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MASTER THESIS

Technical Feasibility Study of Biogas Production for Residential Applications: Case of a community of Manwi District in Ngaoundere - Cameroon

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DECLARATION

I **Waffo Bénédicte MEGNE**, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other work presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

ABSTRACT

ACKNOWLEDGEMENT

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LIST OF ABBREVIATIONS

CO_2	Carbon dioxide
KV/KVA	Kilovolts/Kilovolts Amperes
NPV	Net Present Value
m/s	meters per second
l/s	litres per second
$/USD	United States dollars
€	Euros
FCFA	Franc de Colonais Française d’Afrique

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1 CHAPTER ONE: INTRODUCTION

1.1 Background of study

Waste disposal is the main issue nowadays as it contributes to climate change. In subsaharan context, unplanned urbanization with an increasing population will lead in the future to huge amount of waste. For instance, Ngaoundere 3, a locality in Cameroon is facing drawbacks of poor waste management with a tremendous increase of the population. Among these drawbacks, we have high exposure to malaria, water bone diseases, and more CO2 emissions leading to climate change. Hence, there is an urgent need to think about solutions aiming to manage waste efficiently with less environmental impact.

Energy production from waste is actually the appropriate solution for subsaharan countries where the rate of access to clean water and energy is low. [8].In Cameroon, almost 64.1% of the population relies on biomass mostly wood and charcoal [7]. With this high reliance on biomass, Cameroon is loosing its high potential of forest, which favor desertification, drought, then reduce hydropower potential and increase the energy gap. Currently, recurring power shortage is now a handicap for business owners and students. Poor access to water is shown through recurrent cases of water bones diseases like typhoid fever. Concerning access to water, although hydropower projects are implemented, energy transmission is still a challenge due to scattered settlement of the population .Thus, sustainable distributed electricity generation from waste is an opportunity to increase the rate of rural electrification while solving waste management issue in Cameroonian context.

Waste entails biomass wastes (agricultural crop wastes, forest residues, animal manure, organic waste) and Municipal solid wastes. The first resources mostly found in rural areas form a potential solution for electricity and water access through anaerobic digestion technology.

1.2 Problem Statement

1.2.1 State of the art

Anaerobic digestion of animal waste for biogas production has become a subject widely studied and adopted technology worldwide for its output which is biogas helps in solving pressing development issues like food security, clean energy capacity, climate change mitigation and adaptation, economic improvement [1]. Biogas production is an anaerobic digestion process whereby bacteria existing in oxygen-free environments decompose organic matter such as animal manure [2]. Anaerobic digesters are designed and managed to accomplish this decomposition. As a result of this digestion, organic material is stabilized and gaseous byproducts, primarily methane (CH_4) and carbon dioxide (CO_2) are released.

Ranges of temperature of operation in anaerobic digestion are either mesophilic (20-45°C) or (45-60°C).

All countries in the central east-west band of Africa suffer major health and sanitation problems. Many of these countries have the potential to improve their sanitation through use of domestic biogas digesters, and improvements in the technology may further increase the potential for use of biogas digesters [3]. Small scale biogas plants are increasingly adopted in SSA rural communities such as Tanzania, Kenya, Rwanda, Burkina Faso, Mali, Uganda, Cameroon [4] in the framework of pilot projects. In Cameroon for instance, a previous pilot domestic biogas technology phase has been implemented by a partnership between the Netherlands Development Organization (SNV) Cameroon, Heifer Project International Cameroon and the Ministry of Water and Energy (MINEE). The biogas project was thus intended to directly benefit 100 resource limited households with 800 dependents by adopting domestic biogas technology into integrated dairy cattle farming. The project contributes to achieving GEF SGP objectives on land degradation and also to the government of Cameroon's National Energy Plan for Reducing Poverty (PANERP) through increased access to (renewable) energy in rural areas. Scientific literature gathered have always their case studies in rural communities of the North and South West regions where some pilot projects have been implemented [4-6]. In other regions like Yaounde, biogas projects are mostly related to municipal waste management.

1.2.3. Knowledge gap

Until now, several case studies in the region are focused on biogas production through anaerobic digestion or co-digestion for cooking with animal manure and/ or agriculture waste as primary resource. Electricity generation potential from anaerobic digestion hybrid system is still unexplored.

For our master thesis research, we will focus on electricity production for access to water from anaerobic digestion in Manwi district located in Ngaoundere where the population relies on agriculture and stock farming (hens and pigs).

1.3 Research question

- What is the livestock potential in Manwi community of Ngaoundere?
- What is the energy potential from biomass?

1.4 Research Hypothesis

- Does the energy potential can supply to the energy needs of that community?
- Can the energy produced be sufficient for water supply added to the community energy needs?

1.5 Research objectives

1.5.1 Main objective

- to get an overview of livestock potential and their respective energy potential in that area

1.5.2 Specific objectives

The specific objectives are:

- Available animal manure assessment;
- Assessment of potential energy available from animal waste;
- Assessment of energy needs covered

1.6 Significance of the study

As anaerobic digestion system for electricity generation is new especially in Africa, our study will serve as baseline for further research about this type of system and future design and meet sustainably electricity and or water needs in remote locations .

1.7 Delimitation and limitation of research

To obtain our results, we will use a laptop, questionnaire for field survey which will take place in Ngaoundere, Cameroon. Through the survey, data about manure available and energy consumption in that community of seven households will be obtained.

After data collection, we will assess the electricity potential of biogas produced from animal dung (pig). After this, we will simulate differents scenario by varying the amount of feedstock and adding a ratio of another feedstock. This will be done to get which input is needed to get more energy yield.

The phase of energy needs evaluation in that community will show how the potential energy obtained will supply the needs. In the case of positive result (energy supply obtained bigger than energy consumption), we will also apply it to the case of water supply in that community.

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2 CHAPTER TWO: LITERATURE REVIEW

In this chapter, a literature review about biogas fundamentals, the current context of these technologies in Cameroon followed by their different applications on the field in order to settle the pillars of our research.

2.1. Anaerobic Digestion

Anaerobic digestion is defined as fermentation of organic wastes in the absence of free oxygen ([1]). It is the most common biomass energy conversion option used on large scale livestock operations in United States since the early 1980's ([2]).

Anaerobic digestion support programmes in China, India, Nepal and Vietnam ([3]). Biogas introduction in some Subsaharan African countries occurs at different times like Kenya (1950), Tanzania (1975), South Sudan (2001). According to [4], biogas digesters have been installed to date in several Sub-Saharan countries: Burundi, Botswana, Burkina Faso, Côte d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Namibia, Nigeria, Rwanda, Zimbabwe, South Africa and Uganda. Increasing number of biogas installations mainly in the domestic energy sector is due to national domestic biogas programmes in Rwanda, Tanzania, Kenya, Uganda, Ethiopia, Cameroon, Benin and Burkina Faso. ([5]). Biogas technology dissemination in Africa has not encountered success as Asia case. The cause of this is attributes to failure of African governments to support biogas technology through a focused energy policy, poor design and construction of digesters, wrong operation and lack of maintenance by users, poor dissemination strategies, lack of project monitoring and follow-ups by promoters, and poor ownership responsibility by users ([6]). Despite this relative stagnation, biogas plants in recent years in some SSA countries(Ghana, Kenya, Tanzania, Rwanda, Burundi, South Africa) have been built as environmental pollution abatement systems ([7]) **.**

Fresh manure, mainly used in developing countries in general, particularly Cameroon are suitable feedstocks for anaerobic digestion. Swine farms, dairy, caged layer, poultry and livestock operations are all using anaerobic digestion for odors control, value-added products, heat and electricity production.

In Anaerobic digestion (AD), gas resulting from direct organic material conversion is called biogas, a mixture of methane, carbon-dioxide with traces of other gases like hydrogen sulphide. *Biogas production started since 1977 through projects incorporated into cooperative efforts with India and Ethiopian organizations. The first GTZ project about biogas technology transfer and biogas plants construction has been launched in Cameroon (Werner, 1989). Systems built are mostly on a small scale aiming to provide energy and organic fertilizer to family farms.(taken from Fondufe et al.,2011)*

Bacteria play the role of catalyser of biomass conversion in anaerobic environment. Energy contained in the gas produced represents 20 to 40% of the lower heating value of the feedstock ([9]). Commercially proven technology mainly used for treating high moisture content organic wastes (80 to 90% and solid content of less than 25%), the yield can be directly used in spark ignition gas engine, gas turbines or upgraded to natural gas quality by CO2 removal. The conversion efficiency is about 21%. ([10]). This section is divided in three subsections. In the first subsection, description of anaerobic digestion is presented to have a deep understanding of the process as well as the main parameters to take into account when it comes to design a biogas system. Then, the second subsection concern digesters typologies for a comparative study will be applied to our case study in order to select the suitable digester. The third subsection is about biogas current situation in Cameroon highlighted to keep in mind the innovation brought by our research.

2.1.1- Anaerobic digestion process description

Anaerobic digestion happens in four steps described as followed:

- Hydrolysis: this step consists in conversion of complex molecules (large protein macromolecules, fats, cellulose and starch) into simple sugars, long-chain fatty acids and amino acids. For instance, polymers after hydrolysis become monomers and oligomers. Hydrolysis catalysers are enzymes excreted from bacteria. Feedstock complexity influences hydrolysis efficiency. Carbohydrates conversion is faster than raw cellulosic waste (Ostrem and Themelis, 2004. The main reactions and bacteria occurring in hydrolysis are :

$$lipids \xrightarrow{lipase} fatty\ acids, glycerol$$

$$polysaccharide \xrightarrow{cellulase,\ cellobiase,\ xylanase,\ amylase} monosaccharide$$

$$proteins \xrightarrow{protease} amino\ acids$$

Hydrolysis reaction equation is expressed by:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2 \quad (1)$$

- Acidogenesis or fermentation. Hydrolysis products are converted into volatile fatty acids (VFAs ; mainly lactic propionic, butyric and valeric acid), acetates, alcohols, ammonia, carbon dioxide and hydrogen sulphide. Equation 2 and 3 below summarize acidogenesis reaction.

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \quad (2)$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2 \quad (3)$$

- Acetogenesis. Equations 4 and 5 describe this 3rd step of anaerobic digestion and the yields are:

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3{}^- + 3H_2 \quad (4)$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad (5)$$

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+ \quad (6)$$

$$2HCO_3{}^- + 4H_2 + H^+ \leftrightarrow CH_3COO^- + 4H_2O \quad (7)$$

- methanogenesis: catalysers contributing to the production of methane, carbone dioxide and water are according to ([1]) and ([11]) acetrophic, hydrogenotrophic and methylotrophic bacteria. Equations 8 and 9 are :

$$acetic\ acid \xrightarrow{methanogenic\ bacteria} methane + carbon\ dioxide \quad (8)$$

$$hydrogen + carbon\ dioxide \xrightarrow{methanogenic\ bacteria} methane + water \quad (9)$$

Equations 10 to 14 describe methanogenesis in details with other side reactions as well (equations 15 and 16).

Detailed methanogenesis reactions

$$2CH_3CH_3OH + CO_2 \leftrightarrow 2CH_3COOH + CH_4 \quad (10)$$

$$CH_3COOH \leftrightarrow CH_4 + CO_2 \quad (11)$$

$$CH_3OH + H_2 \leftrightarrow CH_4 + H_2O \quad (12)$$

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O \quad (13)$$

Side reactions

$$CH_3COO^- + SO_4^{2-} + H^+ \rightarrow 2HCO_3 + H_2S \quad (14)$$

$$CH_3COO^- + NO^- + H_2O + H^+ \rightarrow 2HCO_3^- + NH_4^+ \quad (15)$$

The following equation (16) is a simplification of the entire process:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \quad (16)$$

Theoretical calculations are made based on the primary methanogenic route which is the acetotrophic methanogenic reaction expressed by equation (11). ([1]).

During anaerobic digestion, the four separate stages occur simultaneously in such a way that the first reaction must perform before the second one proceeds and so on. ([12]).

At the end of digestion, digestate containing hydrogen sulphide and ammonia need to go through ageing in an aerobic composting. The aim is to break ammonia into nitrates and reduce any odour before used as fertilizer.

a) Bacteria

Efficient digestion is linked to presence of suitable bacteria colonies. Identified feedstocks with optimal bacteria content are animal manure, slaughterhouse wastes and sewage. Then, reactors may be supplied with these materials. Table 1 below shows bacteria groups involved in anaerobic digestion.

Stage	**Reaction**	**Bacteria**
2	Hydrolysing and fermenting	*Bacteroides, Clostridium, Butyrivibrie*
2	Hydrolyzing and fermenting	*Eubacterium, Bifodobacterium, Lactobactillus*
3	Acetogenic	*Desulfovibrio, Syntrophobacter wolinii*
3	Acetogenic	*Syntrophomonas*
4	Methanogenesis	*Methanobacterium formicium, M. ruminantium*
4	Methanogenesis	*M. bryantii, Methanobrevibacter*
4	Methanogenesis	*Methanobrevibacter arboriphilus*
4	Methanogenesis	*Methanospirilum hungatei, Methanosarcina barkeri*

Table 2.1. Bacteria involved in anaerobic digestion ([1])

Weiland (2010) identifies other facultative anaerobes taking part in anaerobic digestion like Streptococci and Enterobacteriaceae. Most of the bacteria involved in anaerobic digestion are strictly anaerobes. One of them mentionned by Weiland (2010) are bacteriocides, clostridia, bifidobacteria. In reality, only the final methanogenic step is really anaerobic. Abbasi et al., 2012 mentions other aerobic or facultative bacteria which are cellulolytic, acidogenic and acetogenic bacteria. Bacteria occuring naturally in deep sediments or rumen herbivores are methanogenics ones ([13]).

b) Factors affecting biogas production

Any biomass cannot be used for anaerobic digestion. Ones suitable for this process are chosen according to important factors: total solids content, percentage volatile solids, carbon to nitrogen ratio (C/N), biodegradability of feedstock. Gas yield is function of the hydraulic and solids retention times, pH, temperature of fermentation, loading rate, inhibitory effects of substrate compounds and intermediate products (ammonia, VFAs, hydrogen sulphide), toxicity of any feed or reaction products, degree of mixing/agitation and the presence of any pathogens ([1]). The most important ones affecting biogas yield are volatile solids, organic composition and bioavailability. Their respective description will be done below.

- ***Solid content and dilution***: solid content in reactor must be between 10% and 25%. Solid dilution is made in such a way that slurry obtained allows gas flow upward.

- ***C/N***: optimal carbon to nitrogen ratio is 20:30. Too high ratio implies rapid consumption of nitrogen by methanogens for protein formation and insufficient nitrogen remaining for reaction with leftover carbon. Too low ratio leads to liberation and accumulation of nitrogen as ammonia. Therefore, pH is increased and this has a toxic effect on methanogenic bacteria. Mixing materials is a solution for maintaining an optimal C/N as each material has its own C/N.

- ***pH:*** pH value must be within the range between 6 and 7. At a pH less than 6, methanogenic bacteria cannot survive ([13]). During the first steps of the digestion, there is a decrease followed by an increase as the reaction progresses. Methane production is stabilized when the pH is typically 7.2 to 8.2. In the case of digester operating in batch mode, pH is adjusted by adding lime.

- **Temperature**: digestion types are indentified according to temperature. There are mesophylic, thermophylic and psychrophyilic digestion. Large scale anaerobic digestion is mostly mesophilic. Thermophylic digestion is more advantageous than mesophylic and psychrophylic ones. It has a faster digestion rate therefore small digester. However, it is not easy to control, investment costs are higher, extra energy inputs is required to maintain temperature

- loading rate: this is a measure of the biological conversion capacity of the system. It determines the tolerable amount of volatile solids by a system. Quick overloading causes inadequate mixing, increased VFA content and lower pH, which are system failure proof.

- **retention time:** is the duration of contact in the digester of organic material (substrate) and microorganisms (solids) needed to achieve the desired degradation. (Biomass processing technologies). Lower retention time than the one required increases reactor efficiency. Therefore, reactor volumes will be reduced. In some cases, retention time is from 40 to 100 days ([15]).

- **toxicity:** mineral ions particularly heavy metals and detergents hinder normal bacterial growth. Minerals (sodium, potassium, calcium, magnesium, ammonia and sulphur) quantity must be low in order to stimulate bacterial growth. Heavy metals when low are essential for bacterial growth in very small amount but toxic when their amount is high. Therefore, digestates in that case are not proper to use as fertilizers. However, when the toxicity rate is high, dilution is a solution to reduce the toxicity level.

- mixing/agitation: Process is stable when fluid homogeneity is maintained. Mixing/agitation is applied during digestion for incoming material and bacteria combination, scum formation hindrance, strong gradient temperature avoidance within the digester. Mixing should not be either rapid to avoid pronounced temperature gradients or too slow to avoid short-circuiting**.**

- pathogens: anaerobic digestion feedstock must be free from pathogens to protect workers against infections. Pretreatment at 70°C for 1 hour is a solution to destroy certain pathogenic bacteria and viruses in MSW.

2.1.2. Types of digesters

Many digesters exist. There are: single or multi-stage digesters, low-rate digestion (floating dome, fixed dome, balloon digester), large scale, low-rate digesters (covered lagoon, plug flow, fixed film, suspended media, anaerobic sequencing batch reactor), high rate anaerobic digesters (anaerobic continuously stirred reactor, anaerobic contact reactor) second generation high-rate digesters (upflow anaerobic filter, downflow stationery fixed film, upflow anaerobic sludge blanket, fluidized bed/expanded bed), third generation high rate digesters. The following section discuss about the selected anaerobic digesters in developing countries.

a) Total solid content (wet/dry systems)

Rate of TS content of the substrate fed into an AD system allow to consider a digester system wet or dry. A digester fed with a substrate with TS content less or equal to 16% is qualified wet while bioreactors filled with substrate with a TS content of 22 and 40% are respectively semi-dry and dry ([16]).Compared to wet anaerobic digestion systems, dry systems are better

([17]) for they require a smaller reactor volume, lower energy requirements, minimal material handling efforts. Moreover, the digestate issued from dry digestion can be easily used as fertilizer or transformed into biomass fuel. However, dry digesters systems are not widely spread in developing country context due to a number of practical barriers hindering its commercialization, namely, typical batch wise process and the filling and emptying procedure requiring a large enough opening which regularly needs to be sealed properly.

b) Operating temperature (mesophilic/thermophilic)

Anaerobic digestion systems based on temperature are categorised into three categories: psychrophilic (below 20°C), mesophilic (30-40°C) and thermophilic (45-60°C) systems. The slowness of reaction in the first category render it inappropriate for anaerobic digestion. Thermophilic digestions systems facilitates faster reaction rates, faster gas production and hygenisation of the digestate compared to psychrophilic and mesophilic digestions. However, thermophilic digestions are expensive due to additional cost for energy input to heat digesters. A location with a specific climate should use a digester which temperature of operation close to the temperature in the region. Hence, in developing countries with a tropical climate, digesters operate in the range of mesophilic temperature.

c) Feeding mode

Digester geometry with other components evolve without ceasing. This evolution observed is due to the search for efficiency improvement, simplification of operation and maintenance, suitability of operation under different temperature regimes. Thus, digesters are classified into three feeding modes which are: batch, semi-continuous and continuous modes ([18], [19];[20]).

Batch fed digesters

In batch fed digesters, the reactors are periodically filled and discharged ([21]).

The feedstocks used here are fruits, vegetables, straw, animal dung, human excreta and municipal organic waste. Temperature of operation of batch digesters is in thermophilic range of temperature. Dry anaerobic digestion principle uses batch feeding mode for in batch fed digesters the total solid concentration is high (greater than 15% TS).

Advantages of batch fed digesters are high biogas production due to high retention time (30 to 180 days) ([22]) , less space occupied therefore applicable in urban areas where space is an issue, very cheap and affordable for households ([23]). Nevertheless, reduced size of digesters limit the quantity of biogas produced and stored. Besides, operation and maintenance of batch digesters is laborious, dangerous at the end. Regular closure and opening after each batch sequence require gastight sealing of inlet/outlet which may result in biogas losses and the risk of explosion as residual methane in the reactor mixes with air when emptying. ([23]). Design of such digester is illustrated by the following figure 2.

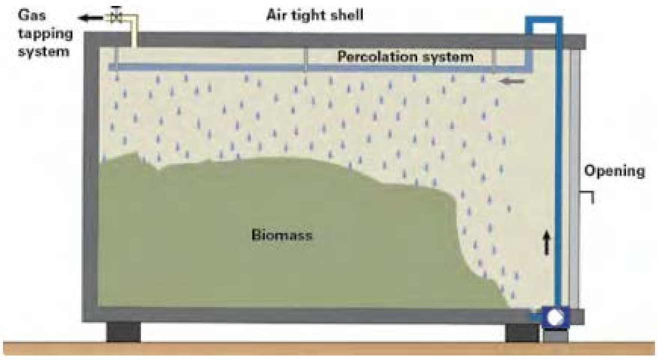


Figure 2.1a. garage - type dry digestion plant ([24])

Figure 2.1b. Dry digestion pilot plant at KNUST, Kumasi, Ghana ([24])

Semi-continuous fed digesters

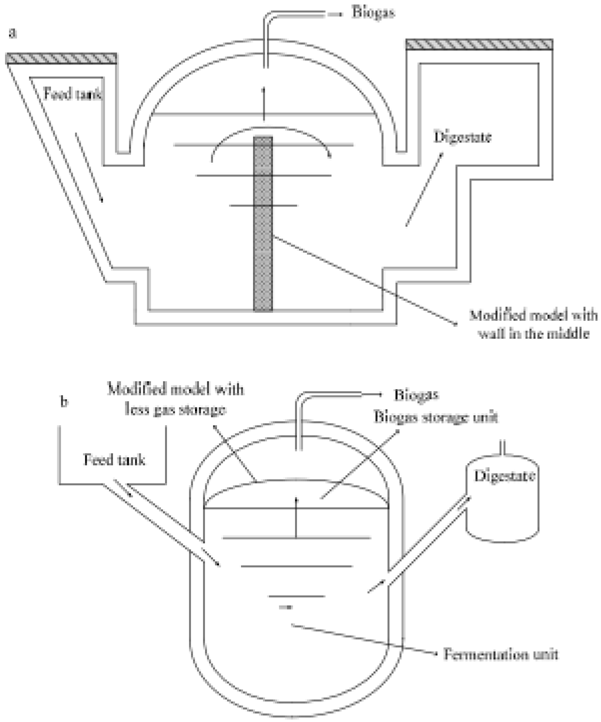
In this category, the feeding mode is characterized by daily loading of the digester through an inlet and automatic discharge through the outlet of the slurry tank. One or more feedstock can be used in such digester which operates within mesophilic range of temperatures and at total solid of influent less than 10% of TS hence suites for wet anaerobic digestion. Compared to batch digester, semi-continuous fed digesters' retention time is low (10 to 60 days) as well as biogas production caused by lower process efficiency. Although the design of such digester is expensive for household, operation and maintenance is less laborious, require more space than batch type, this configuration is mostly found in developing countries. There are fixed dome, floating drums and tubular digesters operating on this feeding mode.

Fixed dome design:

Fixed dome digester is a Chinese design. Also called "hydraulic" digesters they are mainly used in China ([25]) and now spread in sub-Saharan African countries for biogas production. This digester is fed through the inlet pipe. The bottom level of the expansion chamber is the limit to be reached by the feedstock. The storage part, upper part of the digester plays the role of biogas accumulator. Gas pressure is created because of the difference level between slurry inside the digester and the expansion chamber. After gas release, slurry is immediately sent to the digester. ([26]).

Geographical location, availability of substrate per day, climatic condition, number of households influence digester design. Fixed dome digesters are mostly constructed underground. In China for instance, digester size range is from 6 to 10 m3 ([27]). In India the range is from 1 t 150 m3 ([28]) and in Nepal ([29]), the range is from 4 to 20 m3. In Nigeria, digester size of a household of 9 is about 6 m3 ([30]). Community biogas digesters for 10 to 20 homes are better solution than individual ones especially in the case of clustered households as in Nigeria ([31])

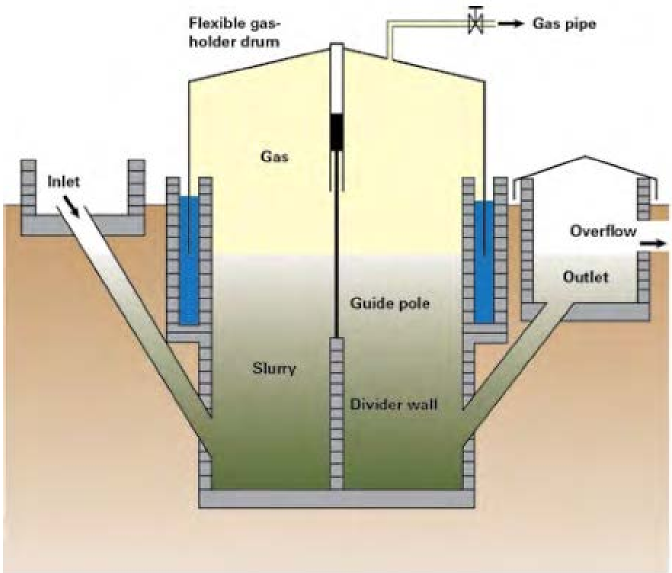
Figure 2.2. Schematic sketch of different digesters model: (a) janta model, (b) deebandhu model. ([32])



Fixed dome is found modified from the original fixed dome model in many countries. In india, janta (figure 1a) and deenbandhu (figure 1c) models are example of fixed dome modification. Deenbandhu model is a modification of janta model designed in 1978 to reduce the price without affecting digester efficiency. Other fixed dome digesters are Chinese, Nepali GGC2047, Vietnamese designs and French types digesters which consist to surround the fixed dome by a steel drum containing biomass to avoid temperature losses ([20] , [33]). Deenbandhu model is claimed to be the cheapest digester among others types of fixed dome. Gas storage of the fixed dome can also be covered by a plastic bag with a wood roof on top to protect the fragile plastic bag from solar radiation and increase the gas pressure by its weight ([33]). Generaly, prefered feedstocks for fixed dome digesters are animal dung (pig, cattle, cow, etc). Also, digesters size of 4 to 10 m3 are used by households while size greater than 10 m3 are suited to community (schools, hospitals, prison).

Floating drum design

Firstly developped by KVIC (Khavic & Village Commission) in India and standardized in 1962 (Charles Gunnerson et al., 1986). Biogas production with floating drum occurs at a constant pressure with variable volume ([34]). Figure 1.3 depicts sketch of floating drum digester. Regular paint of floating drum is necessary to avoid rust.Generally underground, floating drum consists in a cylindrical part (underground) and a moveable part above ground, the floating gasholder. Smaller households scale are fully above ground. The material used to construct this digester type are bricks, concrete, or quarry-stone masonry, then plastered (Figure 1.3). The moveable part, the gas-holder usually made of metal is coated annualy with oil paints to protect it against corrosion. This part is the weak point of this type of digester which does not last longer and make operation and maintenance cost expensive compared to fixed dome. Well maintained metal gas holder last for 3 to 5 years in humid climates and 8 to 12 years in dry climate. Hence to improve gas holder durability, it is necessary to use fiber-glass reinforced plastic or galvanized sheet metal ([35]). Moreover, fibrous materials accumulation is to avoid if possible for it engenders blocking digester movement. Animal dung are feedstocks fitting to floating drum digesters (pig, cow or cattle). Globally floating drum size ranges between 1- 50 m3. Small-medium size farms have floating drum digesters varying from 5 to 15 m3 ([36]). As fixed dome design, floating drum is modified with geographic location change. Thus, there are KVIC, Pragati, Ganesh and ferro-cements designs.



a- Floating drum digester scheme

b- Floating drum for market waste in India

c- Above ground floating drum made of fiberglass reinforced plastic in India

Figure 2.3. floating drum digester: a-floating drum digester; b-floating drum for market waste in India; c- floating drum made from fiberglass reinforced plastic in India ([24])

Continuous fed digesters

Here, load and discharge of digester occurs continuously. They operate only on one type of feedstock, reason why they are also called mono feedstock, under mesophilic range of temperatures and at a low total solid of influent (less than 10 % TS). Retention time and biogas production are lower than batch digesters. Its configuration requiring separation of gasholder from the digester makes it application inappropriate in developing countries.

d) Configuration of digester design

According to fresh effluent interaction with the older content of the digester, two typologies of digesters are identified: plug flow and complete mixed digesters ([11])

Plug flow or tubular digesters

Biogas is produced through plug flow digesters with constant volume at variable pressure. Plug flow digester size varies from 2.4 to 7.5 m3. Figure 1.4 shows its geometry composed of a narrow and long tank with an average length to width ratio of 5:1.Inlet and outlet pipes positioned at opposite ends are kept above ground and the remaining part is buried in the ground in an inclined position. The inlet welcomes fresh feed substrate. The outlet is an exit for digestates flowing towards its position. Process temperature stability is assured by shed roof placed on top of the digester to cover it thus acting as insulator during days and night [37-43].

The only point of interaction between the fresh influent and the older digester content is around the surface area of contact. No mixture occurs. In this digester with a tubular form (also named tubular digester), the feedstock along the digester length is at different stages of decomposition. This results from displacement of the older digester content by the incoming fresh effluent. Hence, the different steps of anaerobic digestion are separated in such a way that methanogenic step occurs towards the outlet of the digester while hydrolysis and acidogenic phases take place close to the inlet of the digester. The principle followed in this configuration is considered as a transition between wet and dry anaerobic digestion principles for the system operate at temperature within mesophilic or thermophilic ranges and higher total solid content in influent (greater than 15% TS). With a retention time ranging from 15-40 days and a feeding mode either semi-continuous or continuous, the horizontal configuration of the tubular digester is the most applicable in developing countries ([44]).

Plug flow digester popularity encountered in Peru is explained by its poratbility, low cost, easy installation, transportation, handling and adaptation to extreme conditions at high altitudes with low temperatures. However, large plug flow digester are difficult to dig under the ground for their construction in high altitudes ([43]). Moreover, althougth this configuration is the most used due to low cost of operation and maintenance as well as construction (materials and skills), it is the very fragile for the material most often used for tubular digester is polythene.

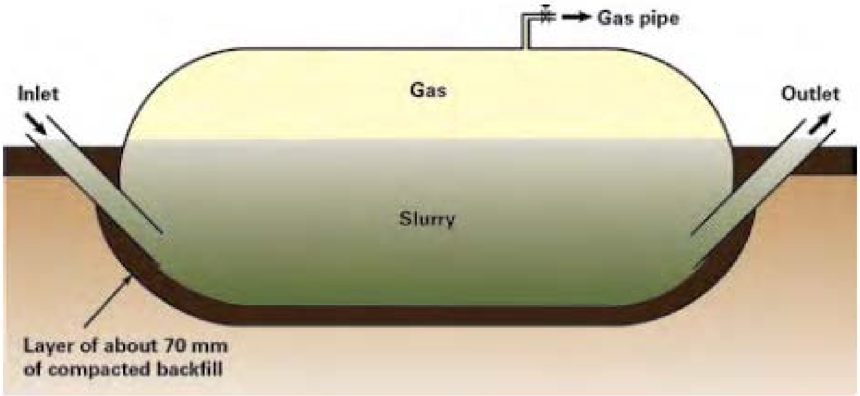


Figure 2.4. Scheme of plug-flow digester ([24])

Mixed digesters

Fixed dome and floating drums digesters are based on this type of configuration where the incoming fresh feedstock and the older digester content are completely mixed. As plug flow digesters, the temperature of operation is within both the mesophilic and thermophilic ranges of temperatures, but the process principle here is wet anaerobic digestion principle (total solid of influent less than 10% TS). The feeding mode is semi-continuous for households applications and continuous for industrial applications. The advantage of mixing here is complete bacteria population growth. However, the fresh influent may be lost without being completely digested when emptying digester. The retention time range from days to 45 days.

Leach bed digesters

Leach bed anaerobic digestion principle is used in this configuration. The leach bed anaerobic digestion principle consists to load feedstock in the digester as a bed of solid, soak it where it is hydrolized. Volatile fatty acids (VFA) resulting from rapid decay of the feedstock forms are extracted into the water phase in the form of a liquor called leachate.This latter is ten recirculated or pumped into another tank where methanogenesis occurs to produce biogas. Existing variations of this kind of digesters are single or multiple staged with batch or continuous feeding mode operating on dry anaerobic digestion principle (high solid content of up to 60%TS). Some benefits of tis digester design are absence of refine shredding of waste and mixing, possibility tooperate at ambient , mesophilic and thermophilic conditions. The only disadvantage is neglectance of development of this digester design for small scale aaplications in developing countries.

e) Microorganism growth strategy

Suspended and fixed –film growth strategies are the main group of digester classified according to growth strategy criteria.

Suspended growth strategy

This growth strategy is the simplest growth strategy. The microorganisms are embedded within the feedstock without special accommodation for their growth. Microorganism grows with time until it reaches the optimum. Most digesters in developing countries use this growth strategy. Microorganisms are flushed out during digester discharge.

Fixed-film growth strategy

Specialised structures called biofilms serve as support for microorganisms growth. The interest in using biofilms here is to maintain the microorganism population at an otimum in order to improve the rate of biogas production. Time does not influence anymore microorganism population which do not vary. Waste water treatment industry like Upflow Sludge Anaerobic Digester (USAB).

f) Number of stages

Single and multi-stage systems are hence specified to separate biochemical reactions that do not share the same optimal environmental conditions.Single stage are more appropriate and predominant system applied to full-scale biowaste anaerobic digestion treatment compared to multi-stage systems. The reasons are the simplicity of the design, construction, operation and cheapness ([45]). Single stage are mostly applied in small, decentralized waste management units while multi-stage digestion correspond to plants with a capacity of more than 50 000 tons/year.

2.1.3. State of biogas in Cameroon

2.1.3.1. Evolution of biogas production in Cameroon

Biogas production from cattle dung is implemented at the scale of pilot projects. This is the case of communities in Bamdzeng area of Kumbo sub-division where ([8]) assessed impact of biogas technology on social life in that community. Practized on a very small scale, he mentioned that this technology has the capacity to improve people's living conditions, enhance the development of that community through energy generation, agricultural improvement in health facilities among others, increase of economic returns, sanitary conditions improvement through avoidance of animal dung littering around the division. This technology has been introduced by SHUMAS (Strategic Humanitarian Services) and Virgin Botanicals NGOS.

Another area in the same region has interested Fondufe and Jude (2012). They aimed to evaluate biogas production impact in Bui division community, one of the major cattle livestocks's kingdom. 90 persons drawn from all the six sub-division have been interviewed to assess blue prints and challenges encountered during biogas production. In addition, the study aimed to determine the most important factor influencing the long term success and sustainability of biogas usage in the Division. They found that the factor is the extent to which planning and strategies help to overcome the economic, technical, institutional and socio-cultural barriers limiting acceptance and biogas installations diffusion. Other benefits of biogas technology added to those mentioned by [8] are reduced indoor pollution, employment generation, environmental renewal, reduction of drudgery for women ([45]). Aside cattle dung, other feedstocks can be used like human waste. Two institutions in Bui Division, Banso Baptist Hospital (BBH) and the St. Pius X Catholic Teachers Training College, Tatum use human wastes to produce biogas for cooking ([45]). Actually, Ngos like Bioenergy-Cameroon and Green Girls project are currently installing equipment in Buea and Bamenda that turns waste from pit latrines and septic tanks into biogas that can be used for cooking or heating and can supply energy to small generators to run electrical household appliances.

In addition, SNV and HYSACAM are the main visible actors in biogas production.

SNV and the Ministry of Water and Energy of Cameroon have initiated a national domestic biogas program in Cameroon in order to address health and environmental hazards in rural Cameroonian population due to the use of firewood as the main cooking and/or lighting source of energy by the majority ([46]). Starting in 2010 with feasibility studies and construction of 105 domestic digesters in 2010, followed by workshop to promote biogas market in the country in 2012, this program resulted in 206 biodigesters installed in 2013. From that program, SNV has started to be involved in the development of biogas in Cameroon in collaboration with others partners and NGOs. Actually, household digesters improvement, promotion of cheap digesters with easy operations and effective use of digestates as organic fertilizers, use of biogas in yoghurt processing are the content of SNV agenda.

At the level of large scale production of biogas in Cameroon, the Hygiene and Sanitation Company of Cameroon (HYSACAM) is the main operator as it is in charge of waste management in the big cities of the country. This company has built two biogas plant at landfill sites: the first constructed in Nkolfoulou-Yaoundé in 2011 and the second PK10 in Douala in 2014 ([47]).Currently, biogas produced is used neither for electricity generation nor heating in households. The aim of building these biogas plants was the reduction of greenhouse gas emissions from landfills in the country (48]). Exploitation of biogas for electrification is in future projects of Hysacam.

2.1.3.2. Feedstocks available in Cameroon and assessment of their biogas potential

Potential feedstocks available in Cameroon are: agricultural feedstocks mainly used in biogas for households programs, wastewater from slaughter houses, agro-industrial wastes, food waste, municipal solid waste and industrial wastes. Actually, those which are yet to be exploited for biogas production are wastewater streams.

a- Wastewater

Contrary to other countries where wastewater stream can be exploited from many industries, distilleries, paper and pulp, drinks, pharmaceuticals, etc, Cameroon has only one industry where potential industrial wastewater streams can go through anaerobic digestion process, which is slaughterhouses.

Slaughterhouses

Generally built for meat commercialization, Cameroon possesses three major slaughterhouses in Yaoundé, Douala and Maroua, with butcheries (small slaughterhouses) in major towns of Cameroon. Northern regions followed by North-West region have the biggest potential in cattle heads production. Slaughter house wastewater results from washing, bleeding, evisceration and deboning processes. This wastewater is generally a mixture of green water (colour due to chlorophyll in plants, chiefly fats and lignocelluloses solid contents), red water from blood and wastewater from toilet wastes. With a total of 856886 cattle heads slaughtered out of 5.95 million cattle heads, 2014’s livestock production in Cameroon, an important amount of slaughter house waste water is a huge source of biogas potentially transformed into electricity. However, with most of slaughter houses which are traditional in Cameroon (except Yaoundé and Douala) slaughter houses wastewater are not completely recovered. Availability of collection systems of this wastewater in modern slaughterhouses such as the one for Ngaoundere (1400 m3 capacity of cold-storage) , Kribi and Ebolowa. ([48]) will optimize recovery of this huge source of slaughter houses wastewater for biogas production.

b- Agro industrial wastes

Socio-economic development of Cameroon relies mainly on agro and food processing industries. These latters entail dairy, sugar, brewing, slaughterhouses, sweets, distilleries, oil mills mainly concentrated in Douala called industrial town as showed by table 1 (7 industries out of 11 are located in Douala). Enormous quantity of discharges from these respective industries constitute a promising feedstock suitable to anaerobic digestion before disposal in the natural environment ([48]). Biogas production from agro industries waste for electricity generation can alleviate environmental pollution due to improper management of industrial wastes especially in Douala.

Table 2.2. Major food processing industries in Cameroon ([48])

Industry	Location	Activity sector
SOSUCAM 1	Mbandjock	Sugar refinery
SOSUCAM 2	Nkoteng	Sugar refinery
CAMLAIT	Douala	Dairy
CHOCOCAM	Douala	Confectionery making
Ok FOOD	Douala	Biscuit factory
GUINNESS	Douala	Brewery
FERMENCAM	Douala	Distillery
AZUR	Douala	Oil Mill/Soap factory
SOFAVINC	Yaoundé	Winery
S.C.R Maya & CIE	Douala	Oil Mill/Soap factory
FERME Henri & Freres	Yaoundé	Livestock

c- Agricultural feedstocks

It encompasses farm wastes, animal dung and agricultural crops.

Farm wastes (liquid animal manure) and animal dung (cow, poultry, goat, sheep, poultry, horse, pig, etc.) are commonly used for domestic biogas production in Cameroon. Table 1.2

summarises biogas potential production from livestocks in Cameroon with a total of 10.52 m3/year (220.92 MJ or 7.01 MW) of biogas from livestocks wastes.

Table2.3. Major livestock and biogas production potential in Cameroon in 2014 (1000 head counts) ([49])

Animals	Heads (1000 Heads)	Residue generation rate (kg DM/animal/d)	Biogas production (m^3/kg DM)	Total biogas potential (10^6 m^3/yr)
Cattle (cow)	**5950**	**1.8 - 2.86**	**0.30 - 0.33**	**3.21**
Pig	**1800**	**0.8 – 1.0**	**3.6 - 4.8**	**5.18**
Goat	**4675**	**0.55**	**0.32 - 0.34**	**0.82**
Sheep	**4015**	**0.33**	**0.40 - 0.42**	**0.53**
Poultry (chicken)	**50000**	**0.05**	**0.31 - 0.32**	**0.775**
Total				**10.52**

As Cameroonian economy is based on agriculture (42 % of the GDP) sector involving 60% of the active population, agricultural crops and their residues produced in large quantities are an important potential for biogas production (Table 2.4).

Table 2.4. Commonly biogas feedstock characteristics in Cameroon (50])

Category	feedstock	production (kg/animal/d)	DM/Ash/TDN (%)	Biogas yield (m^3/kg DM)	Biogas yield (m^3/animal/d)	Biogas yield (m^3/kg/VS)
Agricultural waste	Rice straw		91/13/40	0.18		0.55-0.62
	Rice husks		86/NA/NA	0.014-0.018		
	Maize straw		86/NA/NA			0.4-1.0
	Wheat straw		91/8/43			0.188
	Grass, straw		88/6/58	0.35-0.4		0.28-0.55
	Corn stalk		80/7/54			0.35-0.48
	Fodder beet		16/0.8-0.9/NA			0.278
	Sugar beet		22/0.5-0.6/NA	0.76		0.44
	Coffee pulp		28/8/NA			0.30-0.45
	Cassava peel		NA/NA/NA			0.661(0.132)
Manure	pig	2	17/NA/NA	3.6-4.8	1.43	0.27-0.45
	Buffalo		14/NA/NA			NA
	Poultry (chicken)	0.08	25/33/38	0.35-0.8	0.01	0.3-0.8
	Horse		28/NA/NA			0.4-0.6
	Cow	8	16/14/92	0.2-0.3	0.32	0.6-0.8
Faecal matter	Human excreta / sewage	0.5	20/NA/NA	0.35-0.5		0.04
Food waste	Whey		94/10/82			NA
	Fruit (apple)		17/2/71			NA
	Vegetable		20/NA/NA			0.4
	Kitchen/restaurant		27/3,13/8, NA			0.506-0.65
	Left overs food		14-18/NA/NA			0.2-0.5
	Egg		25/NA/NA			0.97-0.98
	cereals		85-90/NA/NA			0.4-0.9
Food	Maize		20-48	0.25-0.40[b]		
	Barley		25-48	0.62-0.86		
Others	Water hyacinth		7	0.17-0.25		
	Leaf litter			0.06 (m^3/kg)		
	Bagasse			0.165(m^3/kg organic DM)		

DM: Dry matter; TDN: Total digestible nutrient; NA: Not available; VS: Volatile solid; TS: Total solid, a = based on mean biogas yield (m^3/kg DM), b = calculated from methane yield based on biogas of 55% methane.

To obtain biogas potential of agricultural feedstocks, one must multiply the crops production (t/yr) (taken from table 2.4) by processed residue generation ratio, percent dry matter (%DM) and biogas production (m^3/kg DM). Table 2.5 gives the summary of biogas potential of each feedstock calculated as indicated previouly. As noticed from that table, feedstocks in Cameroon are classified as follows: maize crop is the best followed by groundnut, sugarcane, cotton, rice, vegetables and wheat. The total annual biogas yield of all agricultural crops is estimated to be equal to 415.57 millions m^3 (8.73 $*10^9$ MJ or 276.8 MW) ([48]). Comparison between biogas production from animal waste and agricultural crops shows globally that agricultural crops is suitable feedstock for biogas production compared to animal waste. Therefore Cameroon will benefit more from using agricultural residues instead of crops to produce biogas as well as bio-slurry for fertilization.

Table 2.5.annual agricultural crops yields and biogas production potential in Cameroon in 2014 ([51])

Crops	Production (t/yr) [36]	Field/processed residue generation ratio [1]	Percent dry matter (% DM) [7], [10], [25]	Biogas production (m^3/kg DM) [1]	Total biogas potential (10^6 m^3/yr)
Rice straw	203000	1.7/0.35	91	0.18	11.64
Wheat	869	1.75/0.12**	91	0.65-0.75	0.062
Cotton (seed)	250000	2.75/0.44**	75*	0.3-35	24.75
Maize	1600000	2.0/0.47	86	0.4-1.0	258.69
Groundnut	614000	2.3/0.477	75*	0.4	82.34
Sugarcane (beet)	1216320	0.3/0.29	22	0.4-0.7	31.04
Vegetables	783677	0.4/0.15**	20	0.3-0.9	7.05
Total yield					**415.57**

NB: * = assumed value, ** = approximated value from [1].

d- Food waste

Food waste generation in Cameroon increases at the pace of population growth. The exact content of food waste is difficult to determine due to ethnic groups and culture diversity. Income levels, eating habits, cultures and locality are the main factors influencing volume and composition of food waste. Households, restaurants, hotels, schools canteens are identified being the main food waste producers in Cameroon. Food waste management in Cameroon does not follow a specific procedure for they are mostly throw alongside with garbage or disposed in landfills by HYSACAM the main waste management body. As food waste is organic matter with high moisture content, it constitutes 50 % of all domestic waste and 100 % of restaurants. Hence, food waste is a huge substrate available for biogas production in Cameroon ([48]).

e- Municipal solid waste (MSW)

Municipal solid waste in Cameroon is mainly organic (figure 2.6) according to ([52]). [53] gives figures of waste generation state in Cameroon during 2012. It is noticed that waste generation will double between 2012 and 2025 especially food waste. In 2012, 3448000 tones of waste have been generated, 1483000 tones have been collected with annual generation per capita estimated at 281 kg, so 0.77 kg/day. This projection shows that there is a promising energy recovery from solid waste which must be optimized by improving waste collection in Cameroon. The average methane yield probably recovered through anaerobic digestion of MSW is between 0.36 and 0.53 m^3/kg VS. With waste still disposed in landfill, the approximate methane production from solid waste in Cameroon (8.79 $*10^6$ m^3) in 2012 would not be totally recovered.

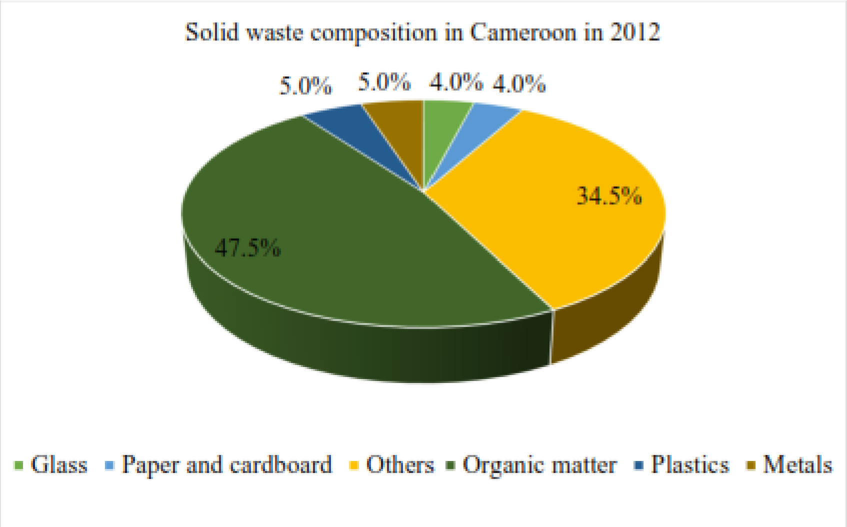


Figure 2.5. Municipal solid waste composition in Cameroon in 2012 ([52])

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3 CHAPTER THREE: METHODOLOGY

This chapter focuses on description of the procedure followed in feasibility study of rural electrification project based on biogas generation. It entails technical assessment. Generally, it encompasses :total feed to the biogas plant, Dilution water required or other pretreatment alternatives, total digester volume and choice of one digester technology, estimated fertilizer production, other estimated digestion parameters such as OLR, TS% and C:N ratio, estimated daily biogas production , estimated number of people that can be cooked for the biogas available, estimated electricity production (if biogas is used in an engine-generator set), estimated heat energy production (if heat is recovered from an engine), optimum gas required to cover electrical or thermal As our case study concerns only electrification, technical assessment will consist to determine all parameters excepted estimated number of people that can be cooked for the biogas available and heat energy production.

3.1. Study location

Our case study is located in Manwi belonging to the district of Ngaoundere 3eme. That place can be qualified of rural area for it has the main characteristics features of such area which are according to the European Commission (2014): isolation, low population density, low economic activities, insufficient infrastructure and lack of statistical data. Our area of study is composed of 7 households, and one pig farm. This area has been chosen for this feasibility study for the fact that houses in Manwi are spread, their inhabitants practice agriculture at small and large scale in their compounds and surrounding areas. Also, the area of our concern has a potential to produce biogas and houses are more closed which make undertaking an electrification project easy. The pig farm has 40 pigs. Besides, inhabitants of that area are exposed to bad odors about which many of them complained. For this area we will start by assessing the local energy sources, followed by the energy consumption, the biogas sizing, selection of other technologies for conversion into electricity.

3.2. Technical Assessment

3.2.1. Feedstocks assessment and characterization

Animal waste is the main focus of this study for data records of biomass available in that zone are not available and not easy to obtain within the time period allocated to our research.

According to the type of biomass, the methodology differs. For instance assessment steps of energy potential from woody biomass is not the same as the one for animal waste.

During animal waste assessment, the procedure used and adapted from the one proposed by biomass assessment handbook has these steps:

Step 1: determination of the number of animals by species in the specific area;

Step 2: calculate the amount of dung produce daily. Field surveys where used to get the number of animals and the amount of dung in literature

Step 3: calculate accessibility

Here, accessibility factor for animal dung may vary from zero to one. For housing animals as pigs in piggeries our case study, dung is 100% accessible and collected. In the case of extensive farms, estimation accessibility is more complicated. Collection efficiency i.e the ratio of amount collected (obtained through survey) to the total estimated droppings is the parameter to consider in such situation.

✓ **Feedstock management**

Identification of other usage of dung on the field is the main focus.

Animal manure is used in agriculture as fertilizer and as binding agent in house building or to coat wall and floors. This is the case in Cameroon context where animal dung are spread in farm or sell to other farmers.

Hence, total animal waste available is the product of the total produced (P), taking into account accessibility factors, collection efficiency and the feed variation factor (according to seasons). Otherwise, the amount is calculated directly from census and information literature which is the method that we used.

✓ **Waste characterization and estimation of biogas potential of the feedstock**

The biogas yield depends on the features of the substrates among which the important ones ([1]) are:

- Dry matter (DM): percentage of dry matter in the substrate;
- Organic matter content (OM): the organic fraction (%) in the dry matter;
- Organic dry matter (ODM) i.e the organic part of the substrate = (DM*OM)
- Maximum specific biogas production (in m3/t ODM).

Total biogas production is calculated using formula 2.1 ([1]):

Biogas production = amount of substrate (t) DM (%)*OM (% of DM)*maximum biogas production (m3/t ODM).* *(3.1)*

Biogas yield is mostly increased through co-digestion. Co-substrates can be obtained from different sources like leftover, sillage, agricultural waste, crops, human manure.

Equation (2.4) is used to calculate biogas yield in case of co-digestion:

*BP = [Ma * DM*OM DM (B*OM)*100]+[Cs*DM*OM DM*(B OM)*1000]* *(3.2)*

Where

BP = Biogas production (m3/yr)

Ma = Manure (t/yr)

DM = Dry Matter content (m)

OM = Organic matter content (m)

B = Biogas (kg)

Cs = Co-substrate

Volume of biogas necessary to meet the energy demand and the proportion of biogas used from the total biogas potential is expressed by equation (2.3) and (2.4) respectively.

$$(B_{igas\ used}) = \frac{P_e * 3.6 * 10^6 MJ/GWh}{CH_4 * H_{vCH_4} * \eta_e} \quad (3.3)$$

$$\textit{Estimated biogas to be used} = \frac{Biogas\ used}{total\ biogas\ potential} \quad (3.4)$$

Electrical energy production is the energy value of methane from bioreactor calculated using equation (2.5):

$$Electrical\ energy\ production = [volume\ of\ Met\square ane\ (m^3) \times met\square ane\ energy\ content\ (kW\square) \times efficiency\ \ of\ biogas\ engine\ (\%)] \div 100 \quad (3.5)$$

According to [2], methane energy content is usually taken equal to 6 kWh (21-23.5 MJ/m^3) equivalent to 0.5-0.6 L of diesel fuel. [3] considered the conversion losses to get the calorific energy content of 1 m^3 of biogas, approximately 1.7 kWh of the usable energy.

Efficiency of biogas engine is the amount of electrical energy from the total energy available ([4]). From 20-30 % at the beginning of biogas engine generators, the efficiency has evolved and attained successively 35 % ([5]), then 40% ([6]).

3.2.2. Energy consumption evaluation

To obtain the energy consumption in that area, we have chosen one household as each household in that area has the same electricity usage: lighting, refrigerator, laptops and phone chargers. Hence, we collected power consumption of each device to get the daily electricity consumption as well as the monthly and annual consumption. These data are needed in order to determine the amount of biogas necessary to meet the demand (equation 3.3).

3.2.3. Digester sizing (put selecting the digester instead)

Whatever the type of digester, it is necessary to determine the volume of biogas digester determined by using the amount of manure and co-substrate, the retention time (days) and the number of days in a year. Equation (3.6) is used to calculate the digester's volume ([1]).

V_d(m3) = [manure (m3/yr) + co-substrate (m3/yr)] retention time (days) 365.* *(3.6)*

Therefore,

$V_d = (B+W)\,R_t$ (3.7)

Where:

B = Biomass (kg)

W = Water (litres)

Biogas production is determined using equation (2.8) ([7])

$G = V_s \times G_y$ (3.8)

With:

V_s = weight of feedstock available per day in kilograms

G_y = Gas yield in cubic meters

G = biogas production in cubic meters

3.2.4. Storage sizing

The post digester storage is calculated as follows:

$$\textit{Size of storage (m3)} = \frac{\textit{Animal substrate}\left(\frac{m3}{yr}\right) * \textit{required time (months)}}{12 - \textit{size of digester}} \qquad (3.7)$$

External bag or foil covering the silo are often used for biogas storage.

When foil is used, the diameter of the digester is calculated as follows:

Diameter of digester (m) = $2 \times \sqrt{Volume}$ *of digester m² height of digester* $(m) \times$ *3.14 (3.8).*

In CHP cases, the storage is taken equal to 20 to 50% of the storage or less in practice.

3.2.5. Technology for power production

In case of using biogas for electricity generation, three options are usually selected:

- Using a biogas engine/generator (spark plug engine)

- Modifying a gasoline engine/generator to run on biogas;
- Using biogas in combination with diesel in a diesel engine / generator. (FACT foundation, 2012);

Electric generators are sized according to the following equation:

$$P\ (kw) = S\ (kVA) \times P_f \quad (3.9)$$

Where:

P (kw) = power in kilowatts

S (kVA) = generator size in kVA

P_f = power factor

The power factor (Pf) for each electric biogas generator and the average electric efficiency of each biogas generator are assumed to be 0.8 and 40 % respectively.

a- Biogas engines

Running only on biogas, the full electricity demand should be covered by biogas. Size and type of the engine, capacity at which it is used and biogas quality influence gas requirements. Gas gensets are available from 1kWe upward. Too large for individual households, it cannot run at very low loads leading to low efficiency and more frequent engine failure.

b- Gasoline engines

Modifying gasoline engines to run on biogas is performed by placing a biogas/air mixing device between the carburetor and the air filter, or replacing the carburetor altogether. The efficiency is similar to that of a biogas engine (1.5 m^3/kWh for a small generator (< 5kW) running at partial load to 0.6 m^3/kWh or less for a large generator (> 50 kW) at optimum load both running on biogas with a typical Net Calorific Value equal to 20 MJ/m^3). Hence, the same gas consumption per Kwh can be used for calculations.

c- Diesel engines

Running diesel engines with biogas require the usage of 20% diesel and 40 % for proper injector cooling. Although biogas replaces a large amount of diesel, it cannot replace it entirely**.** For an existing diesel generator, biogas consumption is estimated from the current diesel consumption taking the maximum replacement rate of diesel equal to 60 % and a replacement value of about 2.5 m^3/litre diesel. For instance, biogas requirements in situation where daily diesel consumption is 5 litres would be $5 \times 60\% \times 2.5 = 7.5 \frac{m^3}{day}$.

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4 CHAPTER FOUR: RESULTS AND DISCUSSIONS

In this chapter, the results of the technical assessment obtained are summarized. The first section will concern technical assessment results and the second section content concerns economical results. At last, there are discussions of results obtained.

4.1 Technical Assessment Results

4.1.1. Waste characterization and biogas potential of the feedstock

Livestock concerned in our study are pigs which are about 40. As the farm is made of concrete accessibility factor is equal to 1 and collection efficiency equal to 100 %. 100% of pig manure is used as fertilizer especially for banana trees. However, even used as fertilizer excessively (the land is overfertilized), the neighbourhood is polluted. Dry matter (DM), Organic matter content, Organic dry matter and Maximum specific biogas production of the current feedstock are found through literature survey and summarized in table 3.1.

Table 3.1. Percentage of Organic and Dry Matter with Biogas Potential Range for pig manure. (Emmanuel .F, 2017)

Feedstock	Dry matter (DM%)	Organic Matter	Biogas Yield (m^3/T ODM)
Pig manure	3-13	65-85	350-550

Biogas production in a year and the biogas yield factor calculations based on the number of production stock and equation 2.1 of the previous chapter are shown by table 3.2 below. As biogas is used to power engine for generating electricity, heat values are neglected.

Livestock species	Production stocks	Dry dung output (kg per day)	Total annual dung output (tones)	Dry matter content (DM %)	Organic matter content (OM %)	Biogas yield factor (m^3/t)	Biogas yield (m^3)
Pigs	40	0.8	11.68	10	90	500	525.6
Total manure biogas yield (m^3/yr)	**525.6m^3 per year**						

The biogas yield factor is taken from [30] and the stocks and dung output is from [31].

Electricity generation potential of the calculated biogas yield is calculated based on equation 3.1 below:

$$P_e = \frac{fCH_4 \times H_vCH_4 \times B_{biogas} \times \eta_e}{3.6 \times 10^6 MJ}$$

With fCH_4 $taken\ equal\ to$ 60 %.

H_vCH_4 the heat value of CH_4 (39.0 MJ/m^3).

η_e the efficiency for the electricity generation system equal to 30 %.

$$P_e = \frac{0.6 \times 39.0 \times 525.6 \times 0.3}{3.6 \times 10^6 MJ} = 1024.92\ kWh$$

4.1.2. Energy demand analysis of Manwi district

One household has been selected as sample for the energy demand estimation of Manwi district. The monthly consumption of that household has been taken into consideration based on electricity bills. The electricity usage varies daily due to the activities, equipments, also blackouts. The table below shows the monthly consumption and bills payable by the sample from 1st January to 31st December 2015.

Month	Monthly consumption (Kwh)	Bills payable (FCFA°
January	76	3800
February	102	5100
March	85	4250
April	89	4450
May	87	4350
June	92	4600
July	81	4050
August	110	5500
September	97	4850
October	86	4300
November	93	4650
December	79	3950
Total	1077	

Table 3. 3. Monthly electricity consumption

From table 3.3, it can be seen that by adding up all the monthly consumption we have 1077 kWh for twelve months. By multiplying by the number of households (7), the annual consumption of that area is 7539 kWh. The amount of biogas needed to supply the annual energy need of the area based on equation 2.3 is about 552.31 m^3 of biogas for one household, then 3866.15 m^3 for the seven households. Comparison between the amount of biogas required to cover the energy need and the biogas potential from the pigs shows that biogas potential from pig represents only 13.6 % of the energy needs. So electricity generated from biogas will cover only 13% of the annual energy need of that area. Considering the household sample, rate of energy needs covered is about 95 %. Then, to cover the gap (87 % or 5 %), another renewable technology like wind, pv or codigestion with other feedstocks (crops, forest resources available in the area) constitute other alternative solutions. This result leads to checking the potential of pig manure for heating and cooking.

5 CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion and recommendations

This study focuses on how pig manure can be used in distributed energy generation. The study shows that manure from pigs existing in one of Manwi household can be converted into energy through anaerobic digestion. It was seen that the annual biogas production covers only 13% of the electrical consumption of that community (without taking into account energy need for water supply), 95 % of electrical consumption of the sample household, which would not be enough . This study has been a purely mathematical evaluation of data derived from field work and literature survey. That community in Manwi district has crop (maize mainly), forest (avocado tree, banana and mango trees mainly) and animal biomass resources (pig and poultry manures) which are most underexploited. The residential application for which the available pig manure could be useful for the whole community is heating and cooking. Therefore, it is recommended to undertake future studies in order to obtain accurate measured ground data of crop and forest biomass resources out of animal dung especially for electricity generation application. Moreover, impact of quality, quantity of food and season on pig manure characteristics should give exact quantity of manure produced yearly.