic dairy cattle per household in the 47 counties. Counties highlighted in green are the focus counties for capacity building activities.

Table 3 - Distribution of exotic dairy cattle per household per county (Source: KNBS, 2019).

County	Households with exotic dairy livestock	Exotic dairy livestock population	Ratio of dairy livestock per household
Lamu	508	12,415	24.44
Isiolo	**596**	**12,900**	**21.64**
Marsabit	1,367	13,693	10.02
Kwale	1,453	10,811	7.44
Samburu	1,046	7,691	7.35
Mombasa	412	3,015	7.32
Nairobi	2,286	11,780	5.15
Kajiado	7,099	36,547	5.15
Tana River	1,302	6,266	4.81
Narok	19,843	93,562	4.72
Mandera	1,203	5,433	4.52
Wajir	1,633	7,352	4.50
West Pokot	11,076	49,863	4.50
Garissa	1,376	6,063	4.41
Kilifi	4,905	19,918	4.06
Turkana	561	2,206	3.93
Baringo	13,012	46,244	3.55
Uasin Gishu	**44,163**	**139,722**	**3.16**
Kisumu	4,642	13,799	2.97
Migori	7,284	21,062	2.89
Elgeyo / Marakwet	13,432	38,735	2.88
Laikipia	9,243	25,846	2.80
Siaya	3,956	10,324	2.61
Homa Bay	5,830	15,095	2.59
Trans Nzoia	34,268	88,662	2.59
Nakuru	**52,739**	**135,235**	**2.56**
Bomet	**39,352**	**99,188**	**2.52**
Machakos	12,759	30,369	2.38
Kenya	**939,916**	**2,209,980**	**2.35**
Busia	5,059	11,740	2.32
Nandi	**54,653**	**125,566**	**2.30**
Kericho	35,358	80,670	2.28
Makueni	9,659	21,517	2.23
Taita Taveta	**7,893**	**17,236**	**2.18**
Nyandarua	**62,978**	**135,895**	**2.16**
Kiambu	**67,014**	**144,311**	**2.15**
More than 2 cows	**539,960**	**1,500,731**	**2.00**
Bungoma	32,344	62,009	1.92
Kakamega	**36,597**	**69,173**	**1.89**
Vihiga	12,316	23,067	1.87
Meru	**63,202**	**114,251**	**1.81**
Nyeri	**51,342**	**92,486**	**1.80**
Tharaka - Nithi	18,185	32,634	1.79
Kisii	28,865	51,458	1.78
Embu	23,852	40,843	1.71
Kirinyaga	29,013	48,488	1.67
Murang'a	**82,912**	**130,152**	**1.57**
Kitui	90,878	10,412	0.11

According to (KNBS, 2019), 539,960 households have in average at least 2 cows in Kenya. According to (GoK, 2020), there was 4,573,871 dairy cows in Kenya for 939,916 households. It is important to notice that the number of dairy cows, greatly differ between (KNBS, 2019) and (GoK, 2020). (GoK, 2020) mention that 28% of these cows are under an intensive system and 51% under a semi-intensive system. These two systems represent the highest potential for biogas. Together, they represent 742,534 households with 4.9 cows per household in average.

Eleven counties have presented data related to the number of zero grazing units. There are summarized in the table below:

Table 4 - Number of zero grazing units per county (Source: GIZ, 2023).

	County	Number of zero grazing units
1	Kisii	18,062
2	**Kiambu**	**12,561**
3	**Taita Taveta**	**10,704**
4	**Nyandarua**	**6,795**
5	**Kakamega**	**3,054**
6	Laikipia	2,683
7	Busia	2,398
8	**Uasin Gishu**	**1,823**
9	**Bomet**	**862**
10	Machakos	674
11	Vihiga	200

Farms with more than thirty dairy cows

We estimate that 30 dairy cows in zero grazing are needed to have sufficient feedstock for a medium scale biodigester (50 to 500m^3). Some counties have provided data for such farms and their sub county locations. These farms are ideal sites for medium scale biodigesters. Some of these farms are in Busia (11), Bomet (8), Uasin Gishu (6), Vihiga (2), Taita Taveta (2), Garissa (3) and Kiambu (21).

Pigs and poultry sectors

Overview of the pig sub-sector

The total pig population in Kenya is 442,761 which are owned by 110,383 households (KNBS 2019). There are in average 4.01 pigs per household. In counties with significant pig population (more than 5,000 pigs), Kajiado county has the highest pig per household ratio (18.14) followed by Machakos (12.92), Uasin Gichu (10.78), Nairobi (10.35), Nakuru (9.94), Kiambu (8.73), Kirinyaga (6.60), Nyeri (6.59), Embu (5.34) and Murang'a (4.41). The number of households in counties with more than 4 pigs per household is 37,130 in Kenya. The number of households in counties with more than 15 pig per household is 902.

Table 5 - Distribution of pig per household per county (Source: KNBS, 2019).

County	Households with pig livestock (2019)	Pig livestock population (2019)	Ratio of pig livestock per household
Mombasa	134	3,032	22.63
Kajiado	683	12,390	18.14
Kisii	85	1,421	16.72
More than 15 pigs	**902**	**16,843**	**18.67**
Turkana	67	992	14.81
Isiolo	**11**	**158**	**14.36**
Kwale	48	675	14.06
Machakos	427	5,517	12.92
Narok	169	2,054	12.15
Makueni	129	1,502	11.64
Taita Taveta	**148**	**1,605**	**10.84**
Uasin Gishu	**847**	**9,132**	**10.78**
Nairobi	1,586	16,412	10.35
Kericho	78	794	10.18
Nakuru	**1,700**	**16,895**	**9.94**
Tana River	2	19	9.50
Kilifi	366	3,319	9.07
Kisumu	537	4,755	8.85
Kiambu	**9,731**	**84,991**	**8.73**
Lamu	33	280	8.48
Elgeyo / Marakwet	49	412	8.41
Laikipia	328	2,685	8.19
Nyandarua	**512**	**4,017**	**7.85**
Trans Nzoia	670	4,832	7.21
Kitui	175	1,254	7.17
Kirinyaga	2,410	15,909	6.60
Nyeri	**2,305**	**15,188**	**6.59**
Baringo	76	432	5.68
Bomet	**54**	**306**	**5.67**
Samburu	48	270	5.63
Embu	2,404	12,837	5.34
West Pokot	64	341	5.33
Murang'a	**11,053**	**48,775**	**4.41**
Nandi	**201**	**862**	**4.29**
Kenya	**110,383**	**442,761**	**4.01**

County	Households with pig livestock (2019)	Pig livestock population (2019)	Ratio of pig livestock per household
Kenya	**110,383**	**442,761**	**4.01**
Vihiga	1,324	4,628	3.50
Marsabit	19	65	3.42
Migori	855	2,922	3.42
Bungoma	5,377	15,930	2.96
Siaya	5,145	14,175	2.76
Meru	**11,730**	**30,789**	**2.62**
Tharaka - Nithi	3,566	8,753	2.45
Homa Bay	1,973	4,457	2.26
Kakamega	**14,057**	**28,634**	**2.04**
Busia	29,180	57,004	1.95

Farms with more than 100 pigs

While small scale pig keepers may qualify for small scale biodigesters, there are a few commercial pig farms that were recorded to have more than 100 pigs. Some counties have provided data for such farms and their sub county locations. These farms are ideal sites for medium scale biodigesters. Some of these farms are in Busia (4), Vihiga (1), Taita Taveta (3), and Kiambu (40).

Case study of a pig farm

The households involved in pig farming are either large integrated commercial farms, medium scale commercial farms, or small-scale commercial farms. Below is a case study for one medium scale commercial farmer that was visited in Kiambu county.

The buildings to the left are the pig stables where the numbers fluctuate from 300 to 500. The pit is filled with wastewater that is an ideal feedstock for the biodigester. Intense gas bubbling was observed during the time of visit. This waste is pumped out to the farms regularly to create room for more inflows.

Figure 8: Pig stables and wastewater pit – © GIZ – Peter Gichohi

Table 6 - Case study of a pig farm

	Proposed Size and cost County: Kiambu	$50m^3$, costing: 450,000KES Sub-County: Gatundu South
1	Type of client Year Established	Pig farm 2018
2	Information about client Type of activity Number of pigs	 Rearing, fattening and selling pigs 62 pigs
3	Total Land size Land under cultivation Digester space availability	0.5 Acres 80% / 20% is occupied by the pig house 10m x 15m
4	Water source: Consumption volume (m^3)	Shallow well-30m depth $0.8m^3$/Day
5	Available Waste: Type of solid waste Type of wastewater Disposal method Pumping frequency Sewer network Other Waste Source	 Pig dung: about 200L (150-200kg/day) All mixed with wash water and washed into soak pit Wastewater from floors, 800L/day Soak pit-6m depthx3.5mx1.5m, pumping to nearby ground which is already saturated. Pumps 3 times per week. None. Excess wastewater flows to the road drainage None
6	Potential uses of biogas Heating Electricity	 1) To replace Kes 10,000/Month used to purchase firewood. Used to cook hotel left-over food waste which is the main feed used for the pigs. 2) Heating pig house at night Not significant. Heating is the main need
6	Potential uses of bio slurry: Own use Sale	 In leased farms nearby to create the demand for bioslurry There is high potential in the area for farming
8	Other Comments	Soakage of slurry not possible. Surrounding farms would be potential customers for bioslurry Can save KES 120,000/yr. of heating costs Current disposal ground is saturated. Candidate for medium scale Can satisfy requirements for Financial Institutions

Overview of the chicken sub-sector

In 2021, the marketed earnings from chicken and eggs amounted to KES 9.7B (EUR 65M) which was an increase from KES 9,5B (EUR 63,8M) in 2020 (Economic Survey, 2022). In 2021, this represented 6% of the KES 161,7B (EUR 1.086B) earned from total livestock and associated products in the same year. Chicken is therefore a significant product in the livestock economy and generated waste can significantly impact the local environment and provide an available feedstock for biodigesters. The total chicken population is 38,816,238 heads (KNBS, 2019) which is a mix of indigenous chicken, exotic layers and exotic broilers.

Chicken manure is not as digestible as mammal manure as their stomachs do not naturally have the necessary bacteria needed for biodigestion. The optimum pH for biodigestion is between 6.7 to 7.4 [Wahid, 2019] while the pH of chicken manure is around 6.1 (Manogaran, 2022). Usually, the biodigestion of chicken manure is initiated with cow dung before slowly increasing the ratio of chicken manure.

The leading counties in chicken population are Kiambu (3,6M), Nakuru (2M), Machakos (1,8M), Murang'a (1,6M), Kakamega (1,6M), Makueni (1,5M), Kitui (1,4M), Meru (1,2M), Kisii (1,1M) in decreasing order. The table below shows the population of chicken in all counties.

Table 7 - Distribution of chicken per household per county (Source: KNBS, 2019).

County	Households with chicken livestock	Chicken population	Ratio of chicken per household
Nairobi	21,716	847,209	39.01
Mombasa	7,883	272,092	34.52
Kiambu	**110,542**	**3,661,661**	**33.12**
Kajiado	38,239	818,122	21.39
Garissa	7,991	123,935	15.51
Kilifi	75,425	1,064,925	14.12
Lamu	11,000	149,931	13.63
Nakuru	**154,659**	**2,021,817**	**13.07**
Wajir	7,050	86,343	12.25
Murang'a	**131,125**	**1,586,146**	**12.10**
Machakos	150,871	1,775,536	11.77
Uasin Gishu	**81,098**	**945,374**	**11.66**
Mandera	16,168	174,904	10.82
Laikipia	53,150	573,934	10.80
Isiolo	**6,585**	**71,087**	**10.80**
Kenya	**3,611,678**	**38,816,238**	**10.75**
Makueni	141,577	1,521,066	10.74
Kirinyaga	80,824	862,599	10.67
Nyeri	**95,616**	**1,017,069**	**10.64**
Taita Taveta	**36,096**	**378,672**	**10.49**
Embu	85,946	896,889	10.44
Kwale	57,994	604,644	10.43
Kisumu	84,782	879,399	10.37
Baringo	56,672	583,505	10.30
Trans Nzoia	84,032	843,361	10.04
Migori	98,438	972,629	9.88
Kitui	152,007	1,445,013	9.51
Bomet	**97.816**	**917,039**	**9.38**

County	Households with chicken livestock	Chicken population	Ratio of chicken per household
Narok	102,160	954,673	9.34
Nyandarua	**89,911**	**828,052**	**9.21**
Homa Bay	112,025	1,013,957	9.05
Kericho	77,751	685,223	8.81
Tana River	11,822	103,169	8.73
Elgeyo / Marakwet	34,594	297,458	8.60
Siaya	115,350	986,958	8.56
Busia	92,429	776,646	8.40
Kisii	130,049	1,084,898	8.34
Nandi	**87,642**	**725,159**	**8.27**
West Pokot	55,834	459,703	8.23
Meru	**149,835**	**1,216,778**	**8.12**
Turkana	6,662	53,322	8.00
Tharaka - Nithi	57,920	460,854	7.96
Bungoma	170,271	1,292,609	7.59
Kakamega	**210,180**	**1,561,945**	**7.43**
Samburu	14,710	102,169	6.95
Marsabit	3,796	26,065	6.87
Vihiga	75,878	517,634	6.82

With the national census, it is not possible to find a single county with 500 chicken per household on average. Therefore, a list of the largest chicken farms in Kenya is provided below.

Table 8 - List of largest chicken farms in Kenya

Name of Poultry farm	Activity	County
Kenchic Ltd	Sell day old chickens	Nairobi,
Engoho Kuku Farmer	Sell day old chickens	Nairobi
Neochicks Poultry Limited	Sell day old chickens	Nairobi
Homerange Poultry	Sell day old chickens	Kiambu
Ziwani Poultry	Sell day old chickens and eggs	Kiambu/Thika
Kim's Poultry Farm	Hatchery and out grower broiler farm	Nakuru
Isinya Feeds	Sell layer and broiler chickens	Kajiado/Isinya
Muguku Poultry Farm	Sell layer and broiler chickens	Kiambu/Kikuyu
Kuroiler Poultry	Chickens and fresh fertilized eggs	Nakuru/Bahati
Jenico Poultry Farm	Chickens and fertilized eggs	Nairobi/Embakasi
Brade Gate Poultry	Chickens and chicken slaughterhouse	Nyeri
Boresha Farm	Chickens and fertilized eggs	Kakamega/Butere
Melpa poultry farm	Chickens and fertilized eggs	Bungoma/Webuye

Potential for biodigesters in chicken farms

Chicken manure has the potential to generate 435 m^3/ton Volatile Solid (Fischer et al 2010). Unlike other livestock such as cows and pigs, the availability of chicken manure depends on the type of chicken house floor and the chicken bedding used.

The three common methods used for rearing chicken are:

Extensive (free-range) - The traditional method used for indigenous chicken where the chicken are free during the day and they are housed during the night. This method is used by households that maintain a small number of chickens. Collection of chicken manure in sufficient quantities for running a biodigester can be challenging. However, manure available from cleaning the chicken can be added to another animal waste to run a biodigester.

Semi intensive -This method is partly free-range and partly intensive. It is common for small holder farms. The potential for using a biodigester is dependent on the quantity of available clean manure.

Intensive - This is the system used by most commercial chicken farms rearing large number of chickens and hatcheries. Some of the houses may have concrete floors with bedding materials or battery cages on concrete floors. The intensive chicken houses systems are more favourable for biodigesters since the chicken manure is readily available from the regular cleaning of the houses. However, the best system for biodigestion is when chickens are in cage as the manure is not mixed by straw or wood chips bedding.

The photos below show such housings and chicken manure collected into a truck in Boresha farm, Kakamega county.

Figure 9 - Chicken houses in Boresha farm and chicken manure in a truck ready for sale - © GIZ - Peter Gichohi

Household expenditure levels per county

Biodigesters have emerged as a sustainable and environmentally friendly solution for household waste management and renewable energy generation. In Kenya, with its rich agricultural and livestock resources, biodigesters present a significant opportunity to promote clean energy production at the household level. This section aims to identify the counties in Kenya with the highest potential for domestic biodigesters, based on household income levels.

Household income levels per county are not available. A proxy measure was used instead, the mean monthly expenditure per adult equivalent provided in the Kenya Poverty Report (KEBS, 2021).

Table 9 - Mean monthly food and non-food expenditure per adult equivalent (Source: KNBS, 2021)

County	Expenditure in KES	County	Expenditure in KES	County	Expenditure in KES
Nairobi City	17,160	**Nandi**	**6,528**	**Rural**	**5,225**
Urban	**12,001**	Tharaka-Nithi	6,438	Garissa	5,157
Kiambu	**11,773**	Laikipia	6,410	Baringo	5,111
Mombasa	10,714	Narok	6,318	Migori	5,019
Nakuru	**7,976**	Lamu	6,126	Elgeyo/Marakwet	5,006
Kajiado	7,890	Trans Nzoia	6,000	Makueni	5,003
Nyeri	**7,503**	Homa Bay	5,965	Kitui	4,990
Machakos	7,424	Kilifi	5,859	Marsabit	4,783
Kenya	**7,393**	Bungoma	5,811	Vihiga	4,694
Meru	**7,267**	Kericho	5,656	**Bomet**	**4,689**
Embu	7,202	**Kakamega**	**5,625**	Wajir	4,629
Taita/Taveta	**7,125**	**Nyandarua**	**5,603**	Mandera	4,514
Kirinyaga	7,121	**Isiolo**	**5,540**	Busia	4,456
Murang'a	**7,028**	Kisii	5,501	Tana River	4,215
Uasin Gishu	**6,669**	Siaya	5,476	Samburu	4,008
Kisumu	6,579	Kwale	5,467	West Pokot	3,839
		Nyamira	5,431	Turkana	3,483

To identify counties with the highest potential for domestic biodigesters based on household income levels, an expenditure level segmentation can be performed with the following categories:

- counties with expenditure level higher that national mean are considered high potential
- counties with expenditure level between rural expenditure level and national mean are considered medium potential
- counties with expenditure level below rural expenditure level are considered low potential

Medium scale biodigesters (50 to 500m³)

Definition of medium scale biodigesters

In the context of this study, anaerobic digesters larger than $50m^3$ are referred as medium scale biodigesters. Typically, farmers who own large herds of livestock in zero grazing units (30 cows), feed lots, pig stables (100 pigs) and chicken pens (2,000 birds in cages) who typically need biogas beyond household cooking are potential clients of medium scale digesters. This also includes production activities that generate other wastes such as wastewaters from institutions (e.g., sewage from schools, hospitals, slaughter houses, industries, prisons and municipalities), organic waste from agro-processing (e.g., fruit processing, coffee wet mills, flower, sisal), market waste etc. The volumes of wastes are usually larger for smaller digesters and often the waste characteristic need to be analysed to decide if any pre-treatment is required. Since ABC desire to accelerate the uptake of the medium scale digesters it is necessary to understand some of the factors that may hinder the uptake and those that will promote it.

Factors influencing the uptake of medium scale biodigesters

Technical barriers

In Kenya, small scale biodigester is a popular technology. However, only a few biodigester enterprises can construct or install larger systems. The contractors face technical challenges related to biodigester sizing, design, how to handle waste in upstream and downstream, how to collect and utilise gas etc. ABC will address these barriers by providing technical support to the contractors with potential to construct or install larger systems. This would build their capacity to evaluate each site individually to integrate the biodigesters in their respective sites for smooth operations and to minimise operational challenges.

Economic barriers

From the data and information received from counties, it was noted that there are only few productive processes in counties that generate organic waste ideal for biodigesters. Of great value is the fact that these few production sites are targets for medium scale biodigesters and they normally utilise commercial fuels for heating or electricity production. They need to be guided meticulously through the evaluation of economic benefits of biodigesters since their energy inputs are obtained commercially (no wood fuel collection). They also need to be guided on the marketability of bioslurry since this can add it to their revenue streams.

There are few suppliers that would competently supply the services for the medium scale biodigesters. This is a barrier itself. For the few available, there is limited access to finances since waste to energy projects are expensive and usually not among the project portfolios financial institutions (FIs) are accustomed to. The productive processes are hindered in actualising biogas as alternative energy source. Similarly, the few suppliers available are hindered by the upfront costs incurred prior to sealing contracts to implement medium scale biodigesters. For this reason, ABC is planning to (i) train (Micro)Finance Institutions on biodigestion and (ii) create a revolving fund for biodigester companies involved in the medium scale biodigester segment.

Commercial farms

While most of the dairy farms in Kenya will qualify for a small scale biodigester, a few of them with more than 30 dairy cows in zero grazing would qualify for a medium scale biodigester. During the data collection, it was determined that there are at least 21 commercial dairy farms in Kiambu, 11 in Busia, 8 in Bomet, 6 in Uasin Gishu, 3 in Garissa, 2 in Vihiga and Taita Taveta. According to (FAO and GIZ, 2019) the number of large-scale dairy farm (more than 50 cows) is 10% of the total number of households with exotic dairy cattle which represents 93,900 farms.

Similarly, there are a few commercial pig farms that were identified to have more than 100 pigs during the study compared to the potential. These farms are in Kiambu (40), Busia (4), Taita Taveta (3) and Vihiga (1). If we use the same approach for commercial dairy farmers (10% of the total dairy households) to estimate the number of commercial pig farmers, we estimate the presence of 11,038 pig farms in Kenya.

In total, our sample represents 101 potential clients for medium scale biodigesters with a theoretical potential of 104,938 farms. The sample data is not exhaustive as it was collected through the 14 Key Informant Interviews and site visits. The potential of medium scale biodigester from commercial farm manure is therefore underestimated.

Generally, the construction of a medium scale biodigester can take between two weeks to one month. The critical aspect is operation and maintenance of the biodigester that must be sustained throughout its lifetime. The ease of operation and maintenance is influenced by multiple factors. Some of these are sustained availability of feedstock. It is therefore necessary to set conditions that will enable such success. The biodigester system should be implemented to solve an energy and fertiliser issue as perceived by the client. It should not constitute a burden to the user. The table below shows potential selection criteria for medium scale biodigester sites.

Table 10 - Biodigester site selection criteria

Criteria	Reason
Absence of grid connection	Biogas electric system will add value
Firewood as source of heating cooking energy	Biogas thermal system will add value
High economic and environmental cost of firewood	Financial and environmental viability
Sewage flow infrastructure is available	No need to invest in infrastructure.
Reliable water supply	Sustainability of biodigester.
High resident population in institutions (800+)	High volume of sewage
High agricultural activity	High chance for fertiliser use
Sloppy ground	Ease of gas conveyance and bioslurry flow
No cultural barriers limiting effluent reuse	Ease of gas and effluent use
Ease of access by road	Ease of construction and monitoring
Integration with existing institutional infrastructure	Sustainability of operation
Availability of baseline data on energy and water costs	Bases for techno-feasibility evaluation of the project
Minimum risk for pollution of the site vicinity	High chance of acceptance and maintenance
Potential to create/generate business from treated waste water (bamboo plantation, wood lot, fish farming, banana, irrigation, reed beds, fodder etc)	Enhanced sustainability of project

Case studies of medium scale biodigesters

Kiambu county – Este Farms

Table 11 - Este Farms Case Study

	County:	Kiambu: Sub-County: Gatundu North
1	**Information about site** Type of activity	ESTE FARM Dairy Farm: ≥ 20 zero grazed cows in 2022 ≥ 50 zero grazed cows in 2004 Numbers grew up to 70 cows, now reduced to about 20
2	**Information on biodigester** Year Established Digester 1 Digester 2 Feedstock: Volume available	 2004 1x60m^3 – 530,000KES 1x50m^3 – 450,000KES ≥ 500L/Day from the entire stable floor including milking area. Includes all cow dung and wash water. Flowing directly into inlet to digester 1. Overflow to digester 2.
3	**Business Activity**	a) Milk production from own cows b) Purchase of milk from neighbouring small farms c) Pasteurizing all milk (500L/Day) and transportation to Nairobi for sale of the pasteurised milk.
4	**Gas Production and usage**	All biogas used in main house cooking and pasteurising about 500L of milk per day.
5	**Feedstock** Volume of daily feed Gas volume measuring device	 400 -500L/day Gas flow meter has been purchased though not yet installed.
6	**Electric generator**	2kW- not in use now
7	**Other Comments**	All effluent used in own farms for fodder production Project finance through a loan borrowed in 2004

Bomet County – Mibei Farm

Table 12 - Mibei farm case study

	County:	Bomet: Sub-County: Chepalungu CHEPKEBIT
1	**Information about site** Type of activity	Dairy Farm: ≥ 42 zero grazed cows and has one biodigester Farmer has another farm with ≥ 90 zero grazed cows in a different farm. There is no biodigester in the second farm.
2	**Information on biodigester** Digester Volume Slurry Storage Feedstock: Volume available Volume of daily feed Gas Production and usage Gas volume measuring device Daily production(M^3/day) Daily usage (M^3/Day)	Volume unknown A large concrete tank with grass thatched shed. All used in own farms for fodder production. There is potential for sale since the farmer has tractors that can transport to other farms. ≥ 400L/Day from the milking shed floor. This is mainly cow dung and wash water from the milking area which flows to a collection pit and excess overflows to the nearby cultivated area. ≥ 300kg /Day is available from the feeding shed floor. This can only be collected by wheelbarrows. Unknown. Digester inlet chamber raised by about 1m above collection pit. Feeding is through drawing by buckets only Cooking and heating milking water only. Gas is not sufficient for cooking in the farmhouse kitchens. Non Unknown. Data not available
3	**Electric generator**	No
4	**Other Comments**	The labour required for feeding digester by bucket is too much and unsustainable Since this farm is highly mechanised, the addition of a sludge pump to feed all the slurry to the digester daily is recommended. Gas leakage was detected at the digester neck and gas pipe near the digester neck A slurry tanker recommended to enhance slurry use and sales Monthly electric bill is Kes 8,000 to 9,000 per month. This farmer has high prospects for improving the existing project and installing a better one in his other farm.

Figure 10 - Biodigester and slurry storage at the left of zero grazing unit with 42 cows

Nandi county- Homeland Dairy Foods Ltd

Homeland Dairy Foods Ltd operates a milk processing plant in Nandi county/Nandi Hills. The main energy intensive processing activity is pasteurising of 1500l to 2000l of fresh milk per day. The pasteurised milk is sold through a milk ATM at Kapsabet town. Other products are yoghurt and sour milk which are packed in 500ml packets and distributed within the county.

Pasteurising is done using steam which is generated by an old firewood boiler. The lagging on the boiler and the steam pipes are worn out. There is a pile of firewood besides the boiler. The company director estimated that it would cost him KES.500,000 to repair the boiler. The current cost of firewood is KES.15,000/month.

Figure 11 - Homeland milk processing site - Nandi county

In addition to milk purchase and processing, the farm has its own herd of 21 dairy cows in a well maintained zero grazing unit. The dung is piled at the lower end of the stables and it is regularly used as manure in the farm.

This site is ideal for adoption of a medium scale biodigester. The primary usage of biogas would be milk pasteurising. By adopting a biodigester, the milk processing operations will be cleaner, firewood would be saved, and the slurry will be of better quality to fertilise the farm. The table below shows more information about the farm operations.

Table 13 - Milk processing at Homeland Dairy Foods Ltd - Nandi county

	County:	Nandi County: Nandi Hills Sub-County
1	**Name of Site** Type of activity	HOMELAND DAIRY FOODS LTD a) Rears 21 dairy cows in zero grazing units. b) Milk processing: Products- Yoghurt, sour milk, fresh milk.
2	Information about site **Total Land size** Land under cultivation Digester space availability	Process 1500-2000L of milk 4 days per week More than 20 Acres 13 acres under tea, about 2 acres pasture 0.5 acres available
3	**Water** Main source Do you have a metering system? Consumption volume(M^3)	 River, pumped to site No 2-3m^3/Day
4	**Available Waste** Type of solid waste Type of waste water Disposal method **Comments on waste disposal status** No. of ponds/lagoons **Other Waste Source**	 Cow dung from 21 cows in stables Washing/wastewater, 2-3m^3/Day Trench to farm Wastewater flows along a trench to lower ground which has tea bushes and nappier grass NA None
5	**Potential uses of biogas** Heating Electricity	 1) Pasteurising milk 2) Cooking for the workers and main house Farm is grid connected
6	**Potential uses of bio slurry:** Own use Sale	 13-acre tea farm around the dairy
7	**Other Comments**	High potential for medium scale bio digester with the aim of replacing firewood. Cost of firewood at about KES.15000/per month Dairy uses an old firewood boiler to generate steam for pasteurising milk. The boiler needs repair at an estimated cost of KES.500,000. The boiler can be replaced by a biogas-powered pasteuriser which will be cheaper and cleaner than the current usage of firewood. Electricity bill is KES30,000 per month

Figure 12 - Wood-powered boiler for milk pasteurising on the left and zero grazing unit with 21 cows on the right (Source: © GIZ – Peter Gichohi).

Sisal sector

Sisal is a plant that is grown to produce a fibre used in the textile industry. Kenya is the third largest global producer with 22,800 tonnes per year (FAOStat, 2020). Biogas potential is available for the leading 10 sisal estates (GTZ, 2010). In Kenya, there are ten sisal plantations with a total area of 34,624 Ha in 2019 (Fibre Crops Directorate 2019).

Table 14 - Main sisal estates and their locations and counties with smallholder sisal producers (Source: Kenya Export Promotion and Branding Agency 2022)

County	Name of Estate	Area (Ha)		County with smallholders	Area (Ha)
Kilifi	Kilifi Plantation	610		Machakos	10
	Rea Vipingo	4,640			
Kwale	Agro processors Ltd	5,880		Kitui	483
Taita Taveta	Voi Estates,	850			
	Teita Estates	10,674			
Makueni	DWA Estate	5,250			
Nakuru	Majani Mingi	968		Homa Bay	176
	Athinai	1,088			
	Lomolo	2,144		Migori	408
Baringo	Mogotio	2,520			
	Total Area (Ha)	**34,624**		**Total Area (Ha)**	**1,077**

The sisal estates are in Kilifi, Makueni, Taita Taveta, Baringo and Nakuru counties. Smallholder sisal farming is spread countrywide with a concentration in:

1. Eastern region - Machakos, Makueni and Kitui counties
2. Nyanza region - Homa Bay, Migori and Siaya counties
3. Rift Valley - plantation farms in Mogotio area in Baringo county
4. Coast region - Kilifi county.

Over 90 % of sisal produced in Kenya is exported to various destinations in the world and the rest is sold to the local cordage and cottage industries.

Small pockets of production by small holder sisal growers are spread all over the arid and semi-arid lands of the country, forming about 5% of the total production. Smallholder sisal is mostly grown as a boundary crop and along contours as hedge rows for soil conservation. Most of it is not grown for harvesting. However, because of improved incomes from the crop, farmers have started planting it as a stand-alone crop in their farms. Area under this crop is estimated at 2,500 acres.

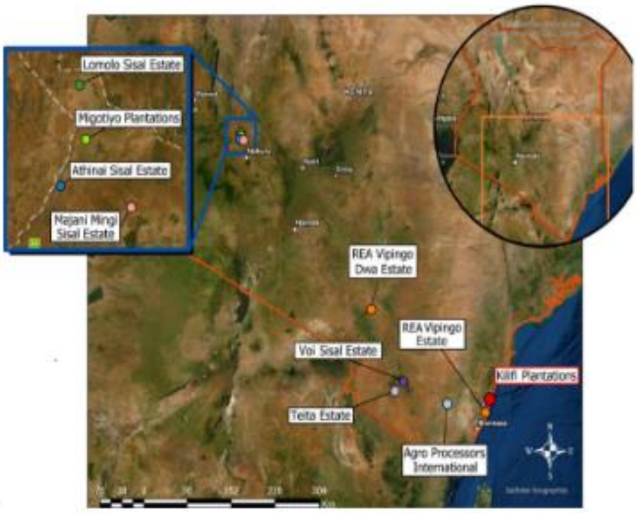

Figure 13: Location of sisal estates in Kenya: (Rural electrification masterplan-2009)

Biogas potential from sisal production

Fibre makes up only 5% of the fresh sisal leaf, with the balance discarded as a blend of solid and liquid residues during the decortication (crushing) process (Mshandete, et al. 2005). This wet residue is well-suited to anaerobic digestion to produce biogas to generate heat and electricity.

The production of one ton of clean and dry fibre will produce about 19t of waste (depending on the production, this is diluted with about 5 tons of water from the washing). A biogas production rate of 0.4 m³/kg VS has been observed during studies led by the Danish Technology Institute (DTI). This corresponds to a typical gas yield of about 54 m³/t of waste. Using typical figures on biogas composition and engine efficiency, this would be sufficient to generate about 1750 kWh per ton of Sisal Waste Pulp.

Table 15 - Biogas potential from sisal waste – adapted from (GTZ, 2010).

Sisal waste-biogas potential based on 2021 sisal production					
Commodity	Unit	Year 2021	VS Content [% DM]	Biogas potential [523m³/ton VS]	Electrical energy [MWh/Yr]
Sisal Export-2021	Ton	31,152.10			
Sisal Waste (95%)-Pulp	Ton	591,889.9	85%	503,106.42	1,006.21

The total mean biogas potential is estimated for the 10 estates at 503,106.42m³/year or 138m³ per day per estate or 923kWh of electricity per day. This will be the equivalent of a biodigester with 400m³ capacity for each of the 9 estate without a biodigester.

Case study of Kilifi Plantations

Kilifi Plantations is the only sisal company in Kenya using decorticator residues (sisal waste) for the generation of biogas and subsequently utilising it for electricity production for its own consumption. The 750m³ biodigester was commissioned in 2007. The biogas produced can power 150 kW_{el} consisting of two 75kW biogas generators for on-farm electricity consumption. Four tons of feedstock is used daily consisting of a mixture of dung from 200 cows (40%) and sisal waste (60%). The bioslurry is utilized as a fertilizer on the farm.

Figure 14 - Sisal pulp and biodigester at Kilifi plantations - © GIZ - Peter Gichohi

Wastewater treatment plants

Water service providers in Kenya are water companies created after the enactment of the Water Act 2002 to manage water resources in Kenya. Water services providers are also responsible for the management of wastewater arising from water use. They are public entities largely referred as Water and Sewerage Companies (WASCOs) which are in all counties. These WASCOs operate sewerage works within the municipalities. The sites for sewerage treatment are suitable for biogas harnessing from the sewage which makes the WASCOs sites potential candidates for medium scale bio-digesters. There are over 87 companies that provide water services in Kenya [IMPACT-Issue No 14. (2022].

Key installations in the sewerage works are anaerobic ponds which makes them attractive for biogas capture. Other installations are pumping stations which are ideal for retrofitting with biogas generated electricity. The table below shows the distribution of water companies in the counties. In the table, 27 counties have one water company each, while Kiambu county has 10 such companies.

Table 16 - Distribution of water companies per county (Source: IMPACT 2022)

No of Utilities	1	2	3	5	6	10
No of Counties	27	10	5	3	1	1
Counties	Mombasa Kwale Tana River Lamu Taita-Taveta Garissa Wajir Marsabit Isiolo Turkana West Pokot Samburu Trans-Nzoia Uasin Gishu Elgeiyo Marakwet Narok Kericho Bomet Kakamega Vihiga Bungoma Busia Siaya Kisumu Homabay Kisii Nyamira	Kilifi Mandera Kitui Nyandarua Kirinyaga Nandi Baringo Laikipia Migori Nairobi	Meru Tharaka-Nithi Makueni Nakuru Kajiado	Embu Nyeri Murang'a	Machakos	Kiambu

In 2020/2021, the water companies had 26,271,419 clients. A significant part of the sewage arising from the population served is received and managed in the existing sewerage works. However, during field visits to water companies, it was learnt a segment of that population is not connected to the sewerage works due to topographic constraints. Such population is served by containerized systems such as septic tanks and pit latrines. Some of the water companies have taken steps by installing decentralized treatment facilities (DTF) in such areas. These areas are ideal for adoption of medium scale biodigesters.

The sewerage works under water companies consists of a series of ponds through which the wastewater flows prior to discharge after attaining the required standards. Among these ponds are the anaerobic ponds, which are normally deeper than the others. At these ponds anaerobic digestion leads to intense emission of biogas to the atmosphere. Often, this contributes to the smell around such sewerage treatment works. The figure 15 shows gaseous eruptions that occur daily in such ponds.

Figure 15 - Gaseous eruption in the middle of anaerobic pond - © GIZ - Peter Gichohi

These facilities are compact and manage wastewater volume that can serve as input for anaerobic digestion (AD). Anaerobic digestion in wastewater treatment plant has the following advantage: water is already present at site, the energy produced can contribute significantly to the energy autonomy of the plant. The main disadvantage is that the biogas harnessed from municipal wastewater is lower than from animal manure (IEA, 2015). Data was collected for 7 wastewater treatment plants in Kenya. Based on (IEA, 2015), the net biodigester volume has been determined as follow:

$$\text{Net digester volume } [m^3] = \text{Hydraulic retention time [days]} \times \text{ Feedstock input } [m^3/\text{day}]$$

The hydraulic retention time is set at 20 days. The Kenyan Association of Manufacturers (KAM) commissioned a study in 2015 that shows that sewage from water companies is an important resource for the generation of biogas. No doubt, the projects sizes may be beyond the medium scale biodigester category for some companies' main treatment works. However, the trend of adopting DTFs by the WASCOs is a significant development which matches the medium scale biodigesters. The largest potential in DTF is from Isiolo (36,000m^3 biodigester), Narok (10,000 m^3 biodigester), Murang'a (3,806 m^3), Nyahururu (1,681 m^3), Nanyuki 1,194 m^3), Vihiga and Laikipia (1,000 m^3 each). However, these volumes represent a theoretical sizing. Introducing AD in Kenyan DTF will require a smaller pilot first qualifying for a medium scale biodigester (100 to 200 m^3) or several ones implemented in series.

Wastewater treatment plants case studies

Two case studies at wastewater treatment plant are presented below in Narok (NARWASSCO), Vihiga (AMATSI) and Laikipia (NYAHUWASCO) counties.

Table 17 - Potential for medium scale biodigester at Narok Water and Sewerage Company (NARWASSCO).

	County:	County: NAROK
1	**Name of Site**	NAROK WATER & SEWERAGE COMPANY (NARWASSCO)
2	**Information about site**	
	Type of activity	Provision of water and sanitation services
	Information about site	New sewerage works commissioned in 2022
		16km out of Narok town
		Design capacity-3500m^3/day
	Proposed Site	Decentralised treatment Facility (DTF) to handle wastewater from settlement clusters. Site 300m from office - opposite Narok Hospital. Site covered by new sewer along the river in the lower ground and along the road.
	Total Land size	About 3-5 acres for the proposed DTS
3	**Available Waste:**	
	Type of solid waste	No
	Type of wastewater	Sewage
	Disposal method	Ponds, Septic tanks, pit latrines
	No of ponds/lagoons	4No Anaerobic, 2No. Facultative, 6No.Maturation
	Sewer network	Main trunk commissioned. New connection under development
	Comments on waste disposal status	About 500 connections by the time of visit with a flow of 200-500m^3/day
4	**Potential uses of biogas**	
	Heating	Gas sale to Narok Hospital, and Narok MTC opposite the proposed site.
5	**Other Comments**	Settlements away from sewer trunk relying on commercial exhausters which must discharge to the new ponds 15km away at a high cost. Consequent to the above, raw sewage is being discharged to the new sewer trunk at remote localities especially at night to avoid transportation to the new ponds 15km away. This leads to frequent blockages. NARWASCO proposes the new decentralised treatment facility (DTF) at the site opposite the hospital. This can include medium scale anaerobic digesters. Exhauster trucks can discharge here while the digester effluent can be discharge to the new trunk sewer.

The figure below shows the proposed site for DTF and Narok referral hospital across the road.

Figure 4 - NARWASSCO-Proposed site for DTF with biogas capture and use in Narok County Referral Hospital (Source: © GIZ - Peter Gichohi).

Table 18 - Potential for medium scale biodigester at Vihiga Water and Sewerage Company (AWASCO – DTF)

	County:	County: Vihiga
1	**Name of Site**	AWASCO-DTF (Decentralised Treatment Facility)
	Year Established	2022
2	**Information about site**	
	Type of activity	Decentralised Treatment Facility
	Information about site	Receives wastewater from containerised residential areas within Mbale town. The wastewater is transported by exhausters owned by AWASCO and private individuals. The service is provided at a fee payable to AWASCO.
3	**Description of DTF**	
	DTF total land size	About 0.5 acres
	Structures	Two concrete tanks with manholes for each segment. A central vent is provided for each tank. There is a constructed wetland for post treatment of effluent prior to discharge to a nearby stream.
4	**Available Waste:**	
	Type of solid waste	Waste from pit latrines and septic tanks. Average of 6 exhausters (50m^3/day) discharge waste drawn from toilets and septic tanks into two tanks
	Fertiliser sales	Proposed treatment and package solids for sale as fertiliser
5	**Potential uses of biogas**	
	Heating	There is no provision of biogas recovery. The DTF is within a settlement with households that would benefit from the generated biogas.
	Bio slurry potential	Fertiliser sale will benefit the surrounding small-scale farms
6	**Other comments**	One tank with vent emitting methane to atmosphere. Provision for biogas capture is not provided. Exhauster charge is KES. 10,000 per truck payable by residents Discharge fee at DTF is KES.3,000 per truck

The figure below shows the commissioned site for the AWASCO DTF and surrounding homes.

Figure 5 - Location of AWASCO DTF (Source: © GIZ – Peter Gichohi).

Prisons in Kenya

Biogas potential in prisons

Potential of biogas production in each prison is a factor of population, existing wastewater management infrastructure, water supply and space available. A study conducted jointly by the Ministry of Energy and the Kenya Prisons Services (MoE 2013) found that some prisons have better chances than others to exploit this potential. Others have a better chance to utilize the effluent for other benefits such as growing of woodlots or food crops. Out of the 31 prisons visited then, a list of 15 prisons that have a good chance for exploiting their biogas potential is presented below. The table below shows the 15 prisons, which excludes the other 13 which already have constructed or were in the process of constructing such biodigesters. Three prisons do not have adequate wastewater collection system or sufficient space for the development of anaerobic biodigestion. It was observed in this study that the main feedstock for the prison biodigesters was wastewater except for a few prisons that have livestock.

Table 19 - Biogas potential in prisons

	Prison	County	Population*	Comments
1	Naivasha Main + Medium	Nakuru	3800 +	Utilize the existing sewer network to converge all waste to central treatment for biogas production. Treated effluent to be used to grow firewood and even commercial plantation in the expansive land.
2	Nakuru Main	Nakuru	2500 +	Utilize all waste to recover biogas.
3	Eldoret Main**	Uasin Gishu	2000 +	Utilize all waste to recover biogas. But there is a great risk of polluting the nearby stream. Great caution would be required to implement such a project considering the limited space between the stream and the prison boundary wall.
4	Kapsabet**	Nandi	500 +	It would be necessary to consider the utilization of the municipal sewer passing through the compound. The digester effluent should all be disposed back to the municipal sewer.
5	Kitale Main	Trans Nzoia	1000 +	Utilize all waste to recover biogas.
6	Bungoma**	Bungoma	1100 +	Utilize all waste to recover biogas. Effluent to be directed to the municipal sewer.
7	Kakamega Main	Kakamega	1300 +	Utilize all waste to recover biogas.
8	Thika Main** + Women	Kiambu	1400+	Though the space in limited, further site survey is required to determine whether municipal sewer can be tapped for biogas recovery.
9	Mwea	Embu	900 +	The new main septic tank can be modified to be a biodigester. There would however be challenges because of possible seepage of the canal water.

10	Nyeri Main** + Medium + Women	Nyeri	2000 +	There is a good chance for utilizing biogas. The waste from all three prisons can be used and combine the gas to be used in the main prison. There is sufficient land for effluent utilization.
11	Machakos Main**	Machakos	1000 +	There is a good chance for utilizing biogas not only from its own waste but from the municipal sewer line passing through the prison compound.
12	Langata women**	Nairobi	1300 +	There is a good chance for utilizing biogas. Further site survey required to establish if other Nairobi city sewer pipes passes through the compound.
13	Manyani		1000 +	There is a good chance for utilizing biogas. The new main septic tank behind block A can be modified to be part of the biogas digester system.
14	Shimo la Tewa - Medium	Mombasa	1000 +	There is a good chance for utilizing biogas, but the planning must take cognizance of the deep sewer pipe during the digester sitting.
15	Malindi Main	Malindi	1000 +	Utilize all waste to recover biogas.

Notes: * Estimated population of inmates and staff members.
** Negotiations between prison and local municipal council required before utilizing waste from the municipal sewer.

Existing biodigesters in prisons

Up to 2013, 13 prisons had constructed biodigesters or were in the process of constructing such biogas digesters. Discussion with prison staff who were trained to construct the biodigester indicated that no new biodigesters have been constructed since 2013. The table below presents the 13 prisons that have biodigesters.

Table 20 - Prisons with biodigesters

	Prison name	County	Digester Size (m^3)	Comments
1	Embu Main	Embu	124	Commissioned in March 2011
2	Embu - Women	Embu	124	
3	Kitui	Kitui	124	Commissioned in August 2012
4	Meru Main	Meru	124	Commissioned in 2008
5	Kangeta	Meru	124	
6	Kisumu Main	Kisumu	124	Commissioned in November 2012
7	Kibos	Kisumu	2x124	
8	Homabay	Homabay	124	
9	Kisii	Kisii	124	
10	Shimo La Tewa Main	Mombasa	2x124	
11	Kamiti Maximum	Nairobi	No info.	
12	Nakuru Main	Nakuru	No info.	
13	Nairobi Remand	Nairobi	No info.	

Case Study of Embu Prison

The implementation of the biodigester was motivated by the following factors:

- High cost of firewood.
- Need for hygienic human and animal waste management system.
- Need for a cleaner kitchen environment.

This is the first successful biogas project in the Kenya Prison Service (KPS) which was commissioned on 21st March 2011. The system consists of a 124m³ digester, a filtration bed and a baffled reactor. The waste is conveyed to the digester through a sewer network. The average inmate population is about 800 men. The prison owns five cows and 8 pigs whose waste is discharged into the same digester. The bio-slurry is spread to the nearby woodlot and Napier grass.

The benefits accrued through the construction of the biodigester are the following:

- Cleaner sanitary waste management, the previous cesspool overflowing with waste frequently.
- 30% savings on firewood, amounting to KES 583,920 annually by 2013. This is computed at 2.5kg/inmate /day and a cost of Kes. 2,400/ton.

Figure 16 - Biodigester at Embu prison (Source: © GIZ – Peter Gichohi)

Figure 17 - Biogas stove at Embu prison (Source: © Peter Gichohi)

Case study Narok Prison

Narok GK Prison is located within Narok town. The prison hosts 750 inmates and 600 resident staff. The prison officer in charge estimated that the volume of fresh water used per day by the total prison community to be about $81m^3$/day. The prison has its own wastewater treatment tank of approximate dimensions -14m x 3m x 3m depth ($126m^3$) with a rock filter downstream. The tank is new as there are no signs of resent overflow into the rock filter. The tank is partitioned into five chambers each with access manhole and a vent pipe.

On site discussions were held with the prison officer in charge, the resident trained biogas prison officer and the technical manager of NARWASSCO. The following points were considered for review as a starting point towards biogas production for this prison.

1. Since existing septic tank is new, a thorough design review is required to determine if it can be modified to become a biodigester with mixers and gas recovered to be stored in a detached storage prior to piping it to the kitchen.
2. Review on the use of digested sludge and effluent from the rock filter for farming downstream of the tanks.

Figure 18 - Narok prison location (Source: © - Google maps)

Prison staff trained in biodigester construction

During the visit, one senior prison officer who had been trained to build biodigesters provided a list of other prisons that have such skilled officers some of whom are still in the service while others have retired. The table below provides the number of the trained officers.

Table 21 - Number of prison officers trained in biodigester construction.

No	No. of officers	Station
1	1	Narok GK Prison
2	2	Kamiti GK Prison
3	1	Embu Men Prison
4	1	Kangeta Prison-Meru

GK Prisons Vihiga

The prison is located within Vihiga town a few meters from the county headquarters. Vihiga GK Prison has a resident population of about 170 inmates and 80 resident staff members including families. Water consumption was estimated at 20m^3/day. The prison relies on firewood for all its cooking needs.

Within the upper prisons compound is located a septic tank estimated at 500m^3 in volume. The septic tank receives wastewater from county HQs, Vihiga Referral Hospital with about 200 beds, hospital staff houses, administration police quarters, Valley Rural Hospital and Medical Training College within the hospital among other areas. Vihiga county director for water, sanitation and climate change estimated the volume of wastewater generation from all above facilities to be about 100m^3/day. Prison wastewater is not drained into this tank since its upstream of the prison. Instead, in the lower-middle ground of the prison compound, there is another septic tank of about 250m^3 in volume which is dedicated to receiving waste water from the prison compound.

Decentralized Treatment Facility (DTF)

Downstream of the 500m^3 septic tank, a biodigester has been constructed to receive effluent from the tank for biogas recovery. This was estimated to be 45m^3. Downstream of the biodigester are a series of ponds and wetlands to treat digester effluent before discharge to a stream. The construction of this decentralized treatment facility (DTF) was started in 2020/2021 though construction is currently on hold. When commissioned, the biogas generated will be used for cooking in the prison. The photo below shows the layout of the DTF.

Biogas recovery potential

Literature review on a study done by the Kenya Association of Manufacturers (KAM) for Nyahururu Water and Sanitation Company in 2015, showed that 580m^3/day of biogas can be generated from 2400m^3 of sewage. Applying the same gas production rate to the 100m^3/day of sewage flow into septic tank at Vihiga shows that biogas can be generated at the rate of 24m^3/day.

The feedstock of the DTF at Vihiga is however the effluent of the septic tank. There are chances that a significant amount of the gas has been generated at the septic tank and lost to the atmosphere through the tank vents. The biodigester downstream acts as a secondary biogas recovery unit.

Figure 19: Layout of DTF at GK Prison Vihiga (Source: © - Google maps)

Lessons learnt

To retrofit an existing wastewater treatment facility with a biodigester, there is need to enhance the skills of service providers with the aim of:

1. Ensuring the correct location of biodigester retrofits to maximize on volume of biogas captured.
2. Ensuring the correct volume of biodigesters with respect to the volume of feedstock upstream.
3. Broadening the knowledge base for service providers in respect to medium scale biodigesters.

Slaughterhouses in Kenya

Data was obtained from 12 counties regarding presence of 160 slaughterhouses and 26 slaughtering slabs. The monthly production (number and types of animals killed) was obtained for 148 slaughterhouses (SH) and 13 slaughtering slabs.

According to (Kabeyi, Moses & Olanrewaju, Oludolapo, 2021) and (Pagés Díaz, Jhosané, 2015), the solid waste quantity produced per each animal slaughtered is 15kg for camel, 10,35kg for cattle, 4,66kg for pig and 2kg for sheep and goats. According to the same sources, the solid to liquid ratio for anaerobic biodigestion of slaughterhouse waste is 1:2,5. Therefore the size of biodigester was defined for 148 slaughterhouses and 13 slaughtering slabs. Where the biodigestion potential was below 4m^3 (the smallest biodigester size available in Kenya), the site was discarded from the counting. The number of potential small-scale biodigesters (4 to 50m^3) is 108, medium-scale biodigesters (50 to 500m^3) is 18 and large-scale biodigester plant to (more than 500m^3) is 1. The table below present the potential per county in terms of overall biodigester volume for the three biodigester categories (small, medium and large-scale).

County	Biodigester category	Name of slaughterhouse and biodigester size
Kiambu	Medium-scale (50 to 500m^3)	Thiani SH (320m^3), Mumu (240m^3), Nyongara (223m^3), Kikuyu Cooperative (178m^3), Bahati-Limuru (80m^3), Thika SH (64m^3)
Kiambu	Small-scale (4 to 50m^3)	Ndumboini SH (46m^3), Ruiru SH (40m^3), Gatundu SH (24m^3), Jujash (24m^3), Muiru SH (24m^3), Mang'u SH (20m^3), Kanunga SH (14m^3), Limuru (14m^3), Kamwangi (14m^3), Ginthunguri SH (13m^3), Lari SH (13m^3), Murera SH (13m^3), Kanyoni (10m^3), Kagwe SH (10m^3), Karia SH (9m^3), Ngewa SH (8m^3), Turi SH (8m^3), Juja Farm SH (6m^3), Kibichoi SH (6m^3), Kimende SH (6m^3), Githiga SH (5m^3), Gachika SH (5m^3), Gathage SH (5m^3), Kiganjo SH (5m^3), Muguga SH (5m^3), Mundoro SH (5m^3), Ngoliba SH (5m^3), Ruiru Pig SH (4m^3), Gitwe SH (4m^3), Mugiko SH (4m^3), Ndumberi SH (4m^3), Ritho SH (4m^3), Tinganga SH (4m^3), Gakoe (4m^3).
Uasin Gishu	Medium-scale (50 to 500m^3)	Cyrus SH - Kapsoya (326m^3), Matunda SH (229m^3), Racecourse SH (195m^3), Cheptiret SH (156m^3), Mwamba SH (116m^3)
Laikipia	Medium-scale (50 to 500m^3)	Laikipia 12 (422m^3), Laikipia 20 (353m^3), Laikipia 8 (70m^3),
Garissa	Large-scale (≤500m^3)	Garissa Slaughterhouse (Sankuri Road - 716m^3)
Garissa	Small-scale (4 to 50m^3)	Masalani Slaughterslab (Gumarey - 23m^3)
Isiolo	Medium-scale (50 to 500m^3)	Isiolo town (218m^3)
Isiolo	Small-scale (4 to 50m^3)	Merti Town (6m^3)

County	Biodigester category	Name of slaughterhouse and biodigester size
Nyandarua	Small-scale (4 to 50m^3)	Olkalou SH (37m^3), Gwakung'u (20m^3), Engineer (18m^3), Mirangine SH (14m^3), Wanyika SH (13m^3), Rironi (12m^3), Umoja (11m^3), Fly over (10m^3), Ndunyu Njeru (9m^3), Gwa Kahii (9m^3), Tumaini SH (9m^3), Murungaru (9m^3), Karangatha (8m^3), Miharati (8m^3), Kasuku (7m^3), Oljororok (7m^3), Njabini A (6m^3), Wanjohi (6m^3), Shamata (5m^3)
Kilifi	Medium-scale (50 to 500m^3)	Vipingo Slaughterhouse (61m^3), Uwanja wa Ndege Slaughterhouse (58m^3)
Kilifi	Small-scale (4 to 50m^3)	Rabai SH (35m^3), Malindi SH (29m^3), Kilifi SH (17m^3), Kaloleni Slaughterslab (11m^3), Tumaini Slaughterslab (4m^3)
Vihiga	Small-scale (4 to 50m^3)	Mukhalakhala SH (34m^3), Mudete Slaughterslab (20m^3), Lunyerere SH (19m^3), Serem (17m^3), Majengo (16m^3), Boyani (14m^3), Jeptulu (12m^3), Mago Slaughterslab (12m^3), Mahanga (7m^3), Ematsuli (6m^3), Esibuye (6m^3), Gambogi (6m^3), Gisambai (5m^3), Hamisi SH (5m^3)
Taita Taveta	Medium-scale (50 to 500m^3)	Kasarini House (97m^3)
Taita Taveta	Small-scale (4 to 50m^3)	Mwatate SH (40m^3), Werugha Slaughterslab (10m^3), Bura SH (9m^3), Kasighau Slaughterslab (8m^3), Maungu Slaughterslab (7m^3), Tausa SH (6m^3)
Busia	Small-scale (4 to 50m^3)	Busia Town SH (24m^3), Malaba SH (24m^3), Sio port bovine Slaughterslab (16m^3), Nambale SH (14m^3), Mundika bovine Slaughterslab (13m^3), Bukiri (11m^3), Bumala SH (11m^3), Sisenye / Port Victoria (6m^3), Butula Slaughterslab (6m^3), Mundika pig Slaughterslab (6m^3), Nambale pig Slaughterslab (5m^3), Amerikwai Slaughterslab (5m^3), Mumbwayo (4m^3), Funyula Slaughterslab (4m^3)
Bomet	Small-scale (4 to 50m^3)	Saunet – Chemagel ward (19m^3), Kapsimotwo - Township (18m^3), Kaplong – Chemagel ward (17m^3), Mulot (14m^3), Chebunyo (12m^3), Sigor (10m^3), Ndanai (8m^3), Siongiroi (7m^3), Chebilat - Rongena (7m^3), Kembu (6m^3), Kipsonoi ward (6m^3), Longisa (5m^3), Olbutyo (4m^3), Makimeny (4m^3).

Table 22 - Potential of biodigester for slaughterhouses per county (Source: authors calculations)

Coffee sector

Kenya's coffee sector employs about 30% of Kenya's agricultural labour force – roughly 5 million people – directly affecting the livelihoods and economic status of more than 800,000 rural households (ICO, 2019). The bulk of coffee waste is generated during wet milling operations all within the coffee growing areas. The farmer delivers the coffee cherry at the wet mill upon which it is weighed and recorded which forms the basis for his coffee earnings.

The delivered cherry has several layers: the innermost green coffee bean, silver skin, parchment, pulp/mucilage, and skin. The layers surrounding the bean provide protection, and as the coffee fruit matures, the mucilage softens which helps to release the seed during pulping. The bean is the most valuable part of the coffee fruit because it is the product sold to coffee buyers. A freshly harvested coffee cherry has a moisture content of approximately 65% and the coffee bean has a 10 - 12% moisture content when ready for consumption (clean coffee). During the initial stages of washed processing at the wet mill, the skin, pulp, and mucilage are removed to leave the coffee bean surrounded by a silver skin and parchment layer. This is called parchment coffee and is carefully dried, stored, and transported to the dry mill for milling. Of interest to this study is the skin, pulp, and mucilage and the arising wash water, the waste generated at the wet mills.

Pulp Generation

From key informant interviews, it was understood that the conversion ratio of Cherry: Parchment: Clean Coffee is 7:5:1. Further on-site calculations generated the following ratios, Cherry: Pulp: Mucilage: Parchment: Clean Coffee = **7:** 1.6: 0.4: 5: 1 which introduced two waste products (pulp and mucilage) in the ratios. This means that every 7 ton of cherry processed at the wet mill yields 1.6 ton of pulp, 0.4 ton of mucilage, 5 ton of parchment and 1 ton of clean coffee

Pulp and mucilage are removed at the 577 cooperatives doing pulping wet mill while the parchment is removed at the 22 parchment mills. Wet milling has the advantage of involving water in the process. According to (GTZ, 2010) coffee pulp and mucilage have a Volatile Solid content of 93% Dry Matter and a biogas potential of 390m^3/ton Volatile Solid (German Biomass Research Centre, 2010).

Figure 20 - Wastewater and pulp generation in coffee wet mills (Source: © GIZ – Peter Gichohi)

It is important to note that the feedstock is present at the mill only during the two harvest periods: the fly crop in May to July and the main crop in September to December. From January to March, there is no coffee waste available at the mill. Out of the 577 wet mills in Kenya, 56 have biogas potential below the size of the smallest domestic system in Kenya (4 m^3), 205 will qualify for a domestic biodigester (4 to 50 m^3), 255 for a medium scale biodigester (50 to 500 m^3) and 61 for an industrial biodigester (500 to 10,000 m^3). The largest potential is found in

Kirinyaga (11,195 m^3 biogas / day from 16 plants), Nyeri (6,470 m^3 biogas / day from 24 plants), Kericho (4,893 m^3 biogas / day from 81 plants), Murang'a (4,537 m^3 biogas / day from 43 plants) and Bungoma (3,650 m^3 biogas / day from 49 plants).

Harnessing this resource would result in sustainable consumption and production practices. It would help in meeting some of the energy needs in the wet mills and nearby homes. Furthermore, the current practice at the wet mills is for farmers to collect the pulp and use it as a manure in their farms. If pulp was first used to generate biogas, it would be necessary to adjust the pH from its current acidic form by for instance adding cow manure. The digested bioslurry is a better biofertilizer than the non-digested wet coffee pulp due to the acidity of the latter.

Table 23 - Biogas potential at coffee wet mill per county (Source: AFA, 2022)

County	Total clean coffee produced (t/year)	Biogas potential in m^3 / day
Kenya	**22,841**	**45,363**
Kirinyaga	5,637	11,195
Nyeri	**3,258**	**6,470**
Kericho	2,465	4,893
Murang'a	**2,293**	**4,537**
Bungoma	1,838	3,650
Meru	**1,451**	**2,881**
Embu	1,429	2,838
Kiambu	**1,185**	**2,354**
Nandi	**808**	**1,605**
Tharaka Nithi	781	1,551
Machakos	517	1,027
Kisii	265	526
Nakuru	**235**	**466**
Nyamira	157	312
Baringo	136	270
Trans Nzoia	97	193
Migori	93	184
Elgeyo Marakwet	47	93
Makueni	41	81
West Pokot	32	65
Bomet	**21**	**41**
Homabay	14	28
Kakamega	**14**	**27**
Narok	9	18
Uasin Gishu	**9**	**18**
Laikipia	4	9
Busia	4	8
Kisumu	1	1
Vihiga	0	1

Case study Kiandu coffee mill

Kiandu coffee factory started its operations in the 1970s. There is a secondary school nearby which utilizes firewood for cooking. Biogas generated from the pulp can be piped and sold to the school. The mill relies on direct water pumping from a nearby stream since its creation. The water usage is not metered, and the management would not provide an accurate estimate of volume for coffee processing. This is the trend in most coffee factories which are located next to rivers and streams for ease of water supply. The recommendations by coffee stake holders are to reduce, reuse, recycle water; to treat wastewater and to undertake continuous improvement to attain sustainable production practices. There are a few small scale and individual millers that have embraced water efficient pulpers. The change requires making costly investments to change the existing infrastructure.

Flower sector

Today there are about 220 flower farms in Kenya, about 70 of them are located around Lake Naivasha. Flowers have become an important economic sector and, along with tea, one of the country's key exports (Bettervest, 2019). Kenya is the third largest producer of fresh cut flowers worldwide after Colombia and Ecuador (KFC, 2022). The volume of exported cut flowers was 176,372 tons in 2021 (ITC, TradeMap, 2021) for an area of 3,850 ha of flower production (AFA, 2020). The leading counties in flower production are Nairobi, Kiambu, Nakuru, Kericho, Nyandarua, Transnzoia, Uasin Gichu, Nyeri, Laikipia, Machakos, Meru, Kirinyaga, Embu, Murang'a and Kajiado (Kenya trade).

The flowers are exported to over 60 destinations globally. But what is largely unknown is the large volume of flower waste generated in the production and packaging processes in the farms. Cut flowers produce two types of waste: the foliage and the fresh stems. Foliage is more digestible than fresh stems due to a lower ligneous content. Stems are also covered with wax for preservation during transport. Between 2011 and 2013, the Ministry of Energy partnered with Kenya Flower Council to undertake a feasibility study to establish whether flower waste can be used to generate electricity.

That study successfully established two pilot projects utilizing flower waste to generate biogas. The gas was used to run biogas powered electric generators. The projects are currently in operation at Simbi Roses in Thika and P J Dave Flowers at Isinya running a 69kVA and a 125kVA biogas generators respectively.

Later, around 2013, a 2MW biogas power plant was commissioned at Gorge Farm in Naivasha. Though the original feedstock was intended to be other farm waste, shortage of such waste caused the operators to widen the waste scope to include flower waste. This has demonstrated the potential of flower waste for use in medium and industrial scale biogas systems. A 42-hectare farm is producing 2.8 tons of foliage waste per day.

The Simbi Roses farm has 25 hectares and a 200 m^3 biodigester to run a biogas-fuelled generator of 55kW 2-3 hours a day to power water pumps at the dam and fertigation station. The Bohemian Flowers farm has installed a 326 m^3 biodigesters based on ten 10 x 20 feet containers. The biodigester treats 1.4 tons of waste per day to run a 20kW generator and to compress biogas used in the farm kitchen. We estimate that the average size of flower farms in Kenya is 17.5 ha. This average farm will produce 1.17t/day of foliage waste all year long which could feed a 140m^3 biodigester. To our knowledge, there are four biodigesters installed at flower farms in Kenya: Simbi Roses in Thika running a 69kVA generator, PJ Dave Flowers running a 125kVA generator, the 2MW biogas power plant commissioned at Gorge Farm in Naivasha feeding the Kenyan grid and the Bohemian Flowers farm in Naivasha with a 20kW capacity. Therefore, the potential at flower farms in Kenya is 216 medium-scale biodigesters of 140 m^3 capacity.

Review of operations in flower farms

The farms consist of blocks of greenhouses of several hectares where the roses are grown in hydroponic systems using pumice as the planting media. The required rose plants nutrients are supplied through drip irrigation systems. On maturing, daily harvesting of the roses takes places continuously throughout the year until such a time when the roses are uprooted and replaced with new ones.

The farms main energy source is the national electricity grid which is connected to the farms. Nearly all the farms have diesel generators that supply power during grid outage.

Upon picking and transporting, the roses are received in the pack houses. In the pack house the roses are defoliated sized and packed ready for export. Large amounts of flowers leaves are generated as they are stripped off the flower stem by both machine and by hand.

Each farm has pumping stations at different locations depending on water source from where all water is pumped to the reservoirs. Another set of pumps are installed in fertigation stations in which the water is injected with fertilizers through the complex fertigation systems. The stations are manned and monitored continuously throughout the operations.

Figure 9 - Flower waste at dump Site - © GIZ - Peter Gichohi

The waste generated at the farms consists of trimmings of foliage and stems from the green houses and pack houses. There is also the whole plant uproots from old flowers that are uprooted for replacement. All these are generated and dumped daily at the designated dump sites within the flower farms. Some of the dump sites are expansive blocks of land. After a few years, when part of the waste has decomposed it is spread out in the area to allow for more waste to be brought in.

Figure 22 - Fertigation pumps – © GIZ - Peter Gichohi

Figure 23 - Foliage in pack house – © GIZ Peter Gichohi

Case study of Primarosa Flowers – Nyandarua county

Primarosa Flowers is located at Ol Joro Orok on the eastern side of Lake Ol borosat, about 190km north of Nairobi in Nyandarua County off Ol Joro Orok – Nyahururu road.

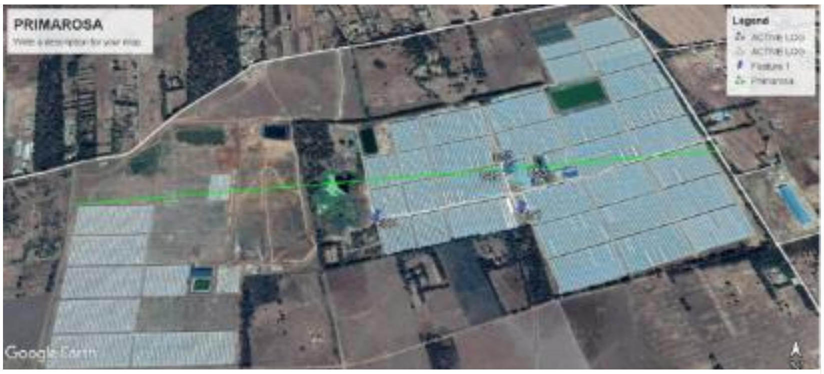

Figure 10 - Satellite view of the Primarosa flower farm – (Source: © Google Earth)

The farm has 42 hectares under greenhouses and cultivate roses of different varieties. The farm employs about 700 workers, all of whom are non-residents: they travel to the farm every morning. Lunch is provided by a private caterer who cooks for the workers using his own fuel (firewood). The primary energy source is the national electricity grid. During outage the farm runs diesel generators.

In the Feasibility study on biogas potential at Primarosa flowers (KAM, 2020), on-site measurements were undertaken to estimate the amount of waste generated at the farm. The table below shows the estimation of waste production from both old and new farms which are known as P2 and P3 within Primarosa.

Table 24 - Waste generation at Primarosa farm (Source: KAM, 2020)

Primarosa Flowers	Total biomass waste generation. (Ton/Day)	Foliage (leaves) waste for AD. (Ton/Day)	Mixed waste (leaves + fresh stems) (Ton/Day)
Old Farm-P2 (43Ha)	1.4	2	3.4
New Farm-P3 (17Ha)	0.6	0.8	1.4
Projected Daily Total	2	2.8	4.8
Projected Annual Total	730 ton/yr.	1,022 ton/yr.	1,752 ton/yr.

The amount of flower leaves available as direct feedstock for a biodigester is 2.8ton/day. This amount does not require additional effort of segregation. There is an additional 2ton/day consisting of flower leaves mixed with some stems in lower proportion. Since the stems and other woody biomass are not suitable for wet digestion, these requires to be segregated.

Case study of Simbi Roses-Kiambu county

The Simbi Rose farm is in Thika, Kiambu county. The farm is situated within a large coffee estate. The farm was founded in 1995 with an original size of 2 hectares which has now increased to about 25 hectares. The biogas system at Simbi Roses uses only flower waste as feedstock. The general layout of Simbi Roses' biogas system is as follows: the system purely uses shredded flower waste and has a digestate capacity of 200 m^3 and a gas chamber of $80m^3$ capacity. The capacity of the biogas-fuelled generator is 55kW. It is a three-phase system. The project was set up as a feasibility study to establish whether flower waste can be used to generate electricity.

The waste is shredded in the receiving area. Two hydrolysis tanks receive the shredded waste. The tanks have automated mixers that operate for 24 hours. A solar water heater heats the hydrolysis tanks. A 200m^3 biodigester is covered with a membrane to collect the biogas. The digester has an automated mixer. The produced biogas is desulfurized before being pump to the generator. A 69kVA Combined Heat and Power (CHP) engine produce electricity and heat the generator.

The 55-kW biogas generator runs 2 to 3 hours a day on average to power the water pumps in the dam and fertigation station. This gives a total electric loading of about 36 kW when the load is connected to the generator. The generator is loaded only to a maximum of about 65%. At full gas storage (80m^3) the generator operates at 65% loading for up to 4 hours projecting a gas consumption of about 20m^3 per hour. The slurry is utilized directly in the green houses. A slurry pipeline has been installed to the greenhouses nearby. The slurry is applied manually using hose pipes as in the photo below.

Figure 25 - Simbi Roses biogas plant

Figure 26 - Slurry application at Simbi Roses - © GIZ - Peter Gichohi

Case study of Bohemian Flowers-Nakuru county

The pilot digester at Bohemian Flowers serves as an interesting case of dry digestion of flower waste, a technology that is not common in Kenya. Below is a presentation of the pilot study project.

Table 25 - Dry digestion pilot study project at Bohemian Flowers.

	County:	Nakuru
1	**Site information**	
	Name	Bohemian Flowers, Naivasha
	Year Established	2020
	Type of activity	Operation of pilot dry digester utilizing flower waste
	Project background	The pilot project was started in 2020 through the partnership of UK government, Qube Renewables, University of Wales and Grants Biotech ltd which is the operator on site.
	Investment	KES 20-25m in 2020 (70% UK grant, 30% from other partners)
2	**Information on the biogas plant**	
	Feedstock	Flower waste
	Digestion process	Dry digester
	Equipment	10 digesters in 10 x 20ft containers
		Gas storage bag and raw gas compressor
		20kW Biogas CHP
		Compressed raw gas used in kitchen
		Testing lab
3	**Water:**	
	Main source	Farm supply
	Gas metering system	Gas is metered for each digester and all other areas of operation.
4	**Available Waste:**	
	Type of solid waste	Unsorted flower waste from pack house
	Waste generated	6Ton/Day x 7 Day/Week = 42Ton/Week
	Disposal method	Composting site
	Waste used	5Ton/Day x 2 times/Week = 10Ton/week
	Excess waste	32 Tons per week of unused waste
	Projections	30 more biodigesters required to utilize all the produced waste
5	**Gas Production**	Each digester produces 230-320 m^3 biogas per 5-ton loading (46-64m^3/Ton) of flower waste 180m^3 CH_4/Ton VS 1620m^3 biogas produced per biodigester since inception
6	**Digester Loading**	3 Steel cages of 1.5-1.8 ton in each digester. Hydraulic Retention Time is 42 days Small bags with magnetite nanoparticles ($Fe3O_4$-NPs), attached to each cage to help enhance the hydrogen trophic/volatile fatty acid interspecies electron transfer.

7	**Digester operations**	The three cages sealed in a gas bag and container closed. Temperature controlled digestate pumped into the container (26-28ºC) The biogas generated flows to the gas bag through the gas meters H_2S scrubbing through activated carbon in sealed tank Currently all 10kw power is used in the operation of digesters (pumping). Digester heating sources: genset heat, solar heat pipes, 6kW immersion heater. Volume of waste reduced by half during the digestion period Occasional dosing of micronutrients to sustain bacteria.
8	**Gas Compression**	3kw COLTRI CNG compressor operating at 200-250bars Cylinders are 62.8kg with a maximum pressure of 450bar. Gas compressed to 60bar in 4 cylinders each taking about 10m^3 of raw biogas.
9	**Projections**	1) Separation of methane and carbon dioxide. 2) Use methane to heat green houses. 3) Use CO_2 in green houses to enhance plant growth

Biogas purification and bottling

The main constituents of biogas are methane (CH_4 - 50% to 75%) and carbon dioxide (CO_2 - 25% to 50%) and various trace gases such as ammonia (NH_3), water vapour (H_2O), hydrogen sulphide (H_2S), methyl siloxanes, nitrogen (N_2), oxygen (O_2), halogenated volatile organic compounds (VOCs), carbon monoxide (CO) and hydrocarbons (Olumide Wesley et al 2018). These contaminants presence and quantities depend largely on the biogas source i.e., feedstock such as cow dung, agro processing waste, sewage, pig dung chicken dropping etc.

The removal of these contaminants especially H_2S and CO_2 will significantly improve the quality of the biogas for its further uses such as internal combustion engines or to increase its portability for uses far from the biodigester sites. H_2S is a corrosive gas, and its presence can damage engines. On the other hand, CO_2 is not a combustible gas and reduce the combustibility of the biogas mixture. The end uses of biogas will determine the extent of purification as demonstrated in three case studies outlined below.

Keekonyoike biogas bottling

Keekonyoike is a company that began operations in 1982. It runs an abattoir that slaughters about 100 cows per day to meet the meat demand in Nairobi and its environs. In 2008, with the support from GTZ, the company constructed two 124m^3 biodigesters that would help manage the abattoir waste, which was becoming a health and pollution hazard. Within a short time, the biogas being produced from the digesters was more than the company could absorb. The company managers started thinking of compressing and bottling the excess biogas, but they needed support to test the technical and commercial viability of their idea.

With financial support from KCIC, Keekonyoike made efforts to bottle raw biogas using modified 6kg LPG gas cylinders and regular air compressors. They also made attempt to compress biogas into old car tyres. However, this initiative did not progress to the commercial level because the gas available was not sufficient to meet the local fuel demand.

Figure 27 - Branded biogas cylinders used by Keekonyoike – © GIZ – Peter Gichohi

Olivado biogas bottling plant

The biogas bottling plant consists of two main components: biogas purification and compression/bottling of biomethane. The commercial scale purification and bottling equipment was sourced from India. In September 2018 the installation was completed, tested and commissioned ready to produce purified biomethane with a methane content of 97%. Since then, this purified biomethane is supplied to two natural gas CHP generators. The excess gas was intended to be compressed and bottled for use as a vehicle fuel and substitute for petrol. Unfortunately, the company is yet to find an agreement with the treasury for the importation of vehicle conversion kits to biogas.

Figure 28 - Olivado purification and bottling plant. From left to right: purifier, compressor, gas cylinders - © GIZ - Peter Gichohi

Bohemian Flowers biogas bottling

Biogas bottling at Bohemian Flowers consists of three stages. In the first stage, the raw biogas is pumped through a H_2S scrubber consisting of activated carbon in a sealed tank. After this, the biogas ($CH_4 + CO_2$) is compressed using a 3kW Natural Gas Compressor capable of compressing the gas to 200-250bars. However, the gas is compressed to 60bar using grid electricity or the biogas retrofitted generator. Finally, the compressed biogas is bottled in cylinders. Each cylinder weighs about 62.8kg and has a maximum pressure limit of 450bar. Since the gas is compressed to 60bar each cylinder takes about $10m^3$ of raw biogas. Four cylinders are mounted on a trolley for ease of transportation for short distances. The gas is used at the farm for the cooking needs of the employees.

Figure 28 - Bohemian compression and bottling plant – © GIZ Peter Gichohi

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