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STUDY OF THE POSSIBILITIES OF SUPPLYING A FUEL-FIRED THERMAL POWER STATION IN COMBINATION WITH BIOGAS FROM THE ANAEROBIC DIGESTION OF HOUSEHOLD WASTE IN A LOCALITY ISOLATED FROM THE INTERCONNECTED ELECTRICITY NETWORK.
Case study: Bertoua town

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DEDICATION

To my dear parents Mr. ISSA souley and Mrs ISSA born Ramatou Oumarou and to my dear husband Mr. MOHAMADOU *Bassirou.*

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ABSTRACT

Energy being an essential element for development and security, the population of Bertoua town must get access to electricity to facilitate the development of small and medium-sized enterprises, and public lighting in order to reduce the insecurity that currently prevails in the city while respecting the rules of environmental protection. To meet the demand for electricity due to population growth, the city of Bertoua use a fuel-fired thermal power station with an install capacity of 17.6 MW that supply 8 MW for a demand of 12 MW. Hence, the city of Bertoua is faced with recurring electricity shortage, which led us to focus as the main objective of studying the possibility of recovering biodegradable household waste by anaerobic digestion into energy, and finally to limit the use of diesel and meet demand for Bertoua town. To achieve this, we proceeded firstly by evaluating the amount of biodegradable household waste produced, followed by evaluating the potential of the biogas produced as well as its energy value and lastly the environmental impact of both anaerobic digestion and landfilling. In the interview survey used, amongst other things, we sought 75200 kg biodegradable waste produced daily and therefore as result we obtained 5519.3 m^3 of biogas produced per day by anaerobic digestion. By assuming that the biogas consists of 60 % methane, this gives a methane yield of 3311.58 m^3/day. Moreover, we evaluated the electricity produced by assuming a turbine efficiency of 35 %, we get a daily energy production of 10822 kWh which correspond to 90 % of the daily energy consumption at Bertoua. Furthermore, we evaluated the performance of the thermal power plant using the specific fuel consumption (sfc), it results that the sfc is greater in biogas-diesel mode and less in diesel mode without modification of the current generator. Also, landfill gases of Bertoua was estimated using LandGEM model, it results that the landfill gases will be emitted even after the closure which is assumes to be by the year 2041. Hence, it was concluded that theoretically, the municipal solid waste of Bertoua could satisfy the energy demands of Bertoua town. Nevertheless, laboratory analysis of quality of biodegradable waste and the biogas produced are needed.

Keywords: Biogas, Anaerobic digestion, Thermal power plant, electricity, Solid waste management.

RÉSUMÉ

L'énergie étant un élément essentiel pour le développement et la sécurité. La population de la ville de Bertoua doit avoir accès à l'électricité pour faciliter le développement des petits et moyens entreprises (PME) et à l'éclairage public afin de réduire l'insécurité qui sévit actuellement dans la ville tout en respectant les règles de protection de l'environnement. Pour répondre à la demande d'électricité en raison de la croissance démographique, la ville de Bertoua utilise une centrale thermique à fuel d'une capacité installée de 17.6 MW qui fournir 8 MW pour une demande de 12 MW. D'où la ville de Bertoua est confrontée au problème de délestage récurant, ce qui nous a amené à fixer comme objectif principal d'étudier la possibilité de valoriser les déchets ménagers biodégradables par la méthanisation en énergie afin de limiter l'utilisation du diesel et combler la demande de la ville de Bertoua. Pour y parvenir, nous avons d'abord évalué la quantité des déchets ménagère biodégradable produit, évaluer le potentiel du biogaz produit ainsi que sa valeur énergétique et la quantité des gaz à effet de serre émit par les déchets solides. A cet effet, pour 75 200 kg des déchets biodégradables produit quotidiennement nous avons obtenu comme résultat 5 519.3 m^3 de biogaz produits par jour par la méthanisation. En supposant que le biogaz est composé à 60 % de méthane, cela donne un rendement de 3 311.58 m^3 CH_4/jour. De plus, pour une efficacité de performance de 35 % de turbine, nous obtenons une production énergétique journalière de 10 822 kWh ce qui correspond à 90 % de la consommation énergétique journalière de Bertoua. De plus, nous avons évalué la performance de la centrale thermique à l'aide de la consommation spécifique en carburant, il en résulte que la consommation de carburant spécifique est inferieure en mode diesel comparé à celle en mode biogaz-diesel sans modification du générateur actuel. Les gazes à effet de serre de la décharge de Bertoua ont été estimes à l'aide du modèle landGEM, il en résulte que les gazes de la décharge seront émises même après la fermeture qui est supposée être d'ici 2041. Par conséquence, il a été conclu que théoriquement les déchets ménagers biodégradables de Bertoua pourraient satisfaire les besoins énergétiques de la ville de Bertoua à 90 %. Néanmoins, des analyses en laboratoire de la qualité de déchet biodégradable et du biogaz produit sont nécessaires.

Mot clés : Biogaz, Méthanisation, Centrale thermique, électricité, Gestion des déchets municipaux.

SUMMARY

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LIST OF ABREVIATION

- **MSW**: municipal solid waste
- **SWM**: Solid waste management
- **GHG**: Greenhouse gas
- **AD**: anaerobic digestion
- **BUC**: Bertoua urban council
- **HYSACAM**: Hygiene and Sanitation Company of Cameroon
- **KPLC:** Kenya Power and lighting company
- **VFAs**: Volatile Fatty Acids
- **C/N**: carbon to nitrogen ratio
- **OLR**: organic loading rate
- **HRT**: hydraulic retention time
- **GPR**: Gas production rate
- **SGP**: specific gas production
- **VS**: volatile solids
- **TS**: total solids
- **TPS**: thermal power station
- **MINAT** : Ministère de l'Administration Territoriale du Cameroun
- **MINMITD :** Ministère des Mines, de l'Industrie et du Développement Technologique
- **MINFI**: Ministère des Finances
- **MINDUH** : Ministère de l'Habitat et du Développement
- **MINENP**: Ministry of Environment and Nature protection
- **MINPH:** Ministry of Public Health
- **MINEE** : Ministère de l'Energie et de l'Eau
- **MINEPDED** : Ministère de l'Environnement, de la Protection de la Nature et Développement Durable
- **AER**: Rural Electrification Agency
- **FER:** Rural Energy Fund
- **ARSEL**: Electricity Sector Regulatory Agency
- **EDC**: Electricity Development Corporation
- **ENEO**: Energy of Cameroon

- **SNV**: Dutch Development Organization
- **FEICOM** : Fonds Spécial d'Equipement et d'Intervention Intercommunale

GENERAL INTRODUCTION

Today, more than 50 % of the world's population lives in the cities and the rate of urbanization is increasing quickly. With the increase of urban population of the cities and towns all other activities associated with population also increases resulting in more and more generation of Municipal Solid Waste (MSW). Waste generation in sub-Saharan Africa is approximately 62 million tons per year (Sataloff and al., 2018). Often, cities and countries are rapidly developing without adequate systems in place to manage the increasing solid waste. Mostly in developing countries Solid waste management practices include: collection, recycling, solid waste disposal on land, and open burning of waste. This poor and inadequate solid waste management result in the consumption of energy and land for the storage, transportation, treatment, and disposal of these wastes and can deteriorate air, water, and soil quality. It is estimated that 1.6 billion tons of carbon dioxide equivalent (CO_2-equivalent) greenhouse gas emissions were generated from solid waste management in 2016 (Sataloff and al., 2018). For this reason, there has been worldwide interest in using biomass as a renewable energy source due to the increasing demand for energy and depletion of fossil fuels. Also, the threat of climate change posed by the continuous emission of greenhouse gases from fossil fuel utilization has become an important stimulation to use « carbon-neutral » biomass for renewable energy production, as the carbon stored in biomass is fixed from the atmosphere; thus, the cyclical use of biomass will not increase the net CO_2 level in the atmosphere (Mckendry, 2002). Moreover, biomass currently provides about 10% of the world's wide energy and has a potential to fulfill more than 25 % of the world's energy demand by 2035 (Kopetz, 2013). Among the many different types of alternative energy, biogas from anaerobic digestion (AD) of biodegradable waste proves to be one of the most promising choices (Chanakya and al., 2004; Akinbami and al., 2001).

To embrace this orientation, this work explores the possibilities of recovering biodegradable solid waste by anaerobic digestion into electricity in order to meets the demand and reduce fossil fuel utilization.

The achievement of our objectives required the use of several data and softwares in particular. For data: firstly, literature review which consist of the consultation of documents, followed by field observation which allow us to gain a general overview of the attitudes and knowledge of

Bertoua city, and lastly, the interview survey which allow us to get information from resource people of the city. For software's we used Arcgis for the layout of the map, Excel for data analysis and LandGEM for the simulation of landfill gas emissions.

This thesis has been divided into three chapters. The first chapter is sub-divided into two parts; the first part deals with the presentation of Bertoua in term of geography, population, climate, sanitation, water availability, solid waste management and history of electricity in Bertoua, and the second part consists of the state of art of key concepts on solid waste management, Anaerobic digestion, Energy recovery, institutional frameworks and institutions governing waste management and electricity in Cameroon. The second chapter deals with the methods used for the study and analysis. The third chapter deals with the presentation of the results and discussion where it will be question of talking about the quantity of waste produced, the amount of biogas yields as well as the potential of biogas/diesel dual fuel thermal power station.

CHAPTER I: STUDIED ENVIRONMENT AND STATE OF ART

Introduction

As the world's population size has grown, waste generation has increased rapidly. This has a significant effect on humanity, wildlife and the environment. As a result, global concern is turn to the sustainable management of solid waste. In this chapter, the area of concern is presented including the municipal solid waste management in terms of waste production rate, types, and the history of the system including those factors that drives the entire system is analyzed, and the state of art concern a global view on solid waste management and ways to valorized them precisely as energy (concept of waste-to-energy).

Section 1: Studied Environment

I.1 Presentation of the study Area

I.1.1 Geography

Bertoua is located at the Eastern Region of Cameroon and is the regional capital of Lom-et-Djerem Division as shown in Figure 1, established as an urban community of Bertoua in 2008 (Decree n° 2008/025 of 17 January 2008). Bertoua covers two (2) subdivisions (Bertoua I and Bertoua II) and two (2) urban councils (Bertoua I urban council (BUC I) and Bertoua II urban council (BUC II)). It is situated at 4°35' latitude north and at 13°41' longitude east. The city is located 350 km from Yaounde and the largest forest region in Cameroon. This locality occupies part of the southern Cameroonian plateau, a vast pen plain whose altitude varies between 400 – 900 m. it is drained from north to south by the river called Djadombe. It's bounded by Central Africa Republic, Congo Brazzaville and 350 km from Yaounde.

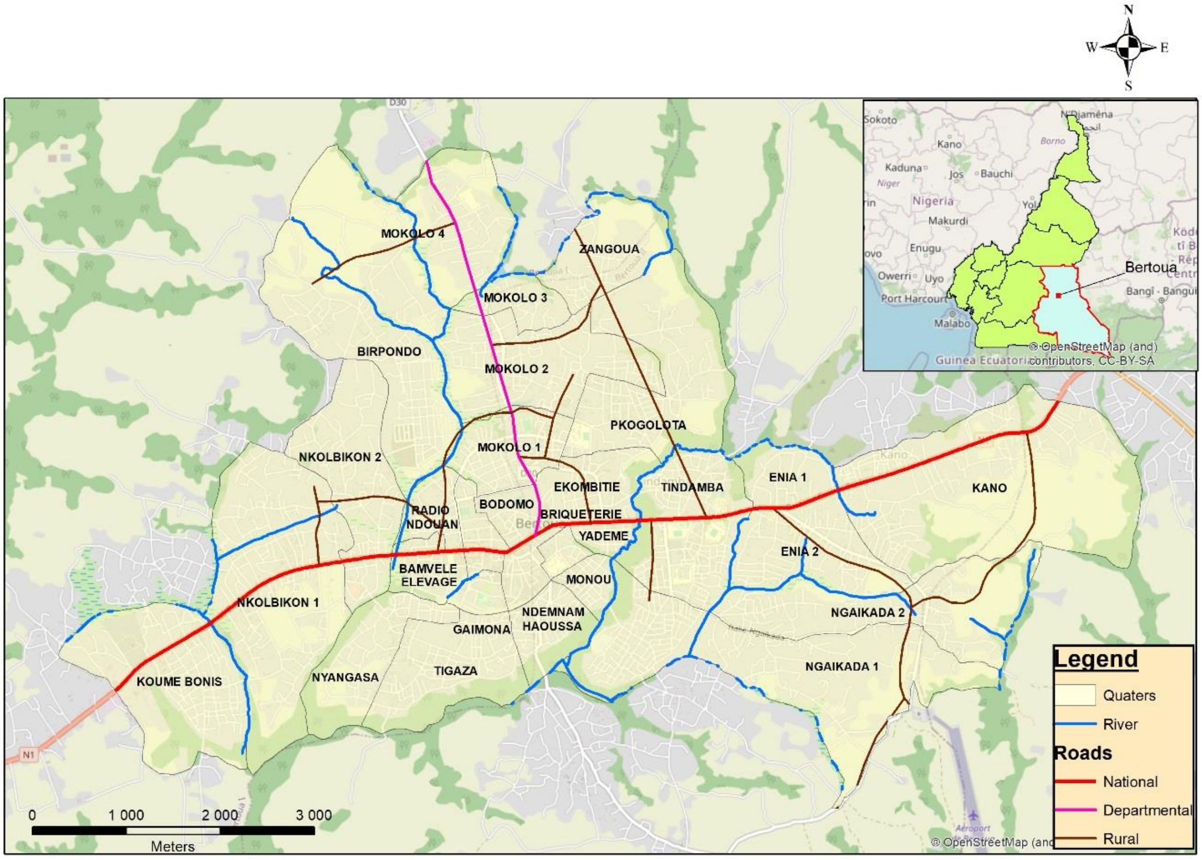


Figure 1: Geographic location of Bertoua

I.1.2 Demography

The population of Bertoua is estimated (2018) to about 395 000 inhabitants. The area of Bertoua is actually estimated at about 100 km^2 with a population density of 3,950 inhabitants per km^2; it has an increasing population due to refugees from the Central Africa Republic.

I.1.3 Climate and relief

Bertoua has a subtropical climate type with three seasons: a great dry season which goes from December to mid-march; a small rainy season from mid-March to mid- May, a large rainy season from mid- September to November. The temperature is high throughout the year, with maximum of 30 °C. The average fluctuates between 23 and 25 °C as shown in Figure 2. Precipitation is relatively abundant there 1500 to 2000 mm of rain per year.

The soil component of Bertoua is mainly granite and red in color.

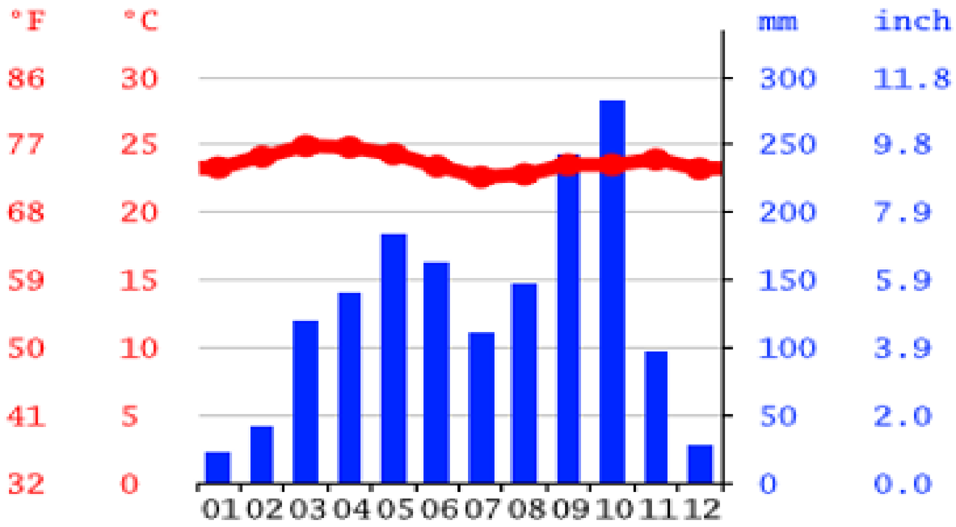


Figure 2 : Illustration of temperature and Pressure of Bertoua

Source: CLIMATE-DATA.org, Accessed 08/02/2021

I.1.4 Social and Economic environment

The Human Development Index (HDI) (2018) is 0.551. This classifies the East region as the 7th out of 10 with low life expectancy, education and per capita income. The vast majority of the inhabitants of the region are subsistence farmers. Major crops are plantains south of Bertoua and Batouri and maize north of there. Famers also raise many other crops in smaller quantities including bananas, groundnuts, cocoyams, manioc, pineapples, oranges, mangoes and yams. The farmers practice the method of slash-and-burn agriculture which allows for high yields in short term but quickly exhausts the soil.

Bertoua has very little industry, its main commerce consisting of logging, timber and mining. Other development projects of the late 20th century included the construction of an improved road from Bertoua to Belabo, the creation of a cassava (manioc) processing complex, and the construction of a peanut (groundnut) oil factory (Ether edge, 2009). Also, Bertoua has a regional airport that is officially part of state-owned camair's network, but it has been out of service since 2003.

According to the portal of the Bertoua Urban Council (BUC), Bertoua town has several establishments, relevant to both secondary and higher education. There are thus 11 nursery schools, 30 primary schools and 10 secondary schools, including 4 technical educations, 1 Catholic private university created in 2007 ("Catholic university institute of Bertoua"), under the leadership of the bishop of the region.

I.1.5 Sanitation, drinking water and energy

Knowing that water plays important roles in our body, it is the major part of most of the body's cells (except for fat cells) and it also lubricates the brain and the joints. Since the launching of the Bertoua water project by the Cameroon government, in 2017 which was earn marked to end by June 2020, the project is far from reaching its objective as work progress has been very slow and Bertoua still suffering from water shortage.

The people of Bertoua have now resorted to or depend on water sources such as wells, and rivers which are of very poor quality and not fit for drinking. The rich can afford to buy mineral water from the market but what becomes of the poor local population in the community who cannot afford to buy processed water that is fit for drinking for their household? (Lord Fred, 2020).

Bertoua population mostly use wood for fuel due to high cost of domestic gas (8000 FCFA per 12 kg cylinder compared to 6500 FCFA with other providers). The hydrocarbon fuel stabilization fund (CSPH) decided to construct a gas filling center for the city of Bertoua to fight desertification and deforestations (BUSINESS in Cameroon).

I.2 The state of solid waste management at Bertoua

Solid Waste Management still remains a challenge to overcome by developing countries. It is crucial to any successful management to understand waste production rate, types, the characteristics and the history of the system including those factors that drive the entire system. Knowledge gained from such data helps guide policy, planning and management strategy. This chapter examines solid waste generation, collection, storage and transportation in Bertoua city. Some data and information are obtained by field observation and interview survey.

I.2.1 Solid waste management strategy at Bertoua

A. Waste Production

Most of the Municipal Solid Waste (MSW) at Bertoua is made up of Household waste due to the presence of little industries. According to the Head of landfill of Bertoua, must of plastic waste (shoes, television cub, tires) are been taken to recycle by informal sectors and it is about 1% per

3months of the total MSW produced. Sawdust is also produced due to the presence of commerce consisting of transforming timber, logging and so on. From 2011 to 2016, MSW quantities have increased from 36260.28 tons/year to more than 58837.44 tons/year respectively. Household waste production is not only a function of the development of the city but also of the standard of living of the populations, it differs according to the zones. The average ratio of the amount of household waste per capita is about 0.94 kg/day (in reference to the data collected, 2021). Waste Storage at household level is through old or adapted buckets, bags, plastics.

B. Waste Collection

Since the arrival of the company HYSACAM, cleanliness has gradually improved in certain areas of the city of Bertoua (areas that are not accessible by trucks due to the bad state of the roads). Household waste produced daily is collected by households to be stored in more or less suitable bins without any source segregation (see figure 3). This waste is then disposed in bins that are disposed by HYSACAM or directly collected by trucks. We notice that most of the bins placed by HYSACAM is by the road side precisely the national road and one part of the populations used inefficient method like wild discharge, swampy areas, and ravines to eliminate their wastes as seen in the following Figures 4, 5, 6 and 7. Let’s recall that method of elimination varies by location. There are mainly two (2) types of collection systems which are:

i. Door-to-door collection

Door-to-door collection consists, for cleaners to recover household garbage cans during rounds within the sectors concerned. At the sound of horn, households bring their trash cans, the contents of which are emptied into the compaction bin, which is the appropriate machine to perform this task. This collection method is carried out in areas of the city where the road is suitable for vehicles.

There is another type of door-to-door so called collective collection, consisting in collecting collective mobile bins made available to “large producers” like collective housing, administrations and public services, schools, bus stations, shops and restaurant. These bins have a capacity of 120 and 770 liters.

ii. Fixed point collection

Fixed point collection is a collection method which consists in collecting the garbage bins placed along the access roads with a capacity of 9 m^3 and 16 m^3 deposited in certain districts of the city. This mode mainly concerns sectors lacking or still insufficiently served by the road ways. It is carried out using machine called “ampliroll type tippers”. The collection at a fixed point also consists for the agents of cleanliness in removing the dumps of the household refuse frequent in the popular districts of the city. All the fixed points are concreted to prevent soil contamination and the populations throw their waste on the concrete instead into the bin this increases the time of collection by cleaners of HYSACAM.

It should be noted that in inaccessible areas, the cleaners do a sort of source segregation of garbage such as plastic packaging, paper, tins, cans, used clothes by means of garbage bags and the pickers to forward them to the nearest bins.

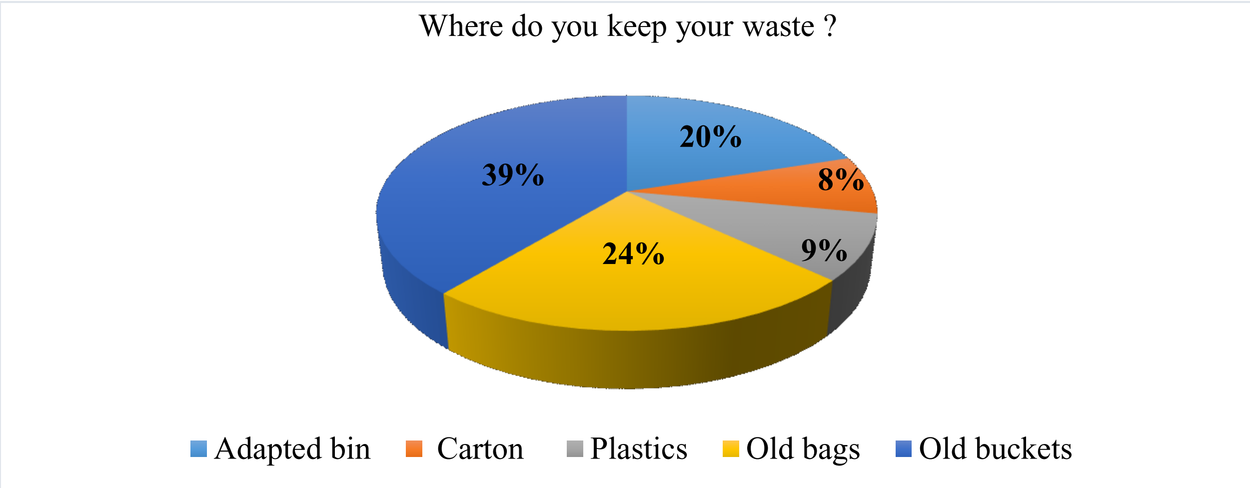


Figure 3: Mode of waste collection at household

Source: Essinga Sapock, 2013

Figure 4: HYSACAM bins by the road side at Nkolbikon 1

Figure 5: HYSACAM bin by the road side at Koume bonis

Figure 6: Waste disposal at the backward Side of the house, Bertoua II

Figure 7: Waste disposal in water streams at Tigaza

C. Waste Transport

The company in charge of the transport of SWM at Bertoua is HYSACAM. All the waste is being transported from the collection site to the landfill site which is located at Kome - bonis and it is about 3 km away from the road side. HYSACAM have three (03) compactor trucks which have a carrying capacity of ten (10) tones, three (03) Tipper trucks as seen in Figure 8 and one (01) Shovel bulldozer for the transport of waste collected.

Figure 8 : A tipper trucks entering the landfill site

D. Waste disposal

The main actions carried out at the level of the landfill commonly called ‘Treatment center of Bertoua’ is the burial of the waste in an anarchic way and during dry season, waste is being burned by bush fire (figure 9 and 10).

Figure 9 : Incineration of Landfill waste

Figure 10 : Pawpaw trees growing on waste and burned at the landfill site

The actual municipal solid waste management of Bertoua can be summarized in Figure 11.

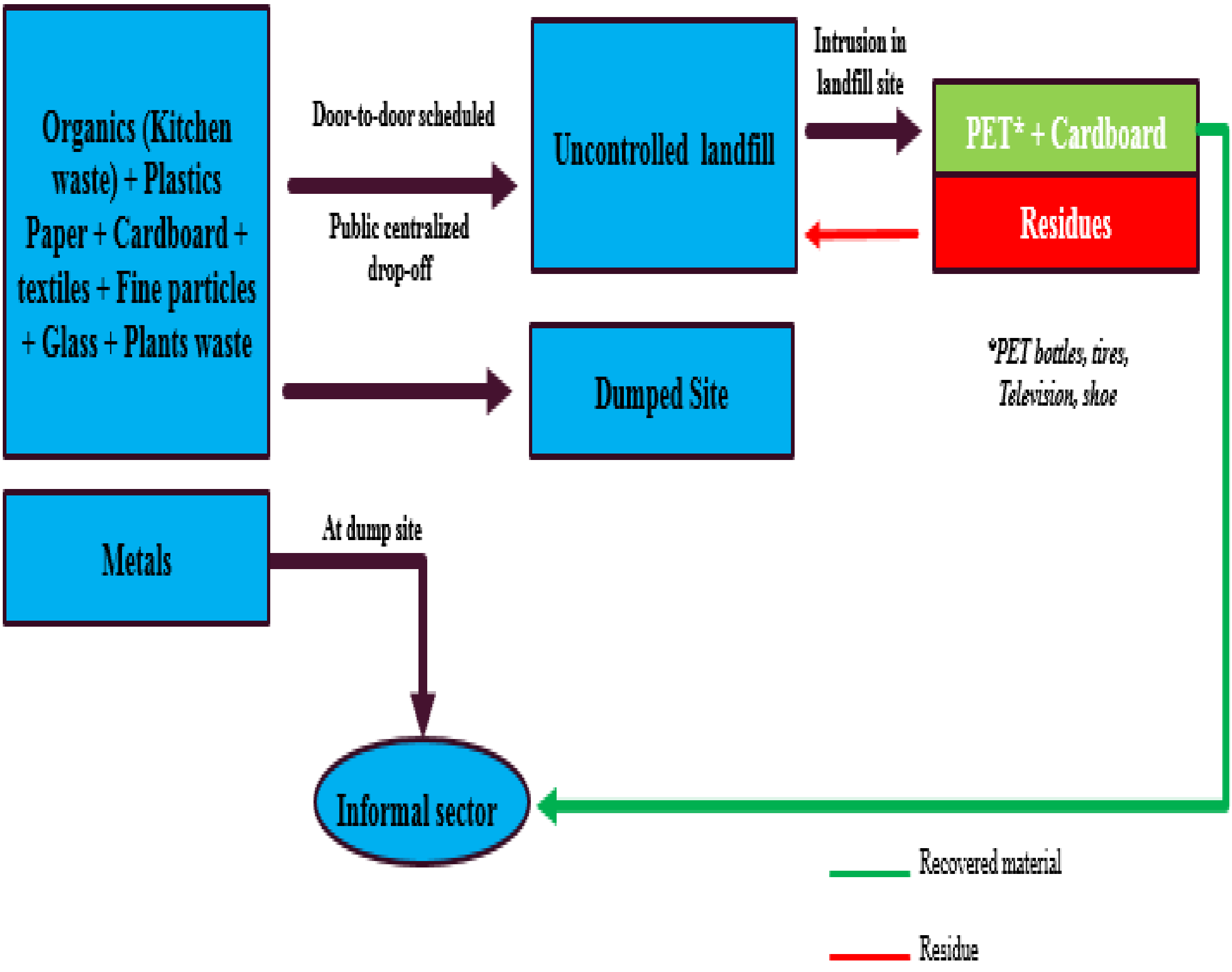


Figure 11: A simplified Municipal Solid Waste Management scheme in Bertoua

I.2.2 Institutional Framework of Municipal Solid Waste Management at Bertoua

Municipal Solid Waste (MSW) management at Bertoua is managed by many actors that works together (Table 1) but the main processes are carried out by a named company HYSACAM. Nevertheless, almost all of the household waste collected or not is being burned either intentionally or not (case of landfill waste burned by bush fire).

Table 1 : Summary of the institutional framework for household waste management at the city of Bertoua

Area of intervention	Actors implies	Action taken
Collection	HYSACAM	Daily except Sunday's door to door and fixed-point collection.
		Sweeping of paved roads and public places
	CUB	Verify that the quantity estimated by the specifications is attained.
Transport	HYSACAM	Transport waste collected to the landfill
	household	Transport waste to the bins or at the appropriate collection point.
Treatment/Disposal	HYSACAM	Burial of waste collected at the level of landfill
		Some waste is being burned by bush fire
Control	DREPDED	Inspection of landfill
		Awareness and information to the various stakeholder on the environmental aspect of management
		Technical support for the sustainable development department
	DRHDU	Quarterly meeting with the other actors on the evolution of accomplished tasks
		Approval of the choice of site for landfill
		Meeting one time per semester with HYSACAM to have a report on the tonnage
	DRSP	Awareness and information of the population on the management sanitary aspect
	CUB	Weekly follow up of the activities of HYSACAM
		Choice landfill site
		Monitoring the landfill
	Prefect	Quarterly meeting with the managing actors regarding the evolution of activities
		Annual meeting of project monitoring with other actors
Finance	CFS	Finance 80% of management activities
	CUB	Pay 20% of benefits of HYSACAM
	FEICOM	Financial assistance to the CUB

I.2.3 Environmental Problems Associated with Municipal Solid Waste at Bertoua

i. Illegal Dumping of waste

During Field observation, we have seen must of the illegal dump site are aimed to be inhabited in future. Must of the household waste is composed of kitchen waste, plastics and as time passed all biodegradable waste release biogas and leached which contaminate the soil and air inhaled. Also, there will be increase of vectors like mosquitoes, rabbits. But plastic take a longer time to degrade hence not good from the esthetic point of view and the soil will be replaced by the plastics which will make the land difficult for agriculture.

ii. Burial of Waste at the landfill site

The landfill site of Bertoua commonly called treatment center of Bertoua is an uncontrolled landfill because there no barrier, no well managed waste disposal, no geomembranes, no leachate collection pipe. We can observe the presence of pawpaw tress, which grow on waste and there is some times intrusion of the population to take valuable waste and the will be tempted to eat the pawpaw. Leachate management is also a major concern. The volume of leachate is directly correlate with precipitation rate. Municipal Solid Waste (MSW) leachate contains a wide variety of hazardous, toxic, carcinogenic chemical contaminants (EEA, 2000).

iii. Waste Burning

The act of burning is the main waste treatment carried out in Bertoua either at the level of Agricultural wastes, landfill waste, waste recovery and so on. This increased particulate matter (PM), Volatile Organic Carbon (VOC) in air and can cause respiratory and cardiovascular diseases. Also, affects vegetation and ecosystems by settling on soil and water, upsetting delicate nutrient and chemical balances.

iv. Health aspect

Poorly waste management is the main cause of many diseases. Table 2 shows a variety of disease and their causes due to the poorly solid waste management.

Table 2 : Diseases linked with waste

Disease	Parasite	Disease Vector	Breeding ground
Malaria	Plasmodium vivax Salmonella typhoid	Mosquitoes from disposal sites	Standing water, ponds, untreated landfills and open dumping
Cholera	Vibrio cholera	Mosquitoes from waste disposal sites	Standing water, ponds, untreated landfills and open dumping
Typhoid	Salmonella typhoid	Infection of humans by fleas and contaminated air	Water borne pathogens
Pneumonia	Mycoplasma pneumonia	Inhalation of contaminated air	Polluted air
Bronchitis	Mycoplasma pneumonia	Inhalation of contaminated air	Polluted air
Paratyphoid	Salmonella paratyphoid	Sucking blood from human and infected merogoite	Open dumps, standing waters and open ponds

Source: Mount Mary Hospital, 2004

I.2.4 Household Solid Waste Management constraints in Bertoua

i. Organizational constraints

Expectations due to the household waste management today differ according to the actors concerned: households want to get rid of their waste for nuisance issue; local authorities are concerned with their management that is urban aesthetic and public hygiene and private operators, while recognizing the social nature of the subject, are in search of profit. The constraints regarding the organization of waste management in Bertoua are characterized by the non-involvement of all the actors and on the other hand by the in civism of the population.

a) Non-involvement of Actors

Household waste management is an area that requires all actors to work together. However, in the town of Bertoua, not only the municipality that not really gets involved but also the other decentralized state services do not seem to want to intergrade it into their programs.

b) The in civism of the population

The incivism of the populations constitutes the fundamental cause of the bad household waste management. In isolated neighborhoods, the waste produced is thrown directly into drains or empty spaces when there is no other form of source segregation. Even in neighborhoods where the roads are passable, some households dump waste anywhere. One can then imagine the consequences on the environment: foul odors, obstruction of drainage and flooding of houses, eutrophication. These spontaneous neighborhoods (not subdivided) often cover a large area of cities and arbitrate the majority of the population (55 - 70 %) (PDU Bertoua 2012). The collection service is poorly organized not only because of the lack of access routes for the collection service but also because of sometimes of the too great distance from the habitats to the service axes. Such as:

- The deposit and abandonment of bins full of waste at the HYSACAM collection point even after the passage of the collection trucks;
- The deposit of waste in swamps, natural channels and ravines;
- The incineration of waste (grass, dead leaves);
- Dumping of household waste in pits latrines;
- Creation of dumpsites near homes.

ii. Technical constraints

Technical constraints of household waste management in Bertoua include:

- The rugged terrain and the insufficiency of the service roads which open up certain neighborhoods and deprive them of the household waste disposal service;
- The continuous extension of the urban perimeter which extends the distances for waste collection;
- The accelerated increase in the population which in turn increase the amount of waste to be collected;
- The spontaneous proliferation of habitats which is characterized by difficult access means that the rates of collection of household waste remain low;

- The very low accessibility and mobility in the neighborhood due to the deteriorated and narrowed roads and trucks;
- The absence of a real landfill as well as waste valorization.

iii. Economic constraints

The household waste management suffers broadly from the absence or the low level of collected taxes, the narrowness of the tax base, and the principle of the uniqueness of cash and cash flow which often causes late payments or reorientation of funds intended for waste collection. Indeed, the sources of funding for waste sector in Bertoua are the municipal budget. In the town of Bertoua, no financial backer is committed to financing this sector for the moment.

I.3 Electricity access at Bertoua

I.3.1 Energy Context and History at Bertoua

The Cameroonian production grid consists mainly of hydraulic and thermal power plants. Cameroon’s electric power system is made up of three power grids that are completely dependent on each other, South, North and East Interconnected Grid (SIG, NIG and EIG). The Grid East, not interconnected, which is designated EIG by analogy to the other two networks covers the eastern region of the country (“Rapport final PDER Cameroun”, 2016). The East region is provided with electricity by nearly six (6) thermal power stations which constitute an autonomous grid. According to the Energies-Media in National, projects and programming, the subsidiary of the British Investment Fund Actis has a diesel thermal power station at Bertoua which have a capacity of 16 MW (most important thermal power plant) but can only provide 8 MW daily for the city of Bertoua, Abong-Mbang, Batouri and Belabo; this is why a new diesel thermal power station of 5 MW was in construction in 2018. According to the director of production of ENEO, with all this, energy supply will be increased from 8 MW to 13 MW, for a demand of 12.350 MW. Nevertheless, there is recurring shortages at Bertoua related to lack of fuel supply (diesel) (Energies Media,). As short-term solution to reinforce the install capacity at the East region, the government bet on “the effect Lom Pangar” on the 20th September 2018 which will permit to inject at the SIG at least 80 MW of power and contribute to provide permanently to all the East population electricity in terms of quality and quantity. According to the PDER, the number of client BT per region from 2006-2014 precisely at Eastern part of Cameroon is from

14 766 to 23 047(estimated) respectively. The electricity access rate from 2015 to 2035 at Eastern part of Cameroon is estimated to be from 71% to 98% respectively. Nevertheless, there is still recurring shortage at Bertoua which limit economic development in that locality.

I.3.2 Electricity generation by source in Bertoua

Cameroon disposed of important potential of hydroelectricity of 20 GW and natural resources. Nevertheless, the petroleum production is decreasing by 12.7% between 2008 and 2009 (Gabriel, 2014). In 2009, exportation and importation of diesel have decreased at the same time, therefore by the year 2010 a decreased in exportation and increased in importation have been observed. This is due to the depletion of fuel reserve (Gabriel, 2014). In term of electricity, Cameroon possesses the second potential hydroelectric in sub-Saharan Africa, estimated around 20 GW which is equivalent to more than 115 milliards of kWh that the country may produce each year if it resources are used efficiently and sustainably (Gabriel, 2014). The equipment of production is hydraulic and thermal, and the total install capacity is around 928 MW, of which 723 MW for the three (3) hydraulic thermal power plant and 205 MW for the thirty-nine (39) fuel-fired thermal power plant.

Electricity production in Cameroon is highly dominated by hydraulic thermal power plant (76 %) which represents only 56 % of the total install capacity. The situation is unfavorable for fuel-fired thermal power station production of Eneo which owns 24 % installed, while it only produces 5 % of the total energy. This energy is produced with an availability rate of 85 % in hydroelectricity, and 80 % for fuel-fired thermal power plants. Hydroelectric installation operates on average 5339 hours on the other hand 1238 hours only for thermal production; which demonstrates the low level of use of “immobilized capacity”. For self-producers, their energy production facilities are comparatively more used than the thermal power stations of the public service concessionaire due to recurring shortage.

According to the director of ENEO of Bertoua, electricity production at Bertoua is strongly dominated by one (1) fuel thermal power plants made up of twelve (11) groups which provides eight thousand (8 000) kW per hour and some solar energy projects. Table 3 show the specification of the thermal fuel power plant group of Bertoua. Also, there will be an interconnection of a high tension of 225 V from Yaounde (SIG) by the year 2022, a hydroelectric power station from lom pangar which will be put in place in the years to come. Also, as a forest zone there is a great potential of biomass (wood waste) which can be used for biogas production and can be used as cogeneration. Self-production capacity is highly demand because the electricity availability rate does not meet their demand.

Table 3 : specification of the group engine used in thermal power station of Bertoua

Parameters	Value
Commercial name/model	CATERPILLAR 3516B
Number of cylinder/strokes	18
Cooling system	Aero water/Air
Bore & stroke	170 mm & 190 mm
Compression ratio	14.0: 1
Maximum output	1280 kW
Minimum rating	1750 kVA
Maximum rating	2250 kVA
Rated speed	1500 rpm
Engine weight	12 and 14 tons
Rating frequency	50 Hz
Rating voltage	380 to 11 000 V

Also, according to the director of Eneo of Bertoua the problems in this sector are linked to insufficient capacity of production, transmission and distribution equipment due to failure to meet renewal deadlines and generally due to maintenance (all groups do not function at the same time).

I.3.3 Final use of electricity in Bertoua

In Cameroun, according to the International Energy Agency electricity consumption in 2014 is as follows: 54.9 % by industry, 20.7 % Residential, 23.0 % commercial and public services and 1.4 % Agriculture/forestry. At Bertoua, consumption rate is mostly Residential, commercial and public services, Agricultural/forestry industries.

I.3.4 Electricity price in Bertoua

Electricity generation is mainly by thermal power plants which uses diesel. According to the Global Petrol Price, diesel average prices from 19 October 2020 to 25 January 2021 in Cameroon are 575.0 FCFA/Liter and 2176.611 FCFA/Gallon updated weekly. In term of price, the thermal power plant of Bertoua consumes 45000 Liter of diesel per day, which cost at least 25 million FCFA.

According to the decision n°_0096_/ARSEL/DG/DCEC/SDCT of the 28 may 2012_setting the sales tariffs excluding electricity taxes applicable by the company Eneo Cameroon for the year 2012. Article 1 (Appendix 1) established the selling price of electricity in Cameroon (Bertoua) which varies from 50 to 99 FCFA/kWh according to the consumption that is price increases as consumption capacity increases.

The high cost of connecting households and social establishments to the electricity network of the public service concessionaire, both in urban and rural areas. These costs vary from sixty thousand (60000) FCfA to one hundred and fifty thousand (150 000) FCFA according to the required connection standard, and can go beyond these values when moving more than sixty meters (60 m) from the network.

I.3.5 Major local pollutant linked to energy (Electricity by fuel-fired thermal power plant)

Although electricity is a clean and relatively safe form of energy when it is used, the production, the generation and transmission of electricity affects the environment. Nearly all types of energy power plants have larger effects than others which can be shown in Figure 12.

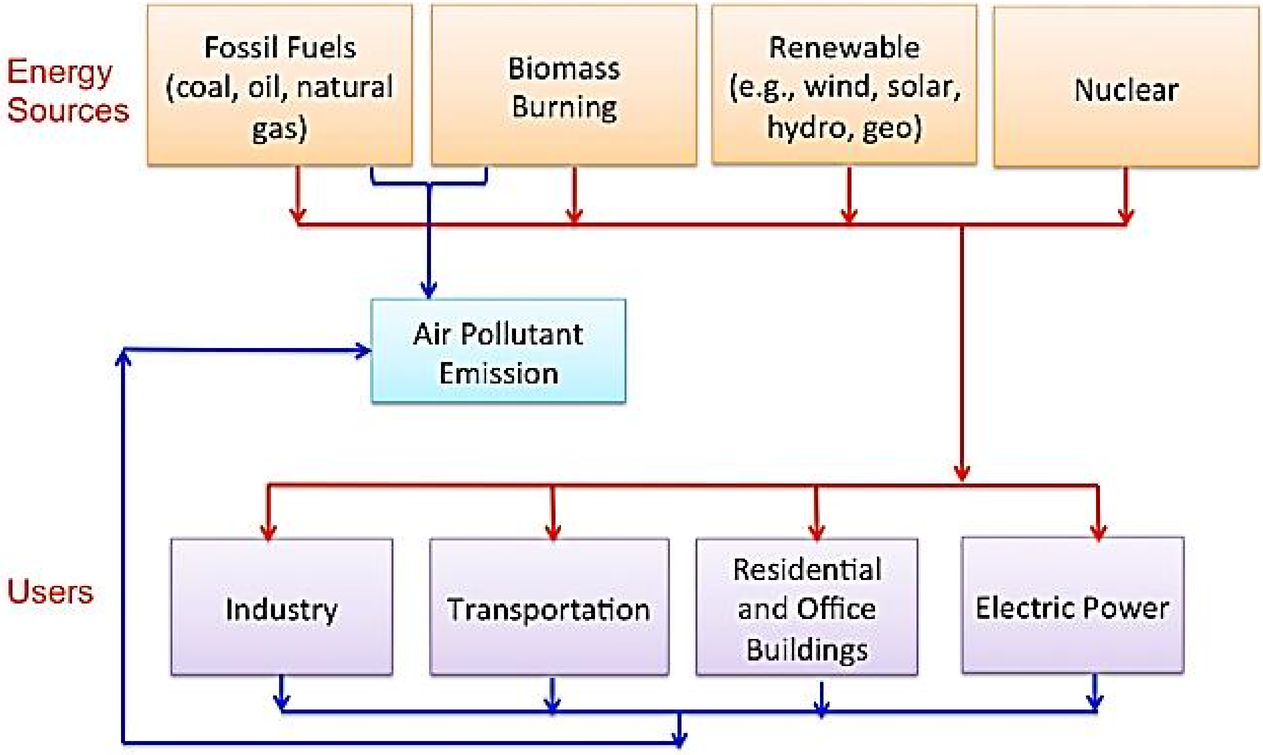


Figure 12: Key components of the global energy system. The red arrows indicate the pathways for use of different energy sources in the different sectors. The blue arrows indicate the pathway for generation of air pollutant emissions

Source: Weubbles and Sanyal, 2015

Many of the pertinent environmental issues today, such as local and regional air pollution, acid precipitation (also called acid rain), and global climate change (or global warming as it gets called by the media), can be traced primarily to emissions from the use of fossil fuels for different energy and transportation sectors. Air quality is most strongly affected by some of the short-lived species like carbon monoxide (CO), different oxides of nitrogen (NO_x), sulfur dioxide (SO_2), ozone (O_3), volatile organic compounds (VOCs), and various atmospheric particles (also called aerosols). The particles of most concern are those that can lodge deeply into the lungs; these are primarily the particle of less than 2.5 µm in diameter (called PM2.5) that are primarily produced from gases like SO_2, but includes black carbon (soot) and other very fine particles. The major sources of $PM_{2.5}$ are biomass burning and fossil fuel combustion. $PM_{2.5}$ can significantly affect human health through the cardio-vascular and pulmonary system, causing shortness of breath, asthma, other issues these effects are particularly harmful for children and the elderly.

Electricity transmission lines and distribution infrastructure that carries electricity from the power plants to customers also have environmental effects. Most transmission lines are above ground on large towers. The towers and power lines alter the visual landscape, especially when the pass through under developed areas. Vegetation near power lines may be disturbed and may have to be continually managed to keep it away from the power lines. These activities can affect native plant population and wildlife. Power lines can be placed underground, but it is a more expensive option and usually not done outside of urban areas.

Section 2: State of art

I.4 Definitions of Key Concepts

I.4.1 Waste

Waste is a left-over, a redundant product or material of no or marginal value for the owner and which the owner wants to discard (Lavagnolo, 2018).

I.4.2 Solid Waste

The term solid waste may be used to refer to municipal waste and falls under seven categories: residential (household or domestic waste), commercial, institutional, street sweeping, construction and demolition, sanitation and industrial wastes (Rush, 1999).

I.4.3 Municipal Solid Waste (MSW)

Municipal Solid Waste (MSW) refers to solid wastes from houses, streets and public places, shops, and offices which are very often the responsibility of municipal or other governmental authorities. Solid waste from industrial processes and hospital is generally not considered as municipal. However, because this waste finally ends up in the municipal waste streams, it should be taken into account when dealing with solid waste.

Rapid growing population and development related to increase in standard of living have led to rapid solid waste production as shown in Table 4 which has a negative impact on our environment (air, water and land) and health. The world generates 0.74 kilogram of waste per capita per day and an estimated 2.01 billion tons of municipal solid waste (MSW) were generated in 2016, and this number is expected to grow to 3.40 billion tones by 2050 under a business-as-usual scenario (Sataloff and al., 2018). However, waste generation is growing the fastest in Sub-

Saharan Africa, South Asia, and the Middle East North Africa regions, where, by 2050, total waste generated is expected to approximately triple, double, and double, respectively (Sataloff and al., 2018). In Cameroon, MSW generation is about 281 kg/capita yearly and 3448×10^3 t/year of collection with an efficiency of 1483×10^3 t/year by the year 2012 and about 365 kg/capita and 6601×10^3 t/ year of collection with an efficiency of 3961×10^3 t/year by the year 2025 (Scarlat and al., 2015). Increased waste generation does not, however, determine the degree of efficiency in the management of waste. The developed world is not only a great waste generator but also a better waste manager compared to the developing countries. In recent decades, there has been an increasing pressure on developing countries to reduce their waste by minimizing single utilization materials. This is to preserve depletion and degradation of natural resources including energy and reduce the amount of materials disposed in landfills. The main aim of waste management is to decrease the amount of waste generated by encouraging circular economy.

Table 4 : Global Dimension of Solid Waste production

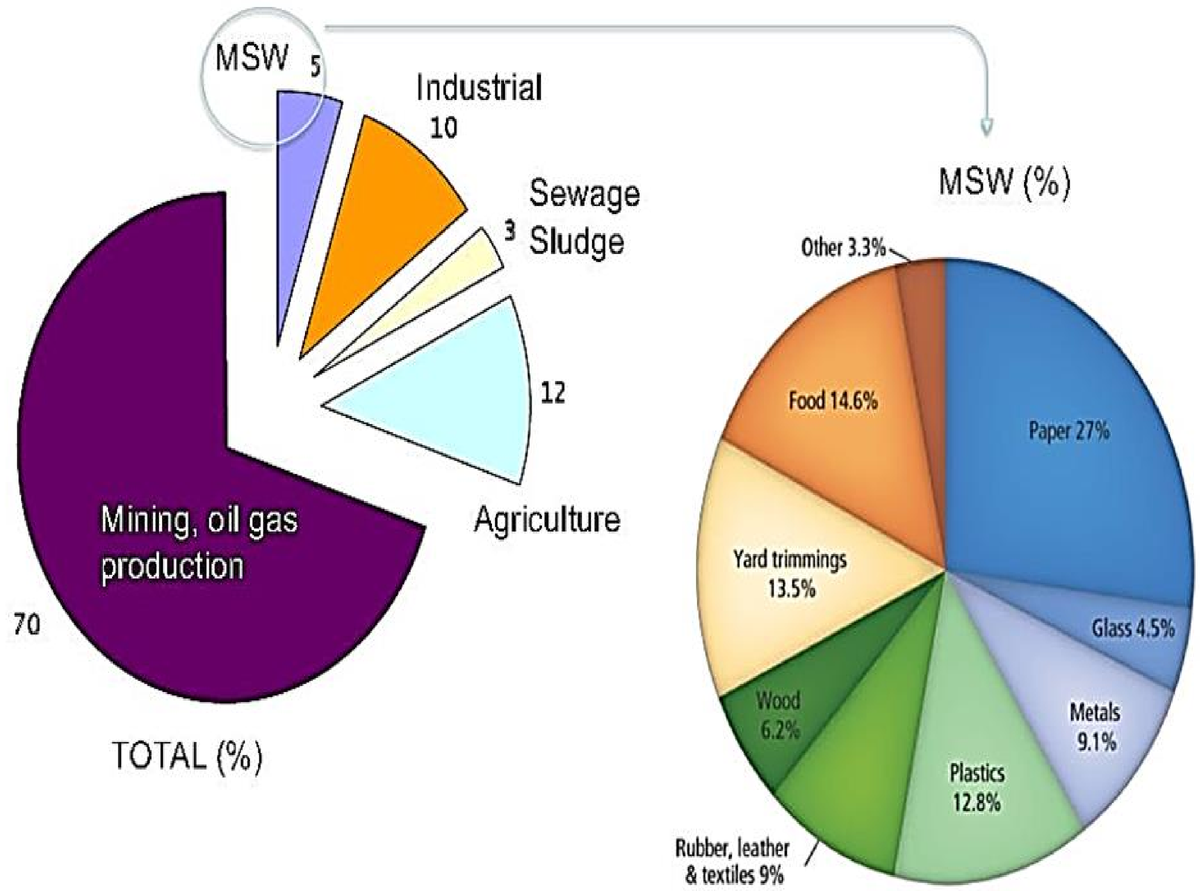
Factors	Observation
Population	By 2050 the global population is projected to be 50% larger than today i.e. 9 billion people, and 95% of that growth is expected to occur in the developing countries (Swell and Morrison 1999)
Consumption	Consumers in certain rapidly expanding non-OECD economies are emulating the ecologically challenging consumption pattern of consumers in the OECD countries.
Affluence	**Some of the highest GNP growth rates in the world are taking place in countries outside the developed world, such as China, India, Brazil and Indonesia (OECD 1997b)**
Technology	The World Bank reports that "massive levels" of industrial investment will occur in developing countries (Harahan 1995). In principle, "leap-frogging" the dirty technologies of past may be possible since many developing countries have fewer sunken costs in older "eco-unfriendly" technologies (Andrews and Socolow 1999)
Impact	**A five-fold increase in global waste generation is possible by 2025 (CSD 1997)**

Source: OECD, 2000

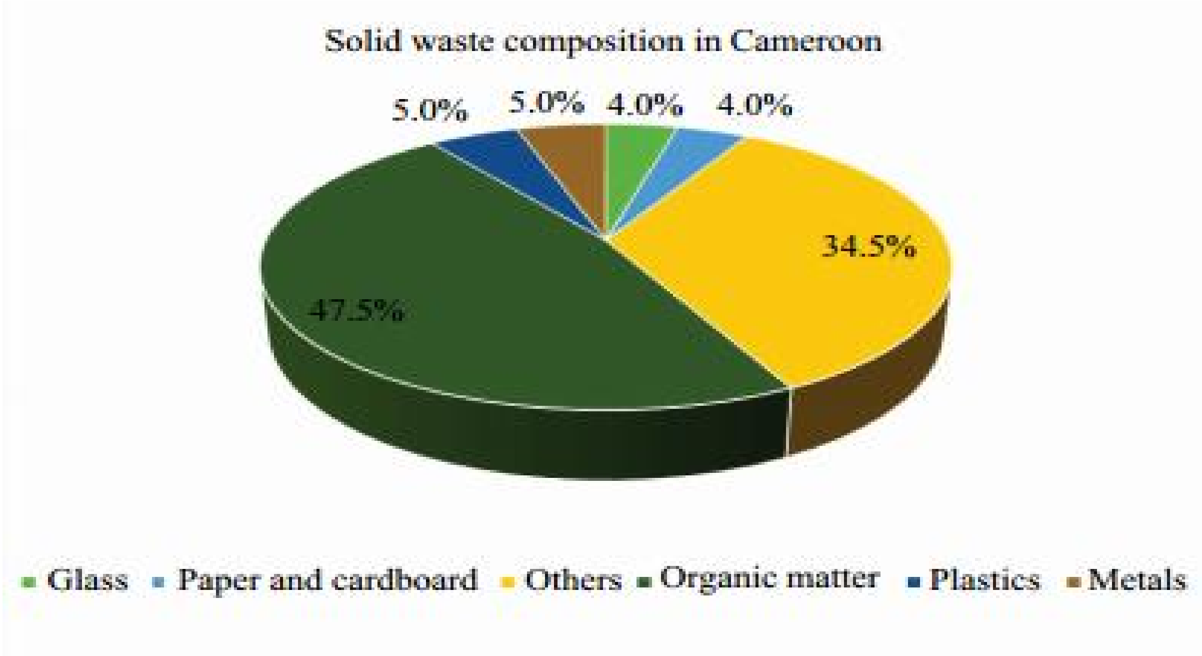
I.4.4 Municipal Solid Waste characterization

Although little or absence of source segregation in African countries, it is estimated that all over the regions the biodegradable fraction constitutes a very high rate in the MSW stream. According to Food and agricultural Organization (FAO, 2011), nearly 1.3 billion tons of food including fresh vegetables, fruits, meat, bakery, and dairy products are lost along the food supply chain.

In Africa it is estimated at 70-90 % (Yhdego, 1995; Fehr, 2000; Tanawa and al., 2002; ENCAPAFRICA, 2004), and in Asia and South Africa 30-75 % (Medina, 1998; Beukering and al., 1999). In a descending order, the general composition rates are ranged as follows: organic, ash (mostly Asia) paper, plastics, glass, metal, textile leather, bones, and feathers. The organic fraction declines in favour of the other types as incomes and western lifestyle increase. Solid waste densities range from 250-500 kg/m^3 and relative humidity of about 50-60 % (Beukering et al., 1999; Tanawa and al., 2002). The composition of municipal solid waste (MSW) in developed countries may differ but the tendency is for non-biodegradable waste to dominate over biodegradable. For example, the average for the US cities shows the following composition as seen in figure 13(a). MSW composition for some other developing countries like Cameroon which is shown in figure 13(b)



(a)



(b)

Figure 13: Main categories of waste and Municipal Solid Waste fraction in US (a) and Municipal Solid Waste composition in Cameroon (b)

Source: Lavagnolo, 2018 (a) and Waste Atlas (b).

I.4.5 Waste Management hierarchy

This is a concept that accords priority actions options to solid waste management (SWM) based on sustainability. The priority options comprise from top to bottom (most to least preferred respectively as demonstrates in Figure 14. However, the waste hierarchy content is being used as the basis of SWM with a lot of progress in focusing on prevention parameters.

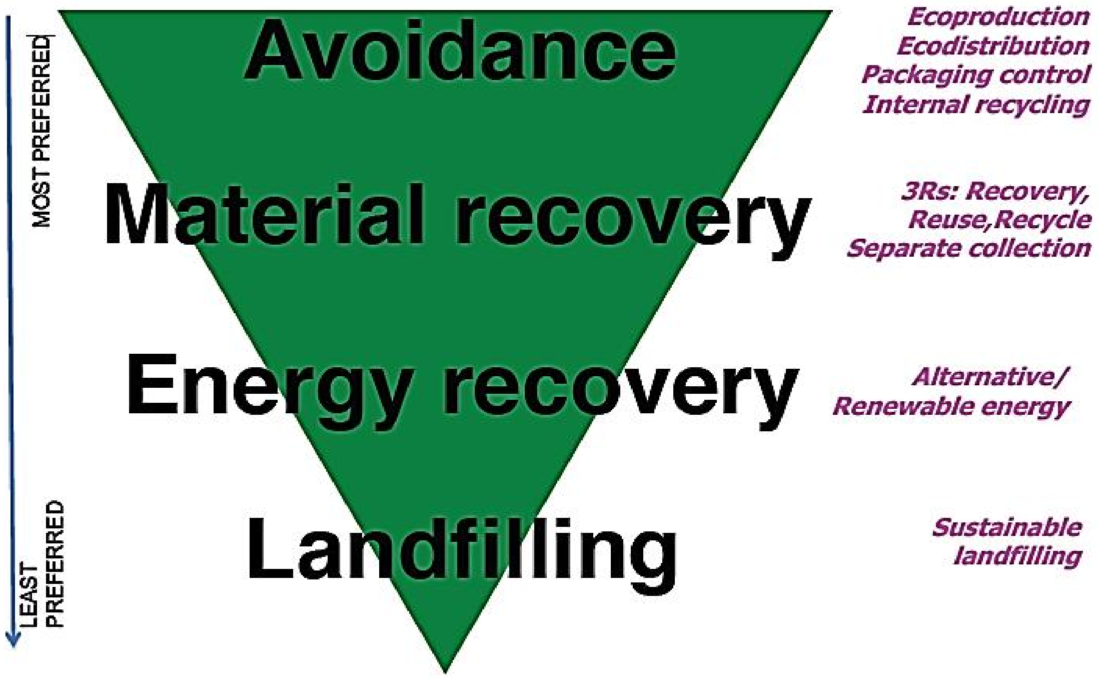


Figure 4: Waste Management Hierarchy

Source : Lavagnolo, 2018

Also, developing counties found it better to develop waste management hierarchy that is the 3S initiative: sustainability, stability and Security. It is launched by 14 African countries to address migration driven by land degradation. It aims at restoring land and creating green jobs for migrants and vulnerable groups.

I.4.6 Energy recovery

To remediate to the problem of waste production due to the world wide increased many countries have decided to practice "energy recovery" either for heat or electrical used. Not forgetting that energy is among the most essential element for a good living standard and development. Thus, to address future energy needs sustainably, renewable sources of energy must be developed as alternatives to fossil fuels.

To date, only one Waste-to-Energy (WtE) developer of note has successfully constructed and started operating a major waste-fed power project in Africa; the 120 m Reppie plant in Ethiopia. Developed by Cambridge Industries and commissioned in 2018, the facility is designed to convert 1,400 tons of waste per day from the Koshe landfill site in south-east Addis Ababa into 185 GWh of electricity per year (Davis, 2019). Other African Municipal Solid Waste (MSW)-

fed plants are at various stages of development, including Climate Neutral Group's Joburg WtE Offset Project, intended to produce 19 MW of energy from landfills gas (https://climateneutralgroup.co.za, 2019). Some biogas facilities have been up and running for few years, like the food-waste-fed Ketu Ikosi Biogas project in Lagos, Nigeria, and Tropical Power's 2.4 MW Gorge Farm Anaerobic Digestion Power Plant in Naivasha, Kenya, which runs on vegetable waste. Biojoule Kenya, the independent power producer that operates the Gorge Farm plant, signed an agreement to sell electricity to Kenya Power and lighting company (KPLC) for $0.10 per Kilowatt hour(kWh) sole power distributed in 2016 while diesel generated power, by contrast, cost $0.38 per kWh to produce (Kamadi, 2017). Large-scale production of biogas in Cameroon is carried out by the Hygiene and Sanitation Company of Cameroon (HYSACAM), responsible for the overall solid waste management in the major cities of the country. The first of such plant by this company was constructed at it landfill site in Nkolfoulou-Yaoundé in 2011 and the second at PK10 in Douala in 2014 (Muh and al., 2018). Biogas from both plants is flared instead of being used domestically due to the presence of harmful impurities.

Nevertheless, African countries face great difficulties to manage waste due to economic development, technology access, environmental legislation and population size. Also, most African countries lack regular waste collection and disposal services. There exist different types of energy recovery which are:

- **Thermochemical conversion**

This type of conversion is characterized by higher temperature and conversion rates. Three main types of thermochemical conversion are identified: Combustion, gasification and pyrolysis.

- **Biochemical conversion**

Here, Biomass with complex molecules are broken down into smaller molecules by enzymes or bacteria. Three main types of biochemical conversion are identified: Fermentation, Anaerobic digestion (AD) and Composting. Compared with other bioenergy production methods, the AD process is relatively simple and cheap and has a lower carbon impact and a higher net energy return. A major advantage of AD over other bioenergy production technologies is that it can be adaptable to a wide variety of organic wastes, regardless of their quality and moisture content. For example, the production of bioethanol or biodiesel requires sugar or lipid-rich plants, such as sugarcane and soybeans, while AD accommodate all types of biomass and waste biomass and tolerates low quality feed stocks and certain amounts of impurities, such as plastics and sand. Different from pyrolysis and incineration, which require relatively dry feedstock, the operating moisture content of AD systems can be adjusted to accommodate both dry and wet materials. Another advantage of AD is that it converts almost all raw materials into fuels and fertilizers and theoretically generates no secondary pollutants and waste streams. However, in reality, additional capital investments and management costs are required to control the process, eliminate the emissions, and transport the finished materials for land application (Xu and Li, 2017).

I.5 Anaerobic digestion (AD)

As defined from AgSTAR Handbook Glossary, Anaerobic digestion (AD) is the degradation of organic matter including manure brought about through the action of microorganisms in the absence of elemental oxygen to produce biogas.

Biogas, the metabolic product of anaerobic digestion, is a mixture of methane (CH_4) and carbon dioxide (CO_2) with small quantities of other gases such as hydrogen sulfide (H_2S) (see Table 5) (McKendry, 2002; Hiremath and al., 2009). Methane, the desired component of biogas, is a colorless, blue burning gas used for cooking, heating, and lighting (Itodo and al., 2007). Biogas is a clean, efficient, and renewable source of energy, which can be used as a substitute for other fuels in order to save energy in rural areas (Yu and al., 2008).

Table 5 : Typical composition of biogas from bio-waste

Components	Symbol	Concentration (Vol-%)
Methane	CH_4	55-70
Carbon dioxide	CO_2	35- 40
Water	H_2O	2(20°C) – 7(40°C)
Hydrogen sulphide	H_2S	20 – 20 000 ppm (2%)
Nitrogen	N_2	<2
Oxygen	O_2	<2
Hydrogen	H_2	<1
Ammonia	NH_3	<0.05

Source: adapted from Cecchi et al., 2003

AD can equally occur naturally in landfills, ocean, lakes sediment, waterlogged soil, sludge degradation and stabilization, digestive tracts.

I.5.1 Factors influencing anaerobic digestion (AD)

The main aspect that influence anaerobic digestion are:

- **Temperature**

Temperature is one of the most important parameters that affect the growth of anaerobic microbes. Generally, biological activity doubles for every 10 °C increase in temperature within the optimal range due to the enhancement of enzymatic activity at high temperatures. Although anaerobic microorganisms are viable at different temperatures, methanogens can be classified into three groups based on their optimal growth temperatures, namely, psychrophilic, mesophilic, and thermophilic (Figure 15)

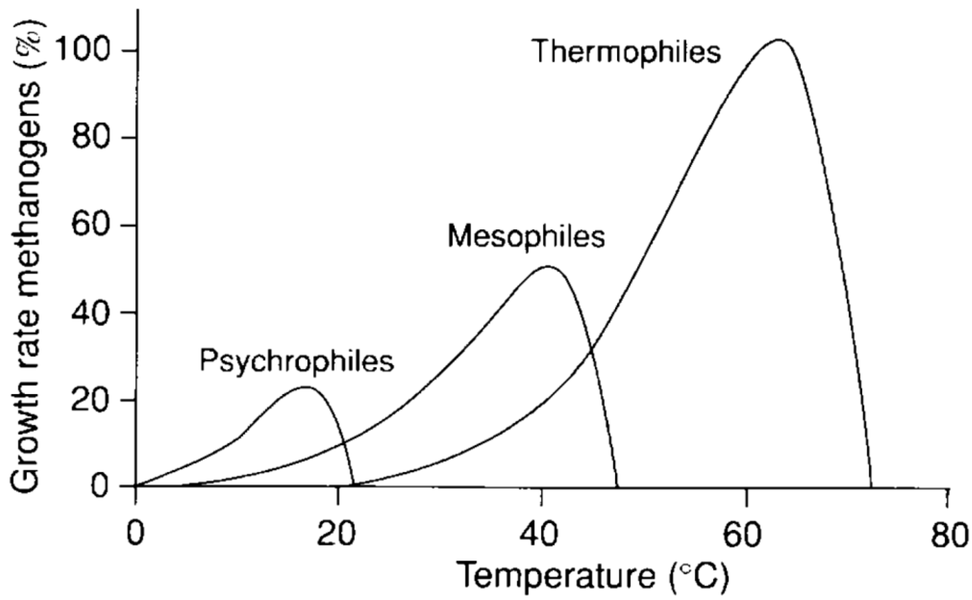


Figure 5 : Relative growth rate of pschrophilic, mesophilic, and thermophilic methanogens
Source: lettinga and al., 2001

- **pH**

Besides temperature, pH is another critical parameter for microbial growth, and a slight shift in pH from the optimum range will adversely affect biogas production. The optimum pH is 5.5-6.5 for fermentative bacteria and 7.8-8.2 for methanogesis. Since methanogens are more susceptible to pH change and have a lower growth rate than other microbes in an AD system, the operating pH for AD is usually controlled at around 7, or a two-stage system can be used in which the acid production and methane production phases are conducted in separate reactors, each operating at its optimal pH value (Figure 16)

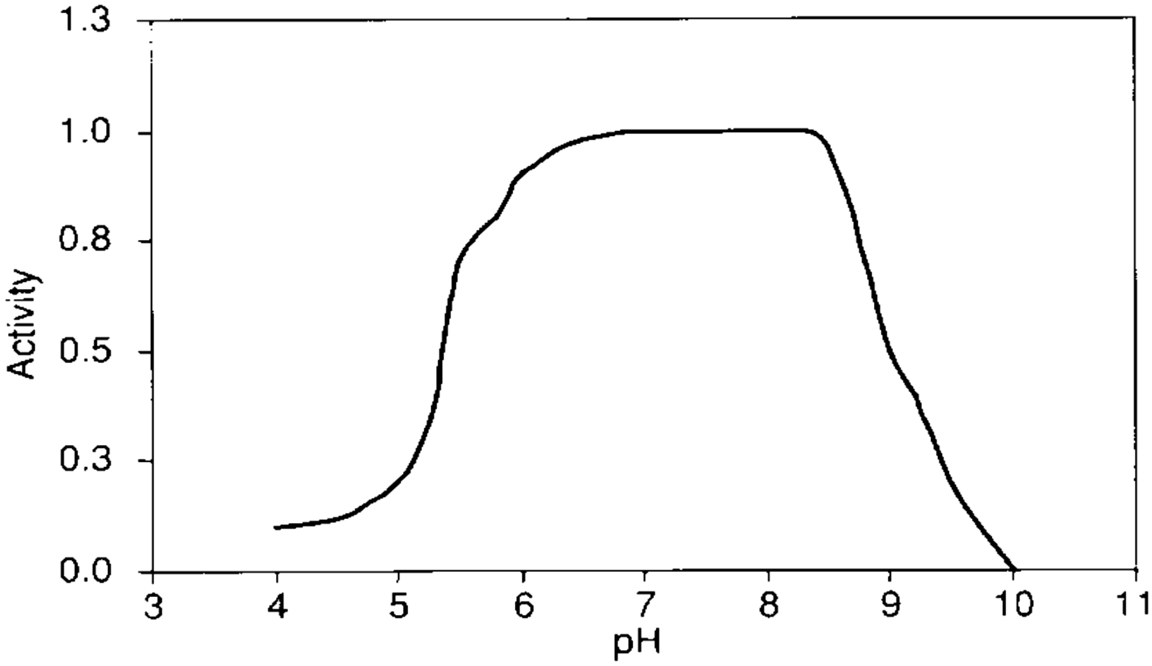


Figure 6: pH dependence of methanogenic activity
Source: Speece, 1996

- **Carbon-to-Nitrogen Ratio**

Carbon and Nitrogen are two fundamental nutrient elements for microbial growth: Carbon is used as energy source, and nitrogen is used for protein and nucleic acid synthesis. The macronutrients required for Anaerobic Digestion (AD) are often estimated based on the carbon-to-nitrogen (C/N) ratio for AD is 20-30, which is calculated, based on the nutrient requirements of microbial biomass synthesis.

In an AD process, high C/N ratios will reduce the biodegradation rate due to the lack of nitrogen and over production of Volatile Fatty Acids (VFAs), whereas low C/N ratios tend to produce excessive ammonia that generates offensive odors and inhibits the anaerobic microbes.

- **Organic loading Rate (OLR)**

The degree of starvation of microorganisms in biological systems is dependent on the OLR. OLR can be estimated through equation (1), where OLR is the organic loading rate [kgVS $(m^3 day)^{-1}$], V is the volume [m^3], Q is the daily flow [kg/day], and VS is the volatile solids [kgVS $(kg)^{-1}$] (Kothari et al., 2014). At high OLR, a fast-microbial growth (but intoxication may occur with high quantities of organic matter) takes place whereas at a low OLR microorganism starvation takes place (Sunil and al., 2018). However, if the applied OLR is too high, microorganism could not use up all produced organic acids and causes acidic state of the digester (Liu and Tay, 2004).

$$OLR = \frac{Q \times S}{V} \quad (1)$$

- **Retention time**

Hydraulic retention time (HRT) can be defined as the time required for a complete breakdown of organic matter or the time in which the organic material remains in the bio digester. HRT can be defined by equation (2), where HRT is the hydraulic retention time (day), V is the volume (m^3), and Q is the daily flow (m^3/day) (Kothari et al., 2014).

$$HRT = V/Q \quad (2)$$

HRT is the key parameter that affects biochemical properties of organic materials (Sunil and al., 2018). The HRT plays an important role in anaerobic digestion (AD) especially for methanogens at low operational temperatures (Halalsheh et al., 2005). The HRT should be long enough to provide sufficient methanogenic activity. Methanogenesis starts at HRT between 5 and 15 days at 25 °C and between 30 and 50 days at 15 °C (Halalsheh et al., 2005); however, it again depends on characteristics of feeding materials.

- **Moisture content in feedstock**

A study on the effect of moisture content ranged from 97 to 89 % on Anaerobic Digestion (AD) of sludge showed that the amount of methane yield was decreased from 330 to 280 mL/g VS (Fujishima et al. 2000). The reason behind this reduction of methane yield was the decrease in removal efficiency of carbohydrate from 71 to 28 % due to decrease in moisture content in the feedstock during AD process (Fujishima et al. 2000). This suggests that optimum level of moisture content is necessary for AD process.

I.5.2 Types of feedstock for Anaerobic Digestion related to their sources

Biogas can be produced from a broad range of feedstock's that are suitable for anaerobic digestion (AD). Most of the existing installations are processing residual sludge from wastewater treatment plants. Other facilities are processing wastes from chicken processing, juice processing, brewing, and dairy production. However, the range of potential waste feedstock's is much broader including: municipal wastewater, residual sludge, food waste, food processing waste water, dairy manure, poultry manure, aquaculture wastewater, seafood processing wastewater, yard wastes, and municipal solid wastes (MSW) which can be summarized in Table 6.

Table 6 : Various feedstock from different sources

Municipal	Agriculture	Industry
Organic fraction of municipal solid waste (« bio waste »)	Manure	Slaughter house waste
	Energy crops	Food processing waste
Human excrete	Algal biomass	Biochemical waste
	Agro-industrial waste	Pulp and paper waste

Source: Vögeli and al., 2014

Biogas yield can be made from most biomass and waste materials regardless of the composition and over a large range of moisture contents, with limited feedstock preparation see Table 7. Feedstock's for biogas production may be solid, slurries, and both concentrated and dilute liquids. In fact, biogas even be made from the left-over organic material from both ethanol and biodiesel production.

Table 7 : Biogas yield recorded from anaerobic digestion (AD) of organic solid waste

Substrate	Methane yield (L/ kg VS)
Palm oil mill waste	610
Municipal Solid waste	360-530
Fruit and vegetable wastes	420
Food waste	396
Rice straw	350
Household waste	350
Swine manure	337
Maize silage and straw	312
Food waste leachate	294
Lignin-rich organic waste	200

Source: Khalid and al., 2011

When considering biogas production from a feedstock, the volatile solid (VS) content of the material is as important as the total solid (TS) content, since it represents the fraction of the solid material that may be transformed into biogas (figure 17). The available percentage of TS and VS of different feed stocks can be shown in Table 8.

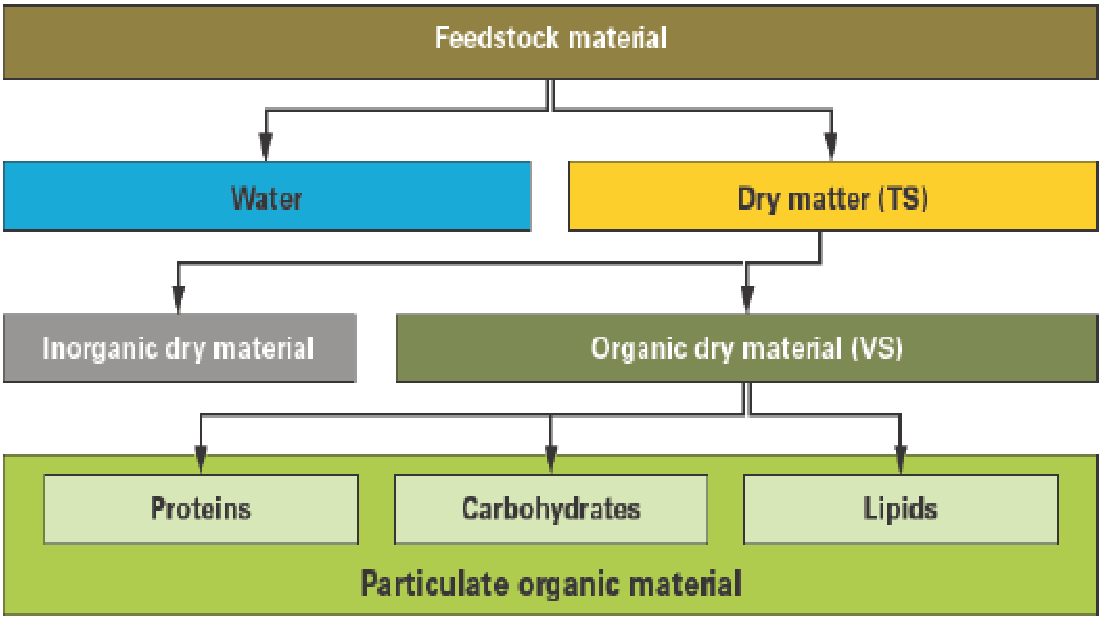


Figure 7: Classification of feedstock material

Source: Adapted from Müller, 2007

Table 8 : Total Solids (TS) and Volatile Solids (VS) of bio-waste

Substrate	TS (% of raw waste)	VS (% of TS)	Literature Source
Spent fruits	25-45	90-95	Deublein and steinhauser (2011)
Vegetable wastes	5-20	76-90	Deublein and steinhauser (2011)
Market wastes	8-20	75-90	Deublein and steinhauser (2011)
Leftovers (canteen)	9-37	75-98	Deublein and steinhauser (2011)
Overstored food	14-18	81-97	Deublein and steinhauser (2011)
Fruit wastes	15-20	75-85	Gunaseelan (2004)
Biowaste	25-40	50-70	Eder and Schulz (2007)
Kitchen waste	9-37	50-70	Eder and Schulz (2007)
Market waste	28-45	50-70	Eder and Schulz (2007)

Source: Adapted from Vögeli and al., 2014

I.5.3 Description of the anaerobic digestion phases

The synergistic process by the consortium of anaerobic microorganism can generally be classified into 4 stages: Hydrolysis, Acidogenesis, acetogenesis, and methanogenesis as shown in Figure 18.

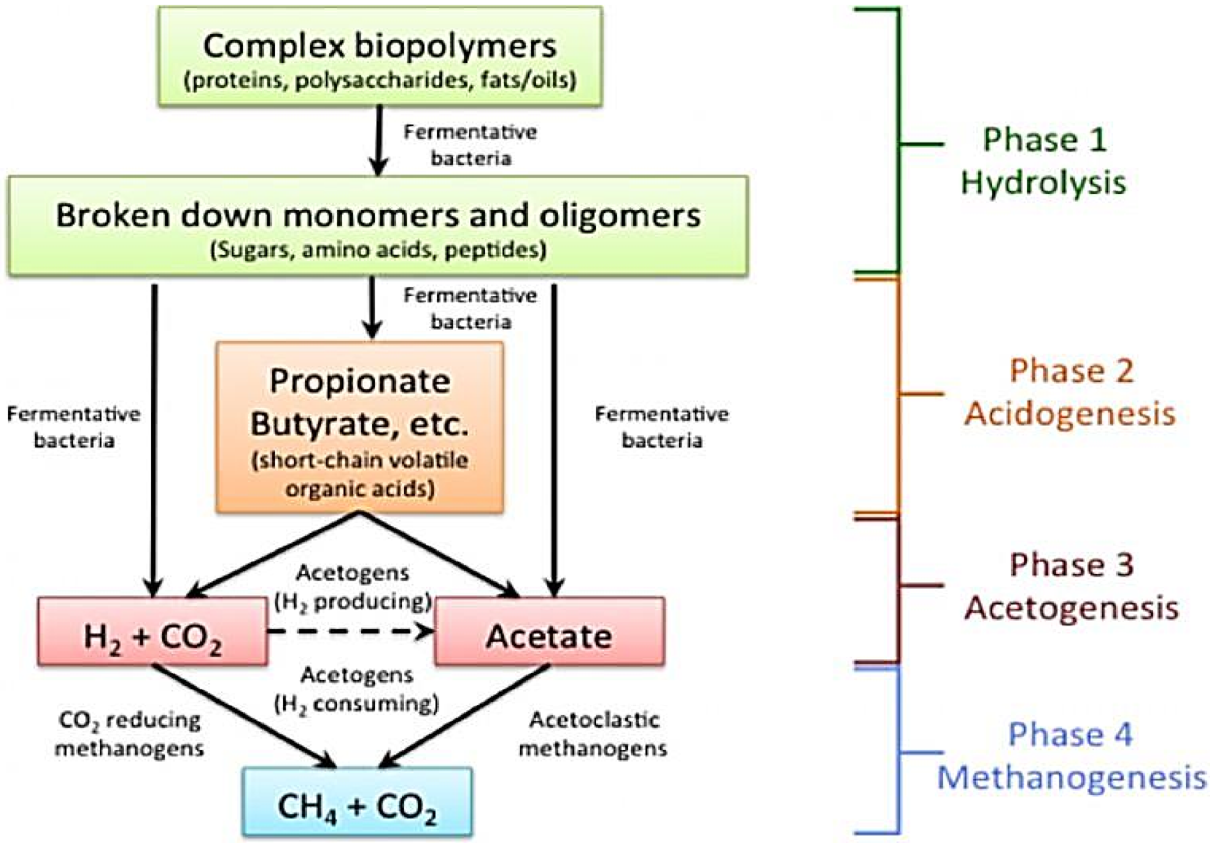


Figure 8: Four Phases towards Biogas Production
Source: Renewable energy resources lecture note

- **Hydrolysis**

It is the first phase of AD. Organic matter consists of particulate, water-insoluble polymers such as carbohydrates, lipids and proteins. Insoluble polymers cannot penetrate cellular membranes and are therefore not directly available to the microorganisms. During hydrolysis, appropriate strains of hydrolytic bacteria excrete hydrolytic enzymes (Shah and al., 2014) which break up the insoluble polymers to soluble mono and oligomers. Carbohydrates are converted to sugars, Lipids are broken down to long-chain of fatty acids and proteins are split into amino acids (Gumisiriza and al., 2017).

- **Acidogenesis**

It is the second phase of AD where the soluble molecules are converted by acidogens to acetic acid and other longer volatile fatty acids (VFA), alcohols, carbon dioxide and hydrogen on acidogenesis. The foremost acids produced are acetic acid (CH_3COOH), propionic acid

(CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), and ethanol (C_2H_5OH). Other acid formers are *Clostridium*, *Peptococcusanerobus, lactobacillus*, and *Actinomyces* (Karuppiah and Azariah, 2019).

- **Acetogenesis**

Here, the longer VFAs and alcohols are oxidized by proton-reducing acetogens to acetic acid and hydrogen. An acetogenesis reaction is shown below:

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

- **Methanogenesis**

In the last phase of the process, methanogens use acetic acid or carbon dioxide and hydrogen, to produce methane and carbon dioxide. Several bacteria contribute to methanogenesis, including: *Methanobacterium, methanobacillus, methanococcus*, and *methanosarcina*, etc. (Toraman, 2020).

I.5.4 Types of number of stages

Considering feed stocks that have undergone pre-treatment for changing the material composition by either: Manual sorting (reject of foreign material), Magnetic separation of metals, Ballistic separation, f.e. air classification, up-current classification, Sink-float separation, screening to separate in different particle sizes, adding nutrients, Mixing of different inputs. There exist mainly three (3) different systems which are:

- **One-stage system**

In one-stage systems all the AD phase occurs simultaneously in a single reactor (Vandevivere and al., 2002). About 90 % of the full-scale plants currently in use in Europe for AD of organic fraction Municipal Solid Waste (FMSW) and bio-wastes rely on one-stage systems and these are approximately evenly split between 'wet' and 'dry' operating conditions (De Baere, 1999). Biological performance of one-stage systems is, for most organic wastes, as high as that of two-stage systems, provided the reactor is well designed and operating conditions carefully chosen (Weiland, 1992). While the one-stage wet systems had initially been inspired from technology in use for the digestion of organic slurries, research during the 80's demonstrated that biogas yield and production rate were at least as high in systems where the wastes were kept in their original solid state, i.e. not diluted with water (Spendlin and Stegmann, 1988; Baeten and Verstraete, 1993; Oleszkiewicz and Poggi-Varaldo, 1997).

- **Two-stage systems**

The rationale of two- and multi-stage systems is that the overall conversion process of Organic Fraction MSW to biogas is mediated by a sequence of biochemical reactions which do not necessarily share the same optimal environmental conditions (chapter 1) (Vandevivere and al., 2002). In fact, the main advantage of two-stage systems is not a putative higher reaction rate, but rather a greater biological reliability for wastes which cause unstable performance in one-stage systems (Vandevivere and al., 2002). It should be noted however that, in the context of industrial applications, even for the challenging treatment of highly degradable bio wastes, preference is given to technically-simpler one-stage plants. A distinction is made between two-stage systems with and without a biomass retention scheme in the second stage. The reason for using this criterion is that the retention of biomass within a reactor is an important variable in determining the biological stability of the digester (Vandevivere and al., 2002).

- **Batch systems**

In batch systems, digesters are filled once with fresh wastes, with or without addition of seed material, and allowed to go through all degradation steps sequentially in the 'dry' mode, i.e. at 30-40 % TS. Though batch systems may appear as nothing more than a landfill-in-a-box, they in fact achieve 50- to 100-fold higher biogas production rates than those observed in landfills because of two basic features. The first is that the leachate is continuously recirculated, which allows the dispersion of inoculant, nutrients, and acids, and in fact is the equivalent of partial mixing. The second is that batch systems are run at higher temperatures than that normally observed in landfills (Vandevivere and al., 2002).

I.5.5 Biogas Technologies (Digester types)

There exist different types of biogas digesters but only three main types of digesters that are implemented in developing countries which are the fixed-dome digester, the floating-drum digester and the tubular digester, all of which are wet digestion systems operated in continuous mode under mesophilic conditions (Vögeli and al., 2014). Table 9 gives the first comparison of the different types of anaerobic digestion (AD).

Table 9 : comparison of the different types

Factors	Fixed dome	Floating drum	Tubular design	Plastic containers
Gas storage	Internal Gas storage up to 20 m^3 (large)	Internal Gas storage drum size small	Internal eventually external plastic bags	Internal Gas storage drum sizes small
Gas pressure	Between 60 and 120 mbar	Up to 20 mbar	Low around 2 mbar	Low around 2 mbar
Skills of contractor	High masonry, plumbing	High; masonry, plumbing, welding	Medium; plumbing	Low; plumbing
Availability of material	Yes	Yes	Yes	Yes
Durability	Very high> 20 years	High; drum is weakness	Medium; Depending on chosen liner	medium
Agitation	Self-agitation by Biogas pressure	Manual steering	Not possible; plug flow type	Evtl Manual steering
Sizing	6 to 124m3 digester vol	Up to 20 m3	Combination possible	Up to 6 m3 digester vol
Methane emission	High	Medium	low	Medium

Source: energypedia, n.d.

i. **The fixed-dome digester**

A fixed-dome plant consists of a digester with a fixed non-movable gas holder, which sits on top of the digester. The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferrocement exist see Figure 19. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, that is with the height differences between the two (2) slurry levels. The main advantage and disadvantage of fixed-dome with respect to another digester is seen in Table 10.

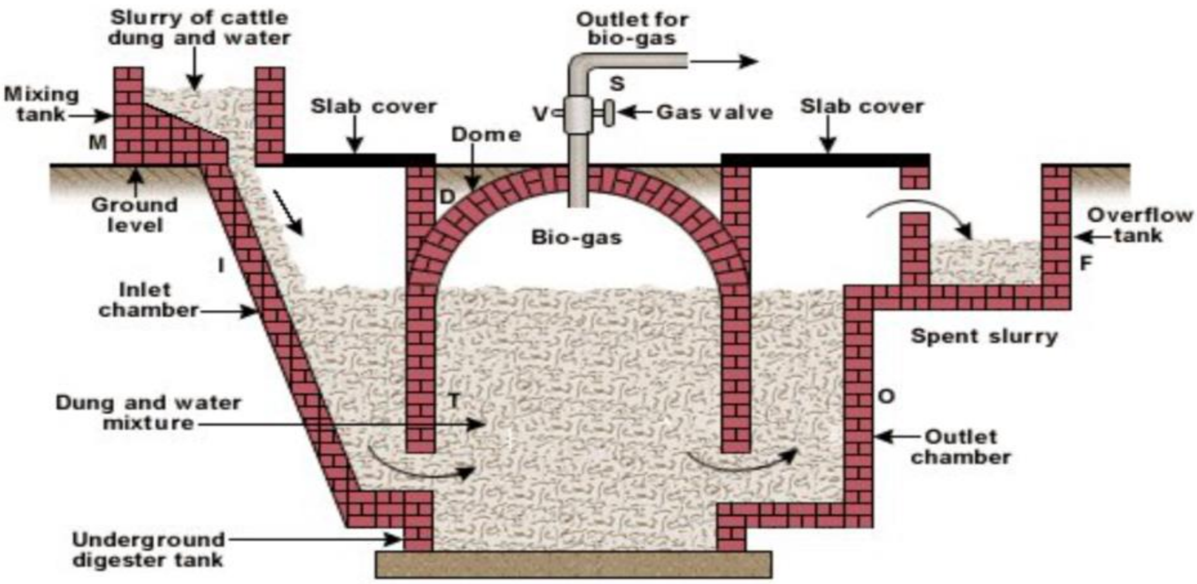


Figure 9 : fixed-dome type bio-gas plant
Source: Saleh A., March 2012

Table 10 : Advantages and disadvantages of fixed-dome digester

Advantages	Disadvantages
Low initial costs	The frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas)
Long useful life-span	Difficult to repair once constructed as the reactor is located under soil
No moving or rusting parts involved	Difficult to construct in bedrock
Basic design is compact, saves space and is well insulated	Special sealing is required for the inside plastering of the gasholder (e.g. bee wax -engine oil mixture, acrylic emulsion)
Underground construction saves space and protects the digester from temperature changes	Fluctuating gas pressure depending on volume of stored gas
The construction provides opportunities for skilled local employment	Gas leaks may occur when not constructed by experiences masons

Source: Kossmann et al., undated; energypedia, undated

ii. The floating-drum digester

Floating-drum plants consist of an underground digester (cylindrical or dome-shaped) and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored see Figure 20. The gas drum is prevented from tilting by guiding frame. When biogas is produced, the drum goes down. The digester is usually made of brick, concrete or quarry-stone masonry with plaster. The gas drum normally consists of 2.5 mm steel sheets for the side and 2 mm sheets for the top. Example of floating-drum plants: KVIC model, Pragati model, Ganesh model and BORDA model (energypedia, n.d). The main advantage and disadvantage of floating-drum with respect to another digester is seen in Table 11.

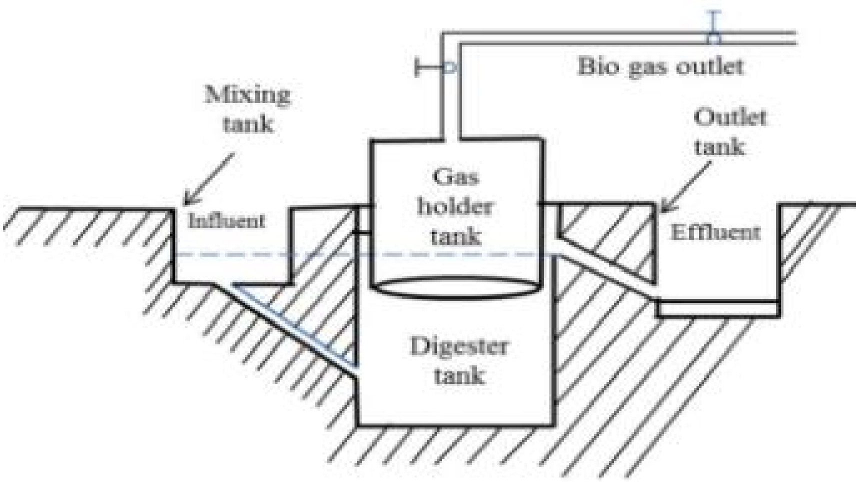


Figure 20 : simple floating-drum digester
Source: Rahman and al., 2017.

Table 11 : Advantages and disadvantages of floating-drum digester

Advantages	Disadvantages
Simple and easy operation	High material costs for steel drum
The volume of stored gas is directly visible	Susceptibility of steel parts to corrosion (because of this, floating-drum plants have a shorter life span than fixed-dome plants)
Constant gas pressure	Regular maintenance costs for the painting of the drum (if made of steel)
Relatively easy construction	If fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the scum layer (if gasholder floats on slurry)
Construction errors do not lead to major problems in operation and gas yield	

Source: kossmann and al., undated

iii. The tubular digester

Tubular digesters are similar to fixed dome digesters in that they are constructed in ground; however, they are normally constructed from low cost polyethylene tubing (lüee M., 2010), with separate storage bag for the biogas see Figure 21. The first plastic tubular digesters were installed in Colombia and Ethiopia in the 1980s by Botero and Preston (Botero and Preston, 1987). After visiting the installed plastic tubular digesters in Colombia in 1992, a Vietnamese group designed a tubular digester using a polyethylene tube and PVC piping. This new design had a lower capital cost compared with using plastic bags. By 1995, more than 800 polyethylene tubular digesters were installed in Vietnam and 100 in Tanzania (An and al., 2014). This type of digester is now commonly referred to as the Taiwanese-model, double tubular polyethylene bag digester. The main advantage and disadvantage of tubular digester with respect to another digester is seen in Table 12.

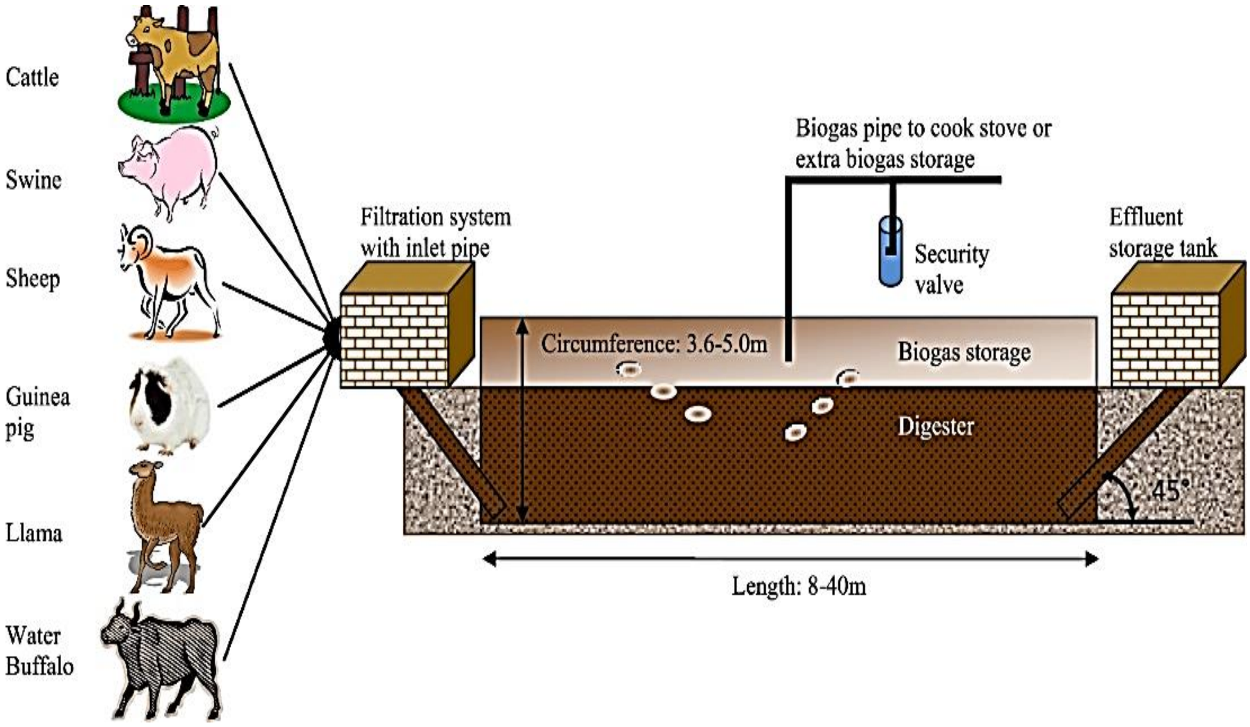


Figure 21 : Schematic representation of the Tubular digester
Source: Maureen and al., 2016

Table 12 : Advantages and disadvantages of tubular digester

Advantages	Disadvantages
Low construction cost	**Relatively short lifespan**
Ease of transportation	Susceptibility to mechanical damage
Easy to construct	**Material usually not available locally**
High digester temperatures in warm climates	Low gas pressure requires extra weights
Uncomplicated emptying and maintenance	**Scum cannot be removed from digester**
Shallow installation depth suitable for use in areas with high groundwater table or hard bedrock	Local craftsmen are rarely in a position to repair a damaged balloon

Source: kossmann and al., undated

I.6 Thermal power station (TPS)

TPS is the most conventional source of electric power (electrical 4U, 2020). TPS is also referred as coal thermal power plant and steam turbine power plant (electrical 4U, 2020). The schematic representation of TPS can be seen in Figure 22. The basic working principle of a thermal power station and its typical components are:

Coal: In a coal based thermal power plant, coal is transported from coal mines to the generating station. Generally, bituminous coal or brown coal is used as fuel. The coal is stored in either 'dead storage' or in 'live storage'. Dead storage which is used generally 40 days' backup coal storage which is used when coal supply is unavailable. Live storage is a raw coal bunker in boiler house. The coal is cleaned in a magnetic cleaner to filter out if any iron particles are present which may cause wear and tear in the equipment. The coal from live storage is first crushed in small particles and the taken into pulverizer to make it in powder form. Fine powdered coal undergoes complete combustion, and thus pulverized coal improves efficiency of the boiler. The ash produced after the combustion of coal is taken out of the boiler furnace and then properly disposed. Periodic removal of ash from the boiler furnace is necessary for the proper combustion.

Boiler: The mixture of pulverized coal and air (usually preheated air) is taken into the boiler and then burnt in the combustion zone. On ignition of fuel a large fireball is formed at the center of the boiler and large amount of heat energy is radiated from it. The heat energy is utilized to convert the water into steam at high temperature and pressure. Steel tubes run along the boiler walls in which water is converted in steam. The flue gases from the boiler make their way through super heater, economizer, air preheated and finally get exhausted to the atmosphere from the chimney.

- **Superheater**: the super heater tubes are hanged at the hottest part of the boiler. The saturated steam produced in the boiler tubes is superheated to about 540°C in the super heater. The superheated high pressure steam is then fed to the steam turbine.
- **Economiser**: An economizer is essentially a feed water heater which heats the water before supplying to the boiler.
- **Air pre-heater**: The primary air fan takes air from the atmosphere and it is then warmed in the air pre-heater. Pre-heated air is injected with coal in the boiler. The advantage of pre-heating the air is that it improves the coal combustion.

Steam turbine: High pressure super-heated steam is fed to the steam turbine which causes turbine blades to rotate. Energy in the steam is converted into mechanical energy in the steam turbine which acts as the prime mover. The pressure and temperature of the steam falls to a lower value and it expands in volume as it passes through the turbine. The expanded low-pressure steam is exhausted in the condenser.

Condenser: the exhausted steam is condensed in the condenser by means of cold-water circulation. Here, the steam loses its pressure as well as temperature and it is converted back into water. Condensing is essential because, compressing a fluid which is in gaseous state requires a huge amount of energy with respect to the energy required in compressing liquid. Thus, condensing increases efficiency of the cycle.

Alternator: the steam turbine is coupled to an alternator. When the turbine rotates the alternator, electrical energy is generated. This generated electrical voltage is then stepped up with the help of a transformer and then transmitted where it is to be utilized.

Feed water pump: the condensed water is again fed to the boiler by a feed water pump. Some water may be lost during the cycle, which is suitably supplied from an external water source.

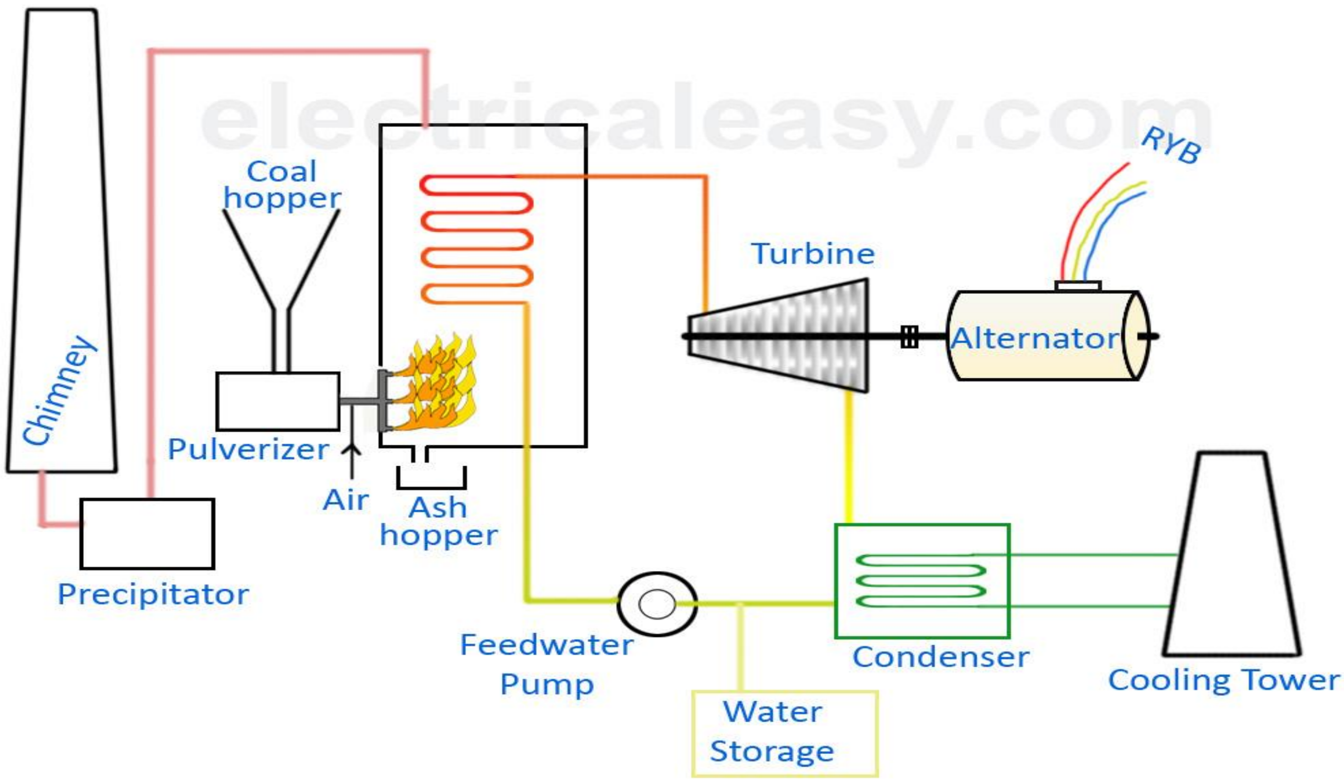


Figure 22: Thermal power plant
Source: **https://1.bp.blogspot.com,** accessed 23/01/2021

It functions according to ranking cycle this can be explain as follows; After the passage of the steam through the steam turbine, it is condensed in a condenser and again fed back into the boiler to become steam. A simplified functioning is as follow,

1. First the pulverized coal is burnt into the furnace of steam boiler.
2. High pressure steam is produced in the boiler.
3. This steam is then passed through the super heater, where if further heated up.
4. This super-heated steam is then entered into a turbine at high speed.
5. In turbine this steam force rotates the turbine blades that means here in turbine the stored potential energy of the high-pressured steam is converted into mechanical energy.

Hybrid system of thermal power station diesel-biogas

Systems that combine renewable energy and traditional power generation such as diesel generators are called hybrid power systems (Journeay-Kaler and Mofor, 2013).

I.7 International and National Legislations governing Environment in Cameroon

I.7.1 International legislations

Due to environmental concerned several texts such as conventions and protocols related to environmental management have been put in place worldwide. We will successively list conventions and protocols of which the Cameroon state has ratified.

a) Conventions

It can be defined according to the law as the agreements concluded between states or subjects of international law with a view to produce legal effects in their mutual relation. The following are some conventions ratified by Cameroon in relation to environmental protection

- Convention of Vienne for the ozone layer protection
- The convention of Stockholm
- The convention of Rio
- The convention of Bamako on the ban on importing hazardous waste into Africa, on the control of Trans boundary movement and on the management of hazardous waste produced in Africa.

b) Protocols

It can be defined according to the law as the agreement or treaty between states, and used more specifically to designate an agreement that completes a previous agreement. The following are some protocols ratified by Cameroon in relation to environmental protection at different time

- The protocol of Kyoto on climate change
- The protocol of Montreal relative on substances that deplete the ozone layer

I.7.2 National Legislation

Several texts are related to environmental management in Cameroon. The constitution which is the highest legal standard has helped to erect the human right to the environment into a fundamental right. Many laws and regulations govern the management of household waste and electricity in Cameroon which are:

a) Household waste management

- Law 96/12 of the 05th August 1996 on the framework law relating to environmental management.
- The Law 98/005 of 14 April 1998 bearing water regime.
- The Decree n°2012/2809/PM of September 26, 2012 setting the conditions for sorting, collection, storage, transport, recovery, recycling, treatment and final disposal of waste.
- The Decree n°2012/0882/PM of March 27, 2012 fixing the modalities for the exercise of certain powers transferred by the state to the municipalities in environmental matters.
- The Decree n°2001/165/PM of May 2001 specifying the methods of protection of surface and ground water.
- The Decree n°2008/0737/PM of April 23, 2008 laying down the rules of safety, hygiene and sanitation in matters of construction.

b) Electricity

- Law n° 2011/022 of December 14, 2011 governing the electricity sector of Cameroon.
- Decree n° 2000/464/PM of June 30, 2000 governing the activities of the electricity sector.
- Decree n° 99/125 of June 15, 1999 on the organization and functioning of the regulatory agency for the electricity sector.
- Decree n° 99/193 of September 8, 1999 on the organization and functioning of the Rural Electrification Agency
- Decree n° 2001/021/PM of January 29, 2001 fixing the rate, the methods of calculation, recovery and distribution of the royalty on the activities of the electricity sector.
- Decree n° 96/227 of October 1st, 1996 on the organization of the Ministry of Mines, Water and Energy.

I.8 Institutional Framework

I.8.1 In term of Waste Management

1. **The Ministry of Territorial Administration and Decentralization (MINAT)**: Follow-up and implement regulations for organizations and functioning of Councils; Oversees the execution of the budgets of the government' council support fund (FEICOM); Restoration of hygiene and public sanitation; supervises Urban Councils which are re-

sponsible for follow-up and control-industrial waste management, management of public spaces and infrastructure; Sweeping of streets, collection, transportation and treatment of household waste.

2. **The Ministry of Mines, Industries and Technological Development (MINMITD)**: Develop strategies for industrial development and the control of classified and commercial installations for pollution, security, hygiene and industrial nuisance; Define norms for industrial pollution; list of dangerous, obnoxious and polluting facilities in order to inform the public; Develops regulations governing installation and exploitation of facilities classified as dangerous, obnoxious and polluting.
3. **The Ministry of Economy and Finance (MINEFI)**: Financial control of organizations benefiting from supplementary budgets and autonomous public establishments; that is Councils; Responsible for management the Finance law was enacted by parliament.
4. **The Ministry of Urban Development and Housing (MINDUH):** Develops and implement Urban restructuring, management strategies, sanitation and drainage; Defines and enforces norms of hygiene/sanitation, collection and/or treatment of household waste; Liaises with international agencies for urban development.
5. **The Ministry of Environment and Nature protection (MINENP):** Collaborates with other agencies to define measures for the rational management of natural resources; Effective control of investigation and pollution in the field; Specifies the criteria (project specific) and supervises environmental impact assessments.
6. **The Ministry of Public Health (MINPH):** Creates Hygiene and Sanitation Units in Councils; Renders technical support to the Hygiene and Sanitation Units Councils, proposes norms for collection, transportation and treatment of industrial, domestic waste and emptying of septic tanks, design and implement public educational campaign on hygiene and sanitation.

I.8.2 In term of Electricity

1. **Ministry of Energy and Water (MINEE):** With a department of renewable energies is in charge of design and implementation of the national energy policy as well as providing administrative and technical oversight of the establishments in the energy sector.

2. **Ministry of Environment, Protection of Nature and Sustainable Development**: Responsible for the promotion of sustainable development in the renewable energy sector.
3. **Rural Electrification Agency (AER):** Responsible for promoting and implementing rural electrification programs in Cameroon. It also manages the Rural Energy Fund (FER).
4. **Electricity Sector Regulatory Agency (ARSEL)**: Responsible for regulating the electricity sector as well as setting electricity rates and determining electrical standards.
5. **Electricity Development Corporation (EDC):** is in charge of construction and development of all hydroelectric projects in Cameroon. It also plays a strategic role in the development of the electricity sector while ensuring conservation of the public heritage in the sector.
6. **ENEO Cameroon**: Responsible for power generation, transmission and distribution.
7. Netherland Development Organization (SNV):

Conclusion

We can conclude that solid waste management (SWM) still remain a great challenge for developing countries and also the concept of waste to energy. The use of alternative energy sources in Bertoua city is a solution to growing energy consumption and to increasing in greenhouse gas emissions due to inadequate municipal solid waste disposal and use of fossil fuels. The absence or little presence of well-defined law concerning SWM and energy sector in developing countries and Cameroon in particular restrict sanitation. Also, the presence of different administration governing the sector cause conflict thereby leading to mismanagement of SWM and electricity sector in Cameroon.

CHAPTER II: METHODOLOGICAL APPROACH

Introduction

The investigation technique employed to acquire answers to issues put forward for our research consist mainly of literature review, field observation, interview survey and data analysis. This chapter is subdivided into three part mainly material used, research methods and data analyses methods.

II.1 Materials used

Some instruments used to carry out this study are:

- An android phone to take pictures during the field study
- A laptop to analyzed gotten data to tables and graph
- A list of questionnaires to carry out interview

II.2 Methods

II.2.1 Literature review

It is the main method used for all scientific research and makes it possible to collect a large number of data useful in clarifying the subject addressed. With regard to this research, it consists the consultation of documents such as Articles, dissertations and thesis, also virtual documentation and works relating to the electricity production from biogas obtain through the anaerobic digestion of household waste in order to better understand this concept. This documentation informed us on solid waste management, solid waste composition, Electricity produced from biogas and about the environmental and socio-economic problems in Cameroun in particular and around the world.

II.2.2 Field observations

This phase, which consists of field observation in relation to the study framework, allowed us to gain a general overview of the attitudes and knowledge of the populations of the city regarding the management of household waste and electricity. These visits carried out in various quarters of the town allow us to observe the habitat, the living environment of the population, the presence of bins and the presence of electricity. It helps us to estimate solid waste composition which is represented by graph and time of energy supply.

II.2.3 Interview Survey

To better understand the management of household waste and electricity profile and generation in the city of Bertoua, we had interviews with resource people from the city who shared with us their opinions on the subject.

It was carried out using a questionnaire which was referred to the company in charge of municipal solid waste (MSW) management of the city (HYSACAM) and Eneo Cameroon. This method has enabled us to collect existing data on waste produced compiled by individuals. The data collected was analyzed manually and computer, tables and graphs were produced using Excel software.

II.3 Data analysis

II.3.1 Softwares used

- **ArcGIS** software is a geographic information system (GIS) for working with maps and geographic information maintained by the Environmental Systems Research Institute (Esri). It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.
- **Land GEM** Model
- **Excel**

II.3.2 Flow and Origin of Waste

To determine the evolution of the waste stream, it is essential to know the tonnage of waste entering the site. The landfill of Bertoua has been equipped with a weighbridge which works with solar energy since January 2011 and it is therefore the result of the weighing carried out by the operator that enabled us to assess the deposit of incoming waste.

II.3.3 Physical characteristics of the waste

This helps us know the quantity of biodegradable waste. It is determined by a field survey carried out in 2013 at Bertoua by Essinga sapock.

II.3.4 Biogas production

As defined in previous chapters, biogas is composed of methane (CH_4), carbon dioxide (CO_2) and some trace elements. Also, it is obtained from anaerobic digestion (AD) of biodegradable waste. Here we will apply a step-by-step guide as to the process involved in determining required size of an AD system (fixed-dome) and calculating the expected biogas production.

Due to the unavailability of the measuring equipment to carry out these test (Volatile solid content, Total solids), data was adopted from a study carried out in developing countries adapted by Vögeli and al. (2014). To calculate the scale of a biogas plant, certain characteristics parameters are used. These are:

- Daily total bio-waste available as feedstock for AD (Q_D):
  This is an equal mixture of biogas feedstock with water feed into the biogas digester in a ratio 1:2. This will result in slurry which can be easily flushed into the digester. Using the approximation that 1 kg is equivalent to 1 Littre.
- Retention time (RT):
  The time by which the biodegradable waste stays in the digester. The ideal Retention Time (RT) for a tropical climate with an average ambient temperature of 25-30°C is recommended to be around 30 days (Vögeli and al., 2014).
- Feedstock characteristics:
  Dry matter refers to material remaining after removal of water.

$$DM = OM \times y \tag{3}$$

Where DM (kg) = Dry matter
OM (kg) = biodegradable organic matter
y= percentage of raw waste
Volatile solids are a substance that can easily transform from its solid phase without going through a liquid phase.

$$VS = DM \times z \tag{4}$$

Where VS (kg) = Total volatile solids
DM (kg) = Dry matter
z= percentage of total solids
Ash content is the biologically inert, dense material.

$$Ash\ content = DM - VS \quad (5)$$

- Substrate concentration in the inflow (S):

  The balance of the biodegradable waste is water which does not contain volatile solid (VS). Therefore, of Q_D (L) of diluted feedstock, the share of VS (kg) for 1000 L (that is 1 m^3) can be calculated as seen in equation (6)

$$S = {}^{VS}/_{Q_D} \quad (6)$$

  Where S is the substrate concentration in the flow (kg/m^3)

- Organic loading rate (OLR):

  This parameter indicates the amount of biogas feedstock material per day is fed to the digester or to be digested. It can be measured in kg/m^3.day and can be calculated as seen in equation (7)

$$OLR = \frac{Q_D \times S}{V} \quad (7)$$

  Where by Q_D is the substrate flow rate (m^3/day), S is the substrate concentration in the inflow (kg VS/m^3) and V is the reactor volume (m^3)

II.3.4.1 Sizing of biogas digester and gasholder

- The size of the digester – the digester volume (V_R) is determined by the length of the retention time (RT) and by the amount of biodegradable waste supplied daily (Q_D) this can be shown in equation (8).

$$V_R = Q_D \times RT \quad (8)$$

  Where V_R (L and/or m^3) = active reactor volume

  Q_D (L/day) = Diluted feedstock

  RT (day) = Retention Time

- Size of the gasholder and whole Anaerobic digestion (AD) system

  A fixed dome digester (example: Nepali GGC 2047 model) is designed so that 75% of the total reactor volume is used for the active slurry and 25% of the volume is used for gas storage. This means that the active volume (V_R) is complemented with 25% of V_R (m^3) for gas storage volume, resulting in a total digester volume of $V_R + V_{gas}$ for the whole reactor.

II.3.4.2 Theoretical evaluation of Biogas and methane yield from solid waste

Here, methane yield was adopted from a study carried out in developing countries by Vögeli and al. (2014). The biogas yield and methane yield can be estimated using equation (9) and (10) respectively

$$Q_B = OLR \times x \times V_R \tag{9}$$

Where Q_B = biogas flow rate (m^3/day)

x = proportion of biogas produced in the substrate (m^3 biogas yield/ kg VS)

V_R = Volume of reactor (m^3)

$$Q_{CH4} = x \times Q_B \tag{10}$$

Q_{CH4} = methane yield (m^3/ day)

x = fraction of biogas produced in the substrate

Q_B = biogas flow rate (m^3/ day)

The Gas Production Rate (GPR) can be calculated by using equation (11)

$$GPR = Q_B / V_R \tag{11}$$

Where GPR is measured in m^3 biogas/ m^3 reactor and day

The Specific Rate Production (SGP) can be calculated by using equation (12)

$$SGP = GPR / OLR \tag{12}$$

Where SGP is measured in m^3 biogas/ kg VS feed material

II.3.5 Available Energy generated from Biogas

To determine the electrical energy that could be available through biogas, equation (13) is defined. This equation is related to the conversion of biogas to useful energy in the form of electricity and heat (Mambelli and al., 2014).

$$E_B = \frac{LHV \times Q_B \times \eta}{\gamma} \tag{13}$$

Where

E_B is the available electrical power (kWh/day),

LHV is the lower biogas calorific value (MJ/m^3),

Q_B is the available biogas flow (m^3/day),

η is the electrical efficiency of the generating element in transforming thermal energy into electrical energy, and

γ is the conversion factor of MJ into kWh (1 MJ/0.28 kWh).

II.3.6 Environmental viability

This section establishes the project's profitability from an economic and environmental point of view. As anaerobic digestion occurs naturally in landfill, we find it good to estimate the amount of greenhouse gas (GHG) produced by landfill waste and liberated into the atmosphere. Mathematical models are a useful and economical tool for estimating the landfill gas (LFG) generation potential at the site. There are numerous models available to calculate LFG production such as the Intergovernmental Panel on Climate Change (IPCC) model, the U.S. EPA Land GEM Model.

Here, the U. S. EPA Land GEM Model was used to estimate the amount of landfill gas emitted at Bertoua. The Landfill Gas Emissions Model (Land GEM) is written and improved by EPA. Emission rates of total landfill gas, methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from municipal solid waste (MSW) landfills are calculated by this program using Microsoft ® Excel interface.

Land GEM is based on a first-order decomposition rate equation and the model needs the following inputs for estimating the amount of LFG generated in specific time period:

- Design capacity of the landfill
- Amount of waste in place or the annual acceptance rate
- The methane generation rate constant k and methane generation potential L0 and
- The number of years of waste acceptance

Users of the Land GEM can utilize their own data (i.e. site-specific data) to estimate LFG emissions. If the site-specific data are not available, the model contains two sets of default parameters, Clean Air Act (CAA) defaults and inventory defaults. The CAA defaults are based on federal regulations for MSW landfills laid out by the CAA. These two inventory defaults are based on emission factors in EPA's Compilation of Air Pollutant Emission Factors (AP-42) (Land GEM Version 3.02 User's Guide).

To this end, the solid waste management, biogas and digestat benefit is analyzed, electrical, operation and maintenance environmental benefit will be analyzed.

II.3.7 Evaluation of Performance of diesel thermal power plant and dual-fuel diesel/biogas thermal power station

Here, the performance of the thermal power station (TPS) engine of will be analyzed using the electric output power, and specific fuel consumption. In the first mode, the engine is run on diesel only. In this study, a study on TPS engine run in dual-fuel mode without any significant modification is proposed. The performance of the TPS engine run in dual-fuel mode without any engine modification will be investigated. The output power P_E (W) of the TPS engine

The specific fuel consumption (*sfc)* [g/kWh] is a comparison of fuel consumption to the useful energy. It can be viewed as how many grams of the fuel is needed to produce 1 kWh of electric energy. For the TPS engine run in pure diesel, it can be calculated by equation (14):

$$sfc = \frac{\dot{m}_{diesel} \times 10^3}{P_E} \tag{14}$$

While for the TPS engine run in the dual-fuel mode it is defined as seen in equation (15):

$$sfc = \frac{(\dot{m}_{dual} + \dot{m}_{biogas}) \times 10^3}{P_E} \tag{15}$$

Where, $\dot{m}_{dual}$ [kg/s], $\dot{m}_{biogas}$ [kg/s] are the mass flow of diesel fuel and mass flow of the biogas, respectively.

Conclusion

The aim of this chapter was the presentation of the various works which was conducted in order to achieve the main objective of this work. It starts with the presentation of the materials used, methods used to collect our data and softwares used for data analysis. Also, we collected actual waste collected data at Bertoua by HYSACAM. The quantity of biogas produced will be analyzed using a fixed-dome anaerobic digestion method. The biogas and waste characterization will be organized in tabular form for analysis to get the energy potential. The performance of the thermal power plant was evaluated using specific fuel parameter. Then the solid waste data collected was put into a software to get the effect of the solid waste on the environment.

CHAPTER III: RESULTS AND DISCUSSIONS

Introduction

One of the potential benefits of converting biogas to energy is in terms of energy product values and valorization of household waste. In this chapter we will be mainly concerned with quantifying potential biogas (methane) emission from household solid waste of Bertoua and estimate energy production rates from the gaz. Also, evaluate the performance of the thermal power plant in diesel mode only and biogas-diesel mode as well as the environmental viability.

III.1 Results

III.1.1 Quantity of waste produced

According to the head of the landfill the average waste production at Bertoua is 160 tons/day. The amount of waste collected by HYSACAM from the year 2011 to 2020 is presented in Table 25 and Figure 23. From 2011 to 2016, the quantities of waste produced by household have increased from approximately 36 tons to 58 tons respectively. At the same time population rate increases by 3.9%. This shows that the production of household waste is not only as the function of the development of the city but also due to the living standard of the population, that is differs according to the zone. Table 26 and Figure 24 shows that there are only slight differences in terms of waste produced between months this can potentially not influence biogas production in term of quantity.

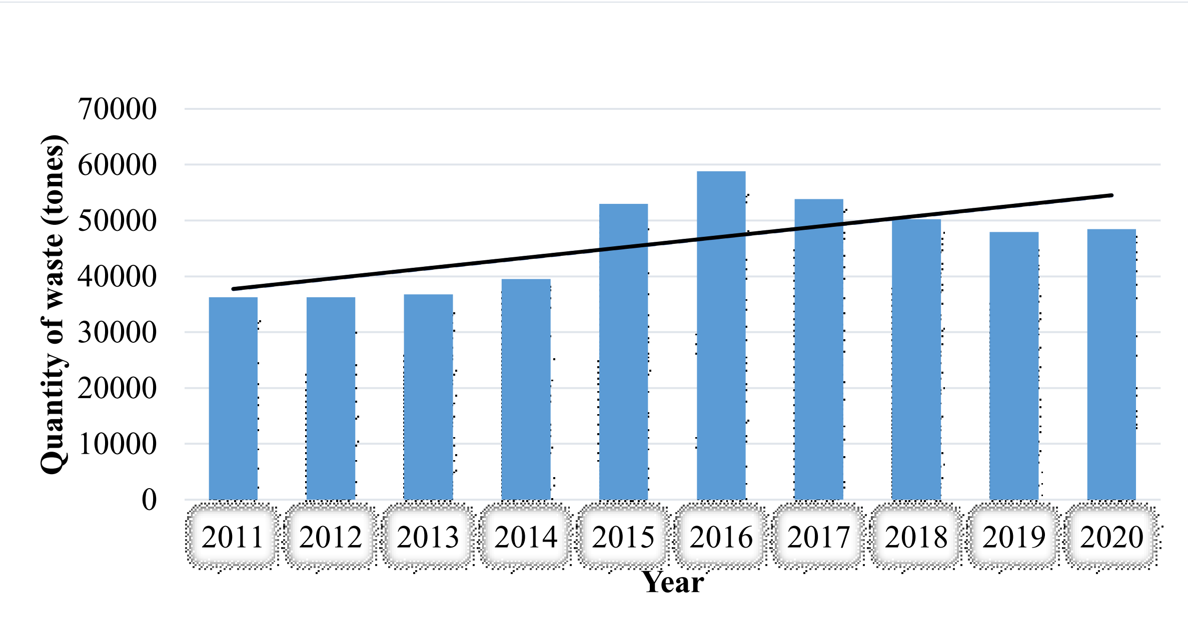


Figure 23: Quantity of waste produced at Bertoua

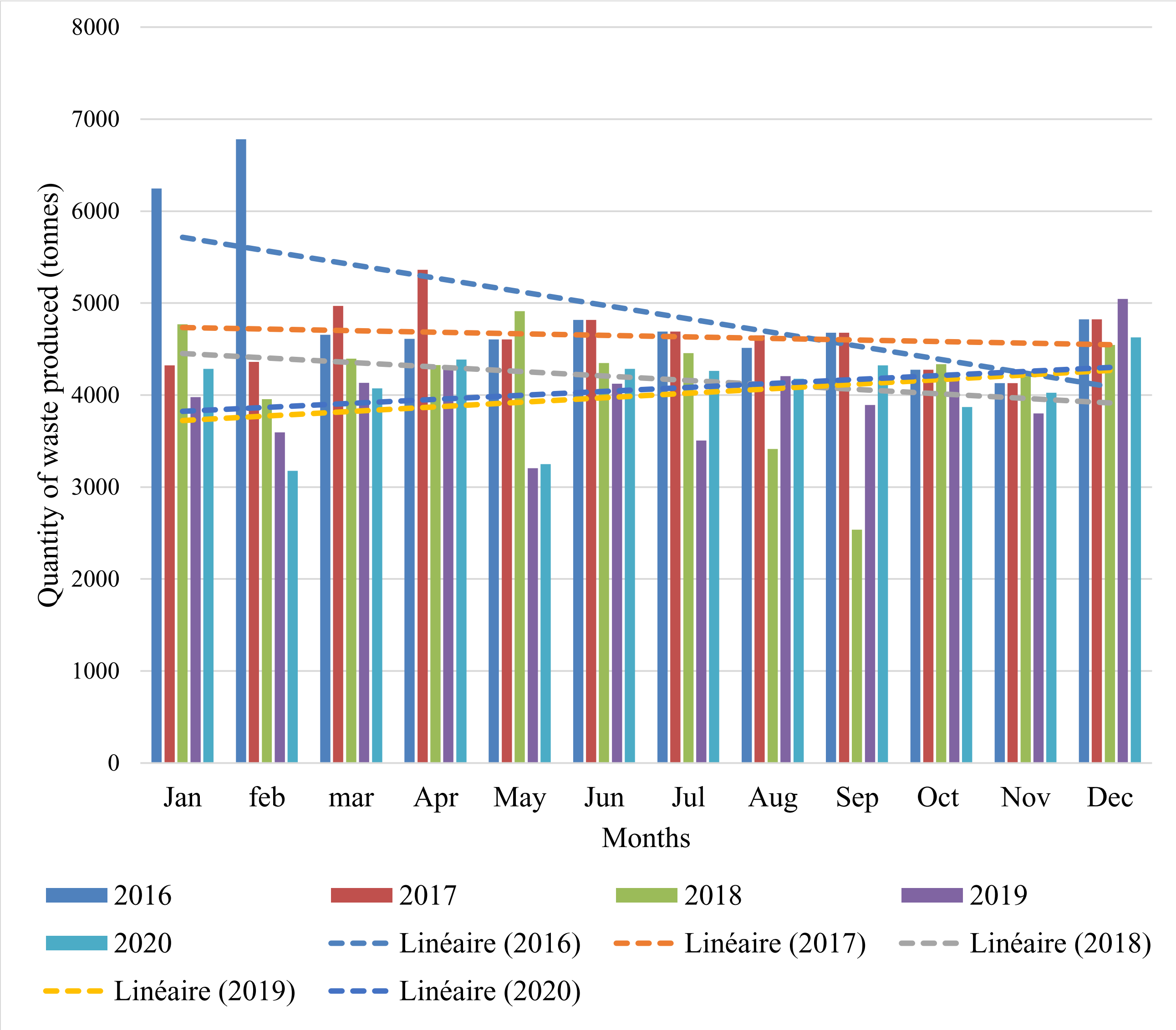


Figure 24: Quantity of waste produced per month during five consecutive years

III.1.2 Waste composition

However, it should be noted that the contents of the bins vary according to the standard of living of the households, season and the activities. The composition of Municipal Solid Waste (MSW) produced at Bertoua can be classified into eight (8) categories: kitchen waste, vegetables (Wood), plastics, metals, glass, textiles, papers and fin particles (sand, construction waste) which can be shown in figure 25 and Table 13.

Table 13 : waste fraction and composition

Waste composition	Waste fraction (%)	Daily production (kg/day)
Kitchen waste	39	62 400
Yard waste	8	12 800
Plastics	28	44 800
Paper + cardboard	12	19 200
Textiles	5	8 000
Glass	6	9 600
Fine particles	2	3 200

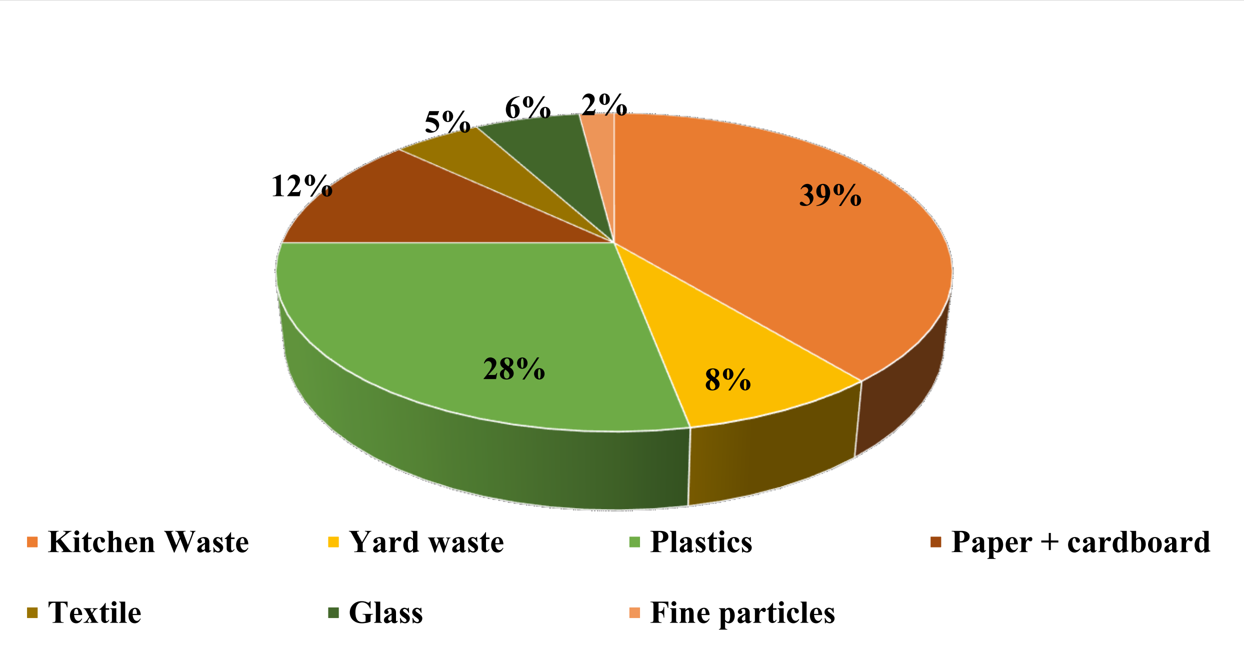


Figure 25: Household Waste composition (%)

III.1.3 Biogas Production

The design of the biogas plants includes the design of: the digester, the gasholder, the digester heat maintaining system, siting of biogas plant. The measure of different parameters and calculation of unknown values was carried out using the equation sited in the literature and methodology. The unit of measurement used is the SI unit. *The SI unit is the metric system that is used universally as a standard for measurement*. The following results were obtained:

III.1.3.1 Sizing of biogas digester and gasholder

Daily average collectable biogas feedstock potential from household biodegradable waste in this study is 75.2 ton/day. Additional of 150.4 m^3/day of water is required for proper digestion of biogas feedstock material to enhance biogas production. The volume of the digester should be 6 768 m^3. The volume of gas holder 1 692 m^3 and therefore the size of the digester for household biodegradable solid waste of Bertoua could be 8 460 m^3.

III.1.3.2 Biogas potential from biodegradable household solid waste

From literatures review methane yield of municipal solid waste is 0.35 m^3 CH_4/kg VS, From Table 7 (see paragraph I.5.2) we can assume Total Solid (TS) to be 30% for the available feedstock which is made up of kitchen and garden waste. Also, from Table 8 (see paragraph 1.5.2) volatile solid (VS) is Assumes to be 70 % of the total solids of the biodegradable solid waste. In Table 7, data regarding to biogas generation rate constant which are used in theoretical calculations are given.

Table 14 : Biogas generation parameter results

Parameters	value	Units
Quantity of bio-waste (OM)	**75 200**	**kg/day**
Q_D	225 600	L
V_R	**6 768**	**m^3**
Dry matter (DM)	22 560	kg
Volatile solids (VS)	**15 792**	**kg**
Ash content	6 768	kg
Substrate concentration in the inflow (S)	**70**	**kg VS / m^3**
Organic Loading Rate (OLR)	2.33	kg VS/ m^3. day

Methane content assuming 60 % of the total biogas yield. Based on the biodegradable solid waste given in Table 14, the biomass, biogas and methane yield potential of the biodegradable solid waste by product is estimated in Table 15.

Table 15 : Values of Biogas and methane yield from household waste of Bertoua

Profile	Biodegradable solid waste (Tons)	Biogas yield (m^3CH_4/kg VS)	Biogas yield (m^3 /day)	Methane yield (m^3 CH_4/day)
Daily average	75.2	0.35	5519.3	3311.58
Yearly average	21657.6	0.35	1 589 558.4	953 735.04

III.1.4 Energy potential estimation from Biogas

To determine the power capacity, it is necessary to assess the generation type. For the present case study, Turbine were chosen because of they are used for high generated power and have a low implementation cost. The choice basically depends on the amount of biogas flow available. Biogas turbines are used because of high biogas generation flow capability of at least 3 MW. Table 16 lists the characteristics of the three (3) technologies that rely on biogas to generate electricity.

Table 16 : Typical information on the technologies that use biogas to generate electricity

Technology	Flow (m^3/min)	Generated Power (MW)	Electrical efficiency (%)	Cost (usd/kW)
Internal Combustion Engines (ICMs)	8 - 30	0.8 - 3	32 - 45	1150 - 1700
Turbine	> 40	> 3	25 - 40	1400
Micro turbine	< 8	0.03 – 0.2	26 - 32	5500

Table 17 summarizes the values imposed for the calculation of energy at the anaerobic digestion plant.

Table 17 : values for the calculation of energy at the anaerobic plant

Variables	Values
Biogas flow (Q_B)	5519.3 m^3/day
LHV (Low heating value)	20 MJ/m^3
Engine efficiency	35 %
Conversion factor of MJ to kWh	3.57

The average electricity production with the 1 MW generator will be **3 950 087 kWh/ year** and **10 822 kWh/day**. With an average electricity consumption of 12 MWh/day in Bertoua, it is estimated that this anaerobic digestion (AD) could provide 90 % of the city with electricity.

The available energy per year will increase with increasing biogas amount from AD by complete removal of CO_2 and H_2S.

III.1.5 Environmental viability

Here we will highlight the importance of anaerobic digestion (AD) as a way to managed solid waste that is economic and environmental point of view and Amount of landfill gas emitted by municipal solid waste of Bertoua. The threat of climate change posed by the continuous emission of greenhouse gases from fossil fuel utilization has become an important stimulation to use "carbon-neutral" biomass for renewable energy production, as the carbon stored in biomass is fixed from the atmosphere; thus, the cyclical use of biomass will not increase the net CO_2 level in the atmosphere (McKendry, 2002). Also due to, continuous emission of landfill gas that contributes to global warming.

i. Economic aspect

1. Benefit of sustainable waste treatment

In most developing countries, municipal solid waste (MSW) is disposed in landfills which are more or less sanitary. The absence of source segregation increased the quantity at of solid waste at the level of landfill with the presence of biodegradable, harmful waste thereby increasing greenhouse gas (GHG) effect. The practice of Anaerobic digestion (AD) process removes a large portion of C, H, and O from the organic waste, reducing the volume and solids in the waste and generating a nutrient-rich residue that can be used as a fertilizer or soil amendment (Nguyen et al., 2015). Also, biogas which can be used as heat for cooking, electricity.

Also, at the level of transport cost, there will be the decreased since most of the biodegradable solid waste will be deviated to AD plant. AD reduces landfilling waste hence saving space and extending life span of the landfill.

2. Biogas benefit

The total value of biogas is a function of the net amount available, the value of the fuel it replaces, and the conversion efficiency (House, 2010). Revenue generated therefore depends mainly on what energy source can be replaced by the biogas (Vögeli and al., 2014).

In our case the thermal fuel-fired power plant of 17 626 kW uses 45 000 L/day which produced only 8 000 kWh/day, we can assume some loss of the diesel as heat. The methane produced is

5519.3 m^3 biogas/day. From the results obtained, we can say that the available biogas can considerably replace approximately 90% of electricity demand and reduced diesel consumption by approximately 40 000 L out of 45 000 L needed.

3. **Benefit of digestate as fertilizer**

The financial benefit of digestate is dependent on the type of fertilizer it replaced, and its quality is depending on the climate, type of storage, type of collection and/or the practices or technique of usage. For this reason, it is important to practice source segregation to better optimized the potential use of the digestate.

ii. **Environmental aspect**

1. **Landfilling**

Landfills are well engineered plant that must be designed, located, operated, and monitored to ensure compliance according to regulations and engineering principles. In Bertoua, approximately all of the solid waste produced is collected and finally disposed at the treatment center which is an open, designed uncontrolled dump site. Leachate causes ground and underground water pollution and uncontrolled landfill gases emissions (composed of methane, CO_2, N_2, water vapor, H_2S, and certain contaminants) cause air pollution and aesthetic pollution. The presence of growing pawpaw trees at the level of the treatment center of Bertoua show the potential or presence of biodegradable solid waste. Under such circumstances Bertoua needs to be immediately regional waste management plan and provide its sustainability. Anaerobic digestion (AD) is considered one of the most cost-effective and environmentally friendly approaches to convert biomass, especially organic wastes, into renewable energy. AD Compared with other bioenergy production methods, the process is relatively simple and cheap and has a lower carbon impact and a higher net energy return. The amount of greenhouse gas emitted by landfill of Bertoua is therefore estimated as follows:

- **Model Inputs:**

a) **Methane Generation Potential Data, L_0**

In first case, Methane Generation Potential (L_0) of inventory wet and in second case default value of methane generation potential of clean air act (CAA) conventional was used.

b) **Methane Generation Rate Constant (k)**

Knowing that annual precipitation of Bertoua is greater than 1000 mm/year we can consider k to be **0.080 yr^{-1}**.

Considering the first order decay equation, $k = {In2}/{t_{1/2}}$

$t_{1/2}$ = 8.66 yr.

c) Percentage of Methane Gas Concentration

In the calculations, landfill gas (LFG) concentrations are taken as 50% for methane, and 40% for carbon dioxide.

- **Model Outputs**

During our investigation many information about household solid waste characteristics was gotten around the landfill of Bertoua, this is why we found it better to estimate the amount of greenhouse gas (GHG) emitted by the landfill. During simulation, in the first case we used an application put in place by the Environmental Protection Agency (EPA) to find out the amount of GHG emitted by the Municipal Solid waste of Bertoua. This method provides default values of L_0 and k, but can also be calculated if solid waste characteristics of defined site are available. Due to absence of data on waste characteristics we used default value for RUN 1 considering values of a bioreactor and RUN 2 considering the conventional value for L_0 and k value was considered using local conditions that is with respect to the precipitation of Bertoua.

EPA Land GEM Model

EPA land GEM Model was run with the input data that is Lo and k, was determined by default values of land GEM model. Lo (m^3/Mg) values were taken as 96 and 107 for RUN 1 and 2 respectively. Other parameters, i.e. k and methane percentage, were used as 0.08 and 50% for both conditions and we assume that landfill closure year to be 2040. The results obtained for RUN 1, RUN 2 are shown in Table 24 and 23 and figure 26 and 27 respectively. The highest landfill gas production was obtained for RUN 2 due to higher input parameters. Also we observed in both case the amount of methane yield is equivalent to carbon dioxide produced.

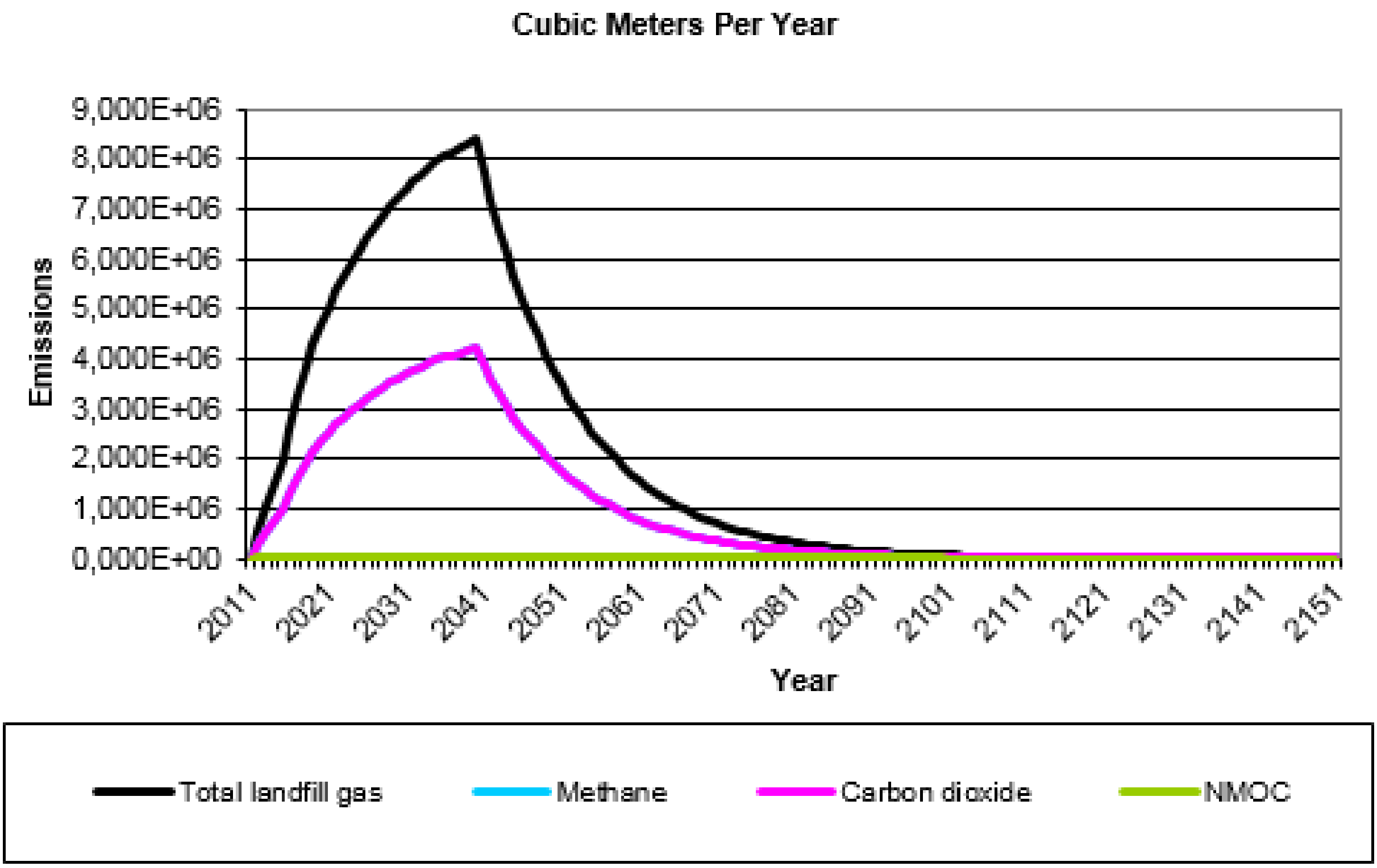


Figure 10: *RUN 1 landfill gas output*

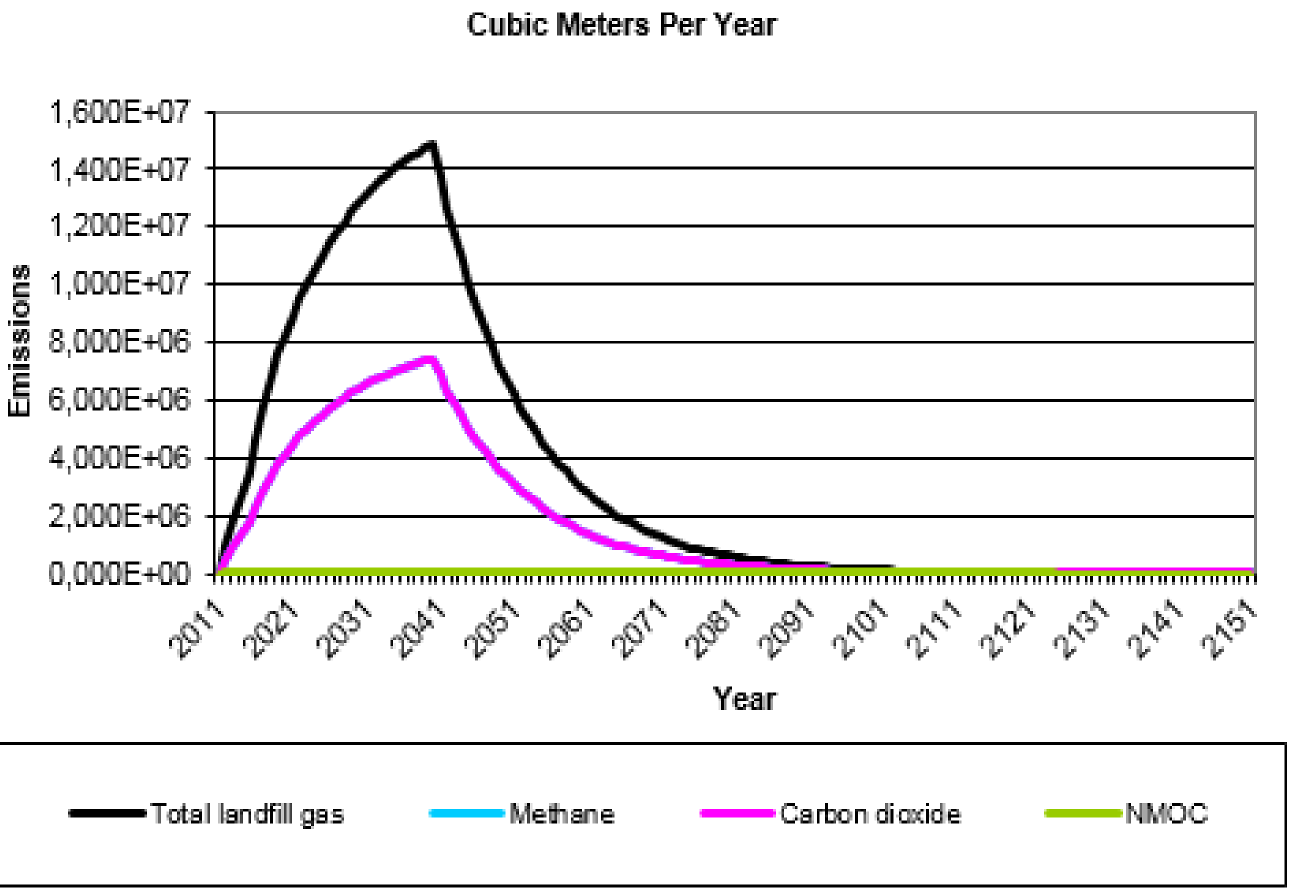


Figure 11: RUN 2 landfill gas output

2. **Global warming potential**

The main aim of anaerobic digestion (AD) plants is the production of biogas thereby reducing fossil fuel consumption, with the final goal of mitigating global warming. However, anaerobic digestion (AD) is associated to the production of several greenhouse gases (GHG), namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide. But in either case there is a great potential of AD saving for this impact. GHG is due to leakage at the level of AD plants that losses CH_4 and from dual-fuel biogas/diesel engine. CO_2 emission from transportation of waste and digestate and from the combustion of biogas is negligible because of their biogenic nature. N_2O emission from the application of digestate on the land.

Bach Maier and al., (2010) calculated the GHG impact of ten (10) agricultural biogas plants. GHG emissions coming from electricity production in the investigated biogas plants ranged from -85 to 251 g CO_2 eq/ kWh_{el}, and the GHG savings was 2.31 – 3.16 kWh_{fossil}/ kWh_{el}.

3. **Human toxicity and ecotoxicity**

As concern to AD the main contributors to this impact is from transport (waste collection diesel Lorries).

4. **Depletion of fossil fuels**

At the AD the only significant contributor is the transportation of food waste and garden waste and distribution of digestate for use on the land.

5. **Pollution**

The main pollution from AD is the application of the digestate on the land. The greatest source of this impact is due to the emissions of ammonia and nitrates which can caused eutrophication if diffused into water and acidification of soil and water. Also, Biogas installations with leakages may result in slurry seeping into the subsurface and slurry pits, which are often not lined, may cause ground water pollution. Although generally harmless, the discharge may pollute nearby water pits. Therefore, construction instructions should also specify a minimal distance between the AD installation and the closest water sources.

III.1.6 Performance of the thermal power plant

Knowing that the main biogas benefit is a function of the net amount available, the value of fuel it replaces, and the conversion efficiency (House, 2010). The input data used to evaluate parameters used to estimate performance of the engine can be shown in Table 18.

Table 18 : Input parameters

Formulated parameters	values
Mass flow rate of diesel	123 L/h
Mass flow rate of biogas	380 L/h
Dual mass flow rate	420 L/h
Heating value for diesel	45.5 MJ/kg
Heating value for biogas	20.5 MJ/kg
Calorific value of Methane	36 MJ/m^3
Calorific value of pure methane	39.8 MJ/m^3

The specific fuel consumption can be viewed as a parameter to show how effective a power generation system to convert an amount of fuel into mechanical energy. In this work, the specific fuel consumption (*sfc)* varies from 0.024 g/kWh to 0.084 g/kWh. The lowest *sfc* is resulted by the thermal power station (TPS) engine run in pure diesel mode and the highest one is the

TPS engine run in dual biogas-diesel mode, respectively. Nevertheless, Table 19 show the summary of the available result of our study.

Table 19 : Output parameters of a diesel thermal power plant and biogas thermal power station.

Municipal solid waste	
Average Quantity	160 t/day
Dry matter assuming TS to be 30% (kitchen and yard waste)	7038.72 tones/year
Biogas produced	5519.3 m^3 CH_4/ day
Methane produced	3311.58 m^3 CH_4/day
Electricity	
Actual Quantity of diesel used	45 000 L/day
Fuel –fired thermal engine power installed	17 626 kWh/day
Actual Electricity demand of Bertoua	12 000 kWh/day
Actual Electrical energy supply by the engine	8 000 kWh/day
Energy supply by each group	1 280 kWh/day
Working hours of each group	15 to 24 h
Possible Electrical energy supply by biogas produced	10 822 kWh/day
Difference between biogas only and demand in electricity	1 178 kWh

III.2 Discussion

III.2.1 Household Waste Management at Bertoua

Household waste management at Bertoua is managed by a private company HYSACAM, which is in charge of only household waste according to their contract with the urban Council of Bertoua (BUC). We observe a slight increase of different waste at the level of the treatment center of Bertoua. This is due to the incoming waste from commercial, road site cleaning, restaurant. From figure 23 according to the linear trend we observe that there is a linear increase of waste produce with year. This waste if not well managed may considerably contributes to global warming due to the production of landfill gases. Also, we observed from the linear trends of figure 24, waste produced does not change a lot irrespective of the month. So, this waste can be used in anaerobic digestion without any decrease in biogas produced.

III.2.2 Biogas potential from Municipal Solid Waste

Biogas production depends on many factors such as feedstock characteristics, temperature, pH, Organic Loading Rate (OLR), Hydraulic retention time (HRT) and so on. During our studies volatile solid (VS) and Total solid (TS) was estimated. But real value of biogas yield can be gotten by carrying out experiment such as the ASTM D 5832-96 method used to determine VS in dry material, the ASTM D 2866-96 method used to determine the Ash content. Feedstocks with high VS and biological degradable component have high biogas potential. The lack of source segregation equally enhances a decrease in biogas potential. Source segregation can be defined as "*actions taken at the point of waste generation to keep and store certain materials (in this case organics) separately from other waste* (Sheinberg and al., 2010)". Applying source segregation reduced pre-treatment cost (sorting of bio-waste fraction), reduced contamination of bio-waste, thereby reducing infrastructure and human resources requirements. Also, source segregation and the purity of the waste is very important if the purpose of the anaerobic digestion (AD) facility is to produce high quantity and quality digestate (Vögeli and al., 2014). However, when the main objective of the treatment facility is to treat waste, with little priority of cost effectiveness or digestate quantity, then collection of mixed waste and subsequent sorting by digestion may be suitable (Monnet, 2003).

Pre-treatment can enhance degradation of VS and thus increased biogas yield. Pre-treatment can either be sorting (if not done at source), reduction in particle size and addition of water before the mixture is fed into the AD system. During our studies we only consider addition of water in the ratio 1:2 but in either case for more biogas yield reduction of particle size most be considered because it leads to large surface area for enzymes action.

It is important to note that the accuracy of gas measurements differ depending on the parameter used. In the list below the accuracy increase from top to bottom, that is the error rate increases from bottom to top (Eder and Schulz, 2007)

1. m^3 biogas / t substrate (wet weight)
2. m^3 biogas / kg Total solids
3. m^3 biogas / kg Volatile solids
4. m^3 CH_4 / kg Volatile solids
5. Nm^3 CH_4 / kg Volatile solids where Nm^3 = Norm m^3

We can therefore consider a slight error at the level of methane yield during our studies since our units of measurements are m^3 biogas / kg Volatile solids for biogas and methane yield.

III.2.3 Energy potential of Household Solid Waste

Biogas production is dependent on the type of feedstock and its characteristic which influences the quality of biogas produced. Biogas is rich in methane (CH_4) with typical range between 40 and 70%, and its lower heating value is between 15 and 30 MJ/Nm^3 (Tippayawong and Thanompongchart, 2010). In order to obtained energy from biogas in a more productive and cost-efficient way, the gas must be enriched and its pollutants eliminated (Osorio and Torres, 2009). This means that all gases except for CH_4 must be removed. Carbon dioxide (CO_2) when present in large quantities in biogas can decrease the energetic content of biogas this is due to the fact that CO_2 is an inert gas in term of combustion. The CH_4 content in biogas will increase if CO_2 is removed. The most common contaminant in biogas is hydrogen sulphide (H_2S) and other sulphure-contamining compounds that come from sulphure-bearing organic matters (Abatzoglou and Boivin, 2009). Depending on the composition of organic matter, the H_2S content in biogas can vary from 100 to 10 000 ppm. This contaminant is highly undesirable in combustion systems due to its conversion to highly corrosive and environmentally hazardous compounds (Tippayawong and Thanompongchart, 2010). Water (H_2O) must also be eliminated because of the accumulation potential of condensate in the pipe line. Therefore, the removal of CO_2, H_2S and H_2O content will significally improved the quantity of biogas thereby increasing the energetic value (Tippayawong and Thanompongchart, 2010).

Various technologies have been developed for separation of CO_2 from gas streams in the past (Tippayawong and Thanompongchart, 2010). These include absorption by chemical solvents, physical absorption, cryogenic separation, membrane separation and CO_2 fixation by biological or chemical (Abatzoglou and Boivin, 2009; Yang and al., 2008; Granite and O'Brien, 2005). There are also a number of techniques to remove H_2S. Examples are chemical absorption in aqueous solutions, physical absorption on solid adsorbents and conversion to base sulphides or low solubility metal sulphides (Horikawa and al., 2004; Osorio and Torres, 2009). According to chemical absorption by solvents in a packed column (Sodium hydroxide (NaOH), Calcium hydroxide ($Ca(OH)_2$) and mono-ethanolamine (MEA)) is an effective technique for removing CO_2 and H_2S over a short operation time, but their absorption capability declined rapidly with time. Chemical absorption by alkali aqueous solution did not appear to be promising for biogas quality upgrade due to the non-regenerable nature, requirement of large liquid solvents volume and the environmental impact (Tippayawong and Thanompongchart, 2010). However, amine solutions may be worth exploring, due to the regeneration capability (Tippayawong and Thanompongchart, 2010).

III.2.4 Electricity potential of Household Solid potential

The percentage of the energy generation processed to generate power is based on the choice of implementation technology. According to Surata and al. (2014), gasoline fueled engine for electric generator can be converted to biogas fueled engine. For this purpose, the biogas should be upgraded to the level of zero hydrogen sulphides (H_2S) impurity and zero level of water (H_2O) content. Also, the carburetor of the gasoline engine should be replaced and only component of the mixer of the fuel and air should be used. Also, Surata and al. (2014), demonstrate that there will be an increased in the performance of the engine, if liquefied petroleum gas (LPG) is mixed up with biogas in the ratio 1:4 that is 20 % LPG and 80 % biogas (see Figure in Appendix 2).

According to the study carried by Tippayawong and al. (2007) to evaluate the effect of biogas/diesel dual fuel operation to assess it endurance over 2000h for electricity generation. The research engine used in the study was a Mitsubishi DI-800, model year 1995 (shown schematically in figure in Appendix 3). Biogas was supplied through a plastic pipe and mixed with inlet air in a venture-type mixer (see figure in Appendix 4) upstream of the inlet manifold. The result of the above experiment were: For long-term engine operation, the engine should be directly coupled to the same alternator, Over 90% of biogas substitution can be achieved, Dual-fuel operation had slightly higher power output than normal diesel operation by about 7% on average (see graph in Appendix 5), With respect to energy conversion, dual-fuel operation lowed superior efficiency compared to normal diesel operation within a range of engine speeds considered (see graph in Appendix 6) and In term of engine durability; the use of biogas/diesel dual fuel operation up to the first 2000 h did not appear to affect the engine performance and wear adversely (see Table and figure in appendix 7).

III.3 Suggestions and Recommendations

- HYSACAM and Municipality should establish a new Solid waste management (SWM) plan of Bertoua each 5 years by considering the growing population.
- HYSACAM should increase bio-waste collection frequency especially during dry seasons when establishing an anaerobic digestion plan. This is due to the fact that longer storage decreases biogas yield as waste has already degraded and lost some of it energy value. Also, storage of bio-waste is directly related to the proliferation of insects, rodents and other disease vectors and even emission of GHG.
- The company in charge of the anaerobic digestion should reduce the size of the bio-waste into fine particles before injection into the anaerobic digestion (AD) plant. This is to avoid blockage at the inlet pipe and to increase surface area for bacteria actions hence ease degradation. Also, we can reduce cost by using local electrical blender.
- HYSACAM should close the landfill site (the treatment center of Bertoua) to avoid intrusion thereby reducing risk of inhaling GHG, eating pawpaw grown on waste and dust particles.

- Municipalities should tar the roads leading to the landfill to ease access of trucks especially during raining season.
- Government should provide regulation for independent energy producers and generation of renewable energy. This will make attractive for investors hence help us to manage and reduce environmental problems.
- Municipalities should sensitize the population about waste management in order to decreased illegal dumpsite which may leads to land pollution, water pollution and air pollution thereby spread of diseases such as air borne, water borne diseases.

Conclusion

We can conclude that, theoretically Municipal Solid Waste (MSW) (household solid waste) of Bertoua can be used to recover energy by anaerobic digestion for electricity production. Nevertheless, the available biogas will help increase output power by 10 MWh daily thereby replacing diesel fuel and help produced 90 % of electricity demand. More information is needed to better understand the quality of methane produce, the future trend of methane (CH_4). This can be carry out by using computer modeling based on available information, carry out field test data.

GENERAL CONCLUSION AND PERSPECTIVES

The introduction of renewable energy sources is a relevant issue in Bertoua, which aims to reduce its dependence on fossil fuels, thereby decreasing its environmental impact. Some renewable alternatives have reached or are reaching technological maturity.

In the content of the thesis, properties of the solid waste management of Bertoua are presented and the biogas potential of solid waste by anaerobic digestion (AD) is determined by fixed-dome AD method. The physical and chemical characteristics of solid waste (SW) are determined by using available data in the literature and used in applied models. For obtaining timely and actual biogas potential, the fixed-dome methods operated with the average waste amounts per year. The specific fuel consumption for the thermal power station was calculated by considering one generator. These calculations were carried out considering the engine working in diesel mode only and biogas-diesel fuel mode. It was calculated at constant speed and varying load. It was found that the thermal power station can work efficiently with biogas without any engine component modification. Also, the amount of landfill gas emitted by Bertoua landfill was estimated by environmental protection agency (EPA) land GEM model.

Also, expected biogas and methane production by AD may be 5519.3 m^3 CH_4/day and 3311.58 m^3 CH_4/day respectively. Accordingly, the energy equivalence of that much of biogas and methane will be 10 822 kWh and 12 661 kWh per day thereby providing an energy supply to 10 MW and 12 MW if considering 60% methane potential.

Since the arrival of HYSACAM in 2011, waste have been dumped in an unsanitary landfilled, using the EPA LandGEM model it was estimated about 8×10^6 m^3/year of total landfill gas (LFG) composed of mostly methane and carbon dioxide gas will be emitted in the year 2041. Total LFG decreases after the closure year (that is 2040) and turns to zero after 50 years of the closure year. Since, this LFG contributes too many environmental problems such as global warming, climate change. Due to recurring shortage of electricity at Bertoua, it is important to use this LFG and avoid the wasted non-fossil fuel renewable energy. Therefore, the biodegradable municipal solid waste needs to be sustainably managed and energy investments should be decided and applied in to use the methane produced beneficially.

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APPENDICES

Appendix 1: Article 1

1. Low Voltage Customers

A. Domestic or residential uses

Monthly consumption ranges

1) Consumption less than or equal to 110 kWh 50 FCFA / kWh
2) Consumption between 111kWh and 400 kWh 79 FCFA / kWh
3) Consumption between 401 and 800 kWh 94 FCFA / kWh
4) Consumption between 801 and 2000 kWh 99 FCFA / kWh

B. Other uses or non-residential

Monthly consumption ranges

1) Consumption less than or equal to 110 kWh 84 FCFA / kWh
2) Consumption between 111kWh and 400 kWh 92 FCFA / kWh
3) Consumption between 401 and 1000 kWh 99 FCFA / kWh

C. Maintenance and renewal of meters and circuit breakers

The various maintenance and renewal costs for meters and circuit breakers are waived.

D. Public lighting

Tariff 66 FCFA / kWh.

2. Medium Tension Customers

The price is made up of two additional terms:

- A fixed monthly premium of 3700 FCFA per kW of power subscribed
- A proportional tariff per kWh consumed which depends on the number of hours of monthly use of the subscribed power and the period of use, in accordance with the tables below;
- The various maintenance and renewal costs for meters and circuit breakers are eliminated.

A. General Regime <1 MW

Number of hours between 11 p.m. and 6 p.m.

From 0 to 200 hours 70 85

From 201 to 400 hours 6585

Beyond 400 hours 6085

B. General Regime >1 MW

Number of hours between 11 p.m. and 6 p.m.

From 0 to 200 hours 70 85

From 201 to 400 hours 6585

Beyond 400 hours 6085

C. Free Points Regime

Number of hours between 11 p.m. and 6 p.m.

From 0 to 200 hours 70 85

From 201 to 400 hours 6585

Beyond 400 hours 6085

Companies established in Free Zones or admitted to the point franc industrial regime after the signing of this decision are exempt from payment of the advance on consumption.

A 10% increase in proportional tariffs will be levied as a guarantee of compliance with the minimum export rate of 80% of the company's production in the free Zone or Industrial Franc Point concerned. This withholding will be retroceded at the end of each financial year in the form of a credit note after proof to Eneo Cameroon of compliance with the export rate of 80% of production.

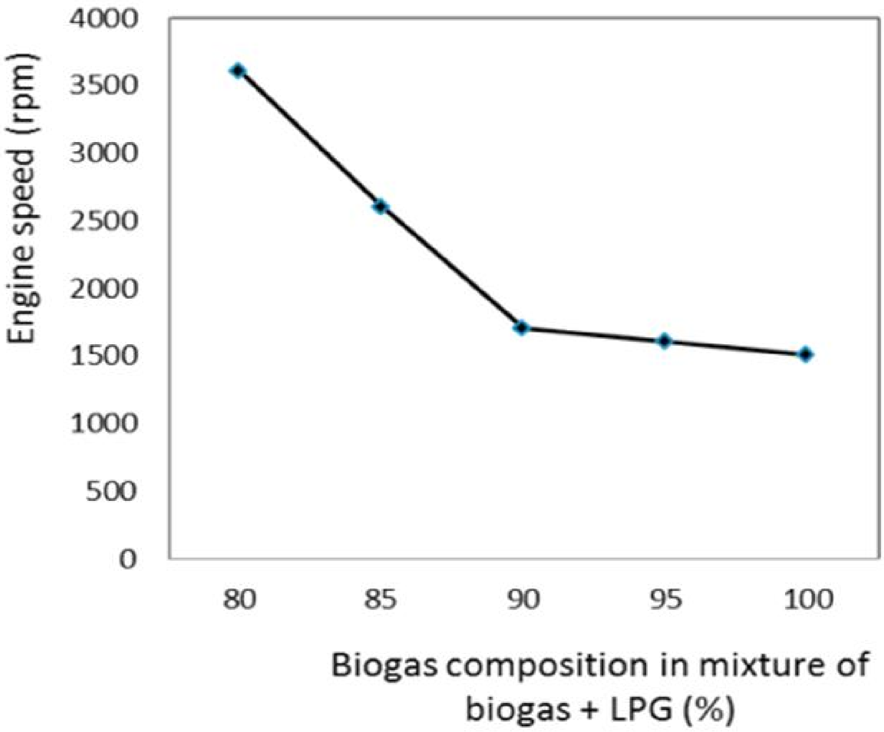
3. High Tension Customers

The prices for the sale of high voltage electricity to new subscribers are set within the framework of the contracts concluded between Eneo Cameroon and the said subscribers, after consultation with the Electricity Sector Regulatory Agency, according to the provisions of the specifications of the Eneo Cameroon's framework concession and license agreement.

The tariffs for the sale of high voltage electricity to existing subscribers on the date of signature of the concession and license constracts of Eneo Cameroon remain in force and are revised according to the provisions of the specifications of the framework concession and license contract.

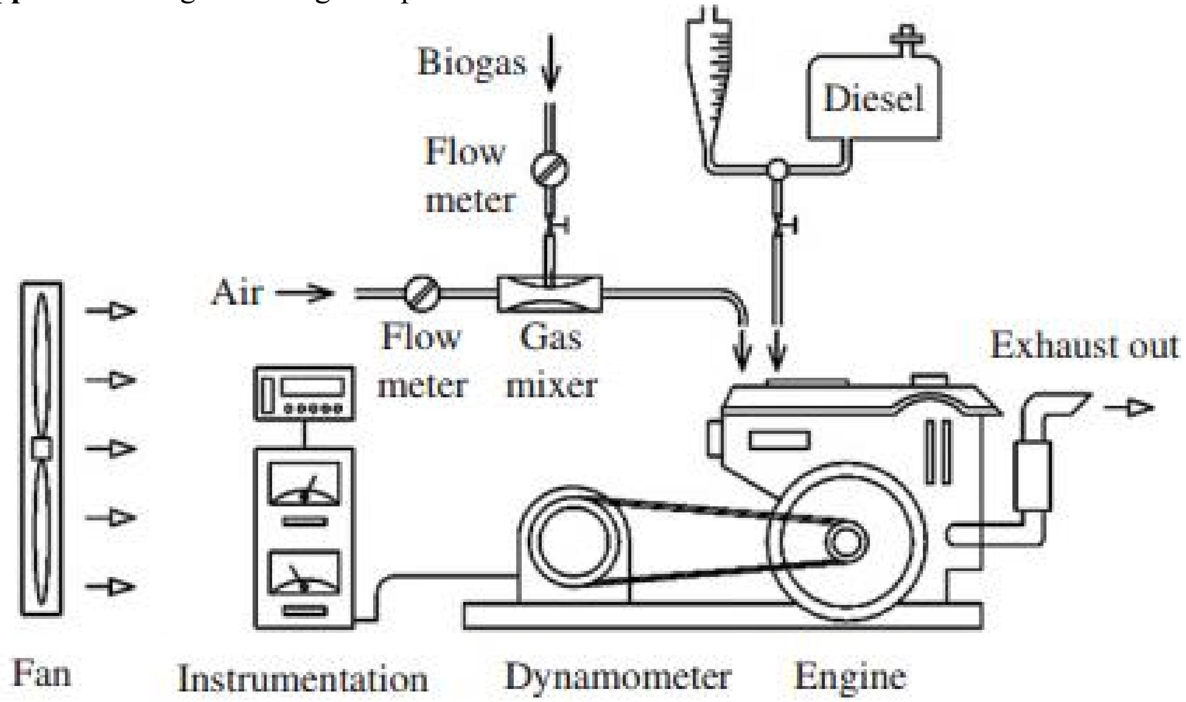
Appendix 2:

Figure 12 : the effect of composition of biogas-LPG mixture on the speed of the engine

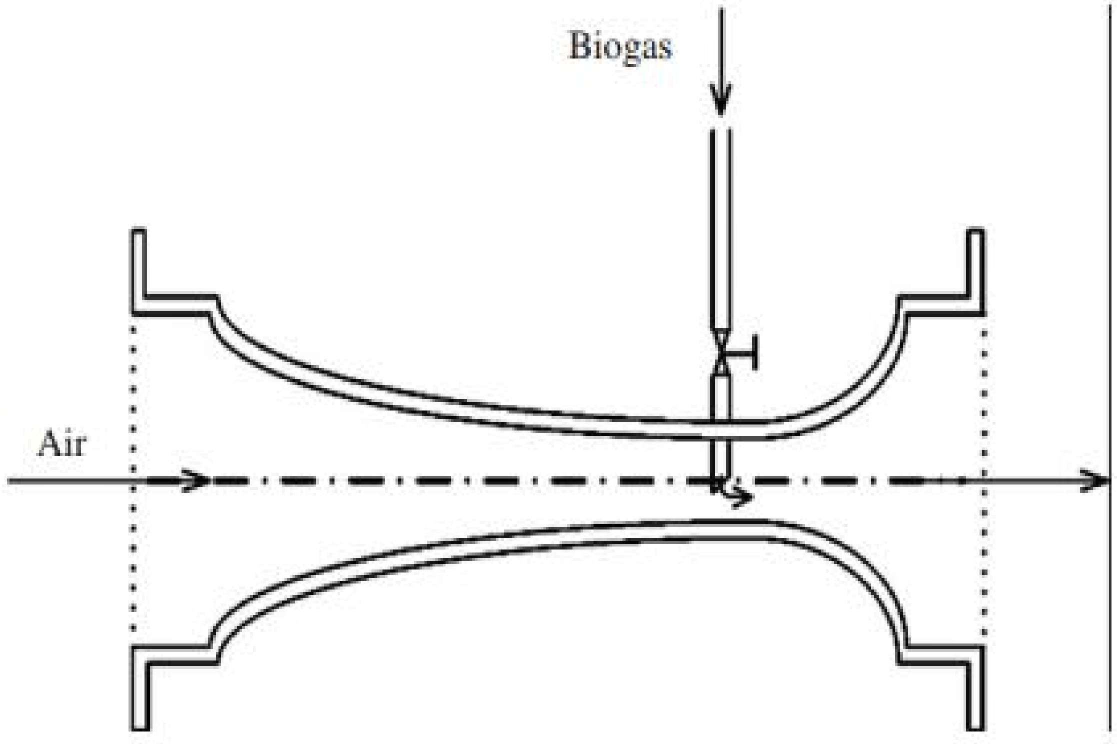


Source: Surata and al., 2014

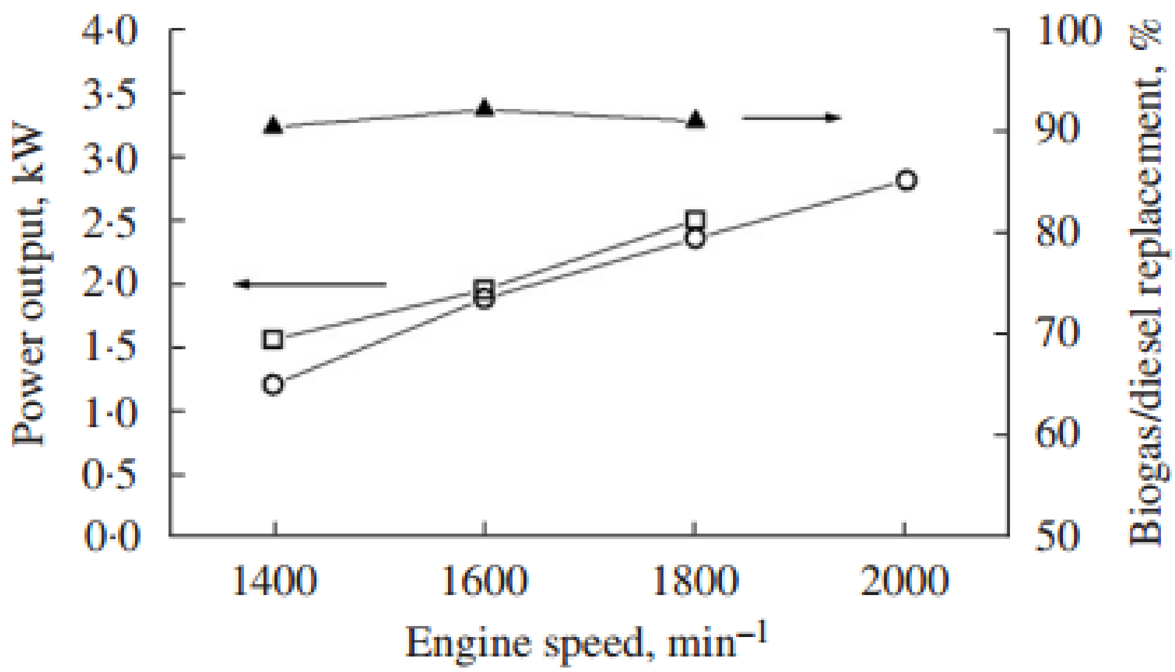
Appendix 3: Engine test rig set-up



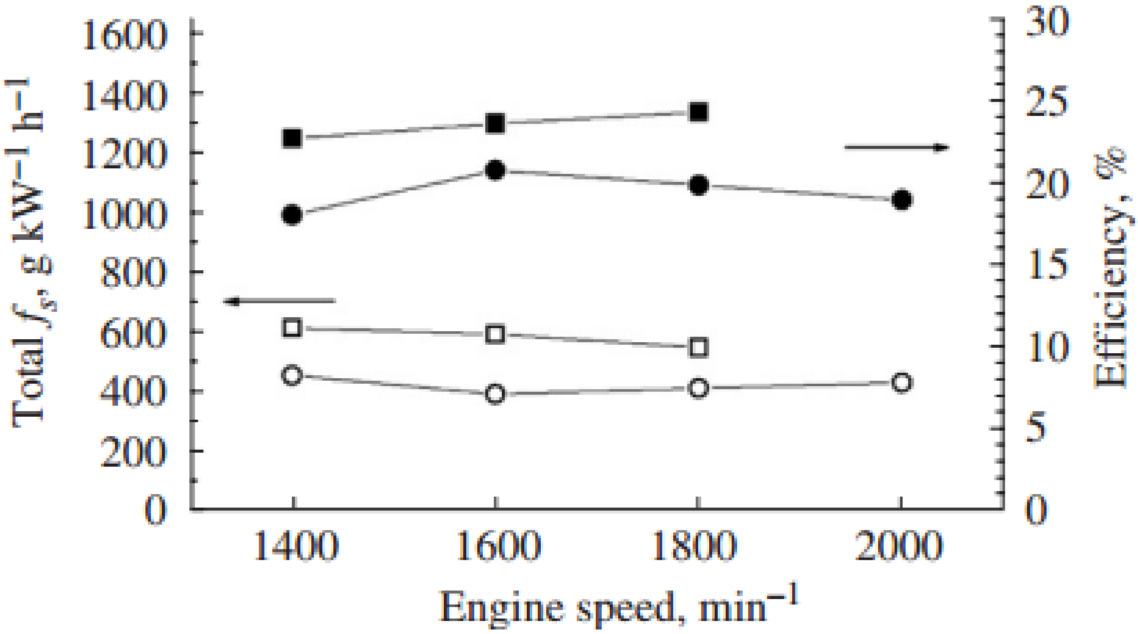
Appendix 4: Biogas-inlet air mixing device



Appendix 5: Comparison between short-term engine power out from diesel (○) and dual-fuel (□) operations, and fraction of biogas replacement (▲) in dual-fuel operation.



Appendix 6: Comparison between short-term engine fuel economy and thermal efficiency from diesel (○ ,●) and dual-fuel (□ ,■) operations.



Appendix 7

Table 20 : Engine component wear shown as mass loss over 2000 h of operation

	Initial mass, g	Final mass, g	Mass loss, g
Intake valve	45.96	45.61	0.35
Exhaust valve	42.71	42.21	0.51
First piston ring	13.88	13.28	0.60
Second piston ring	11.74	11.50	0.24
Third piston ring	11.42	11.24	0.18
Lube compression ring	18.30	18.12	0.18
Connecting rod bush	25.36	20.07	5.29
Connecting rod bearing	41.26	41.04	0.22

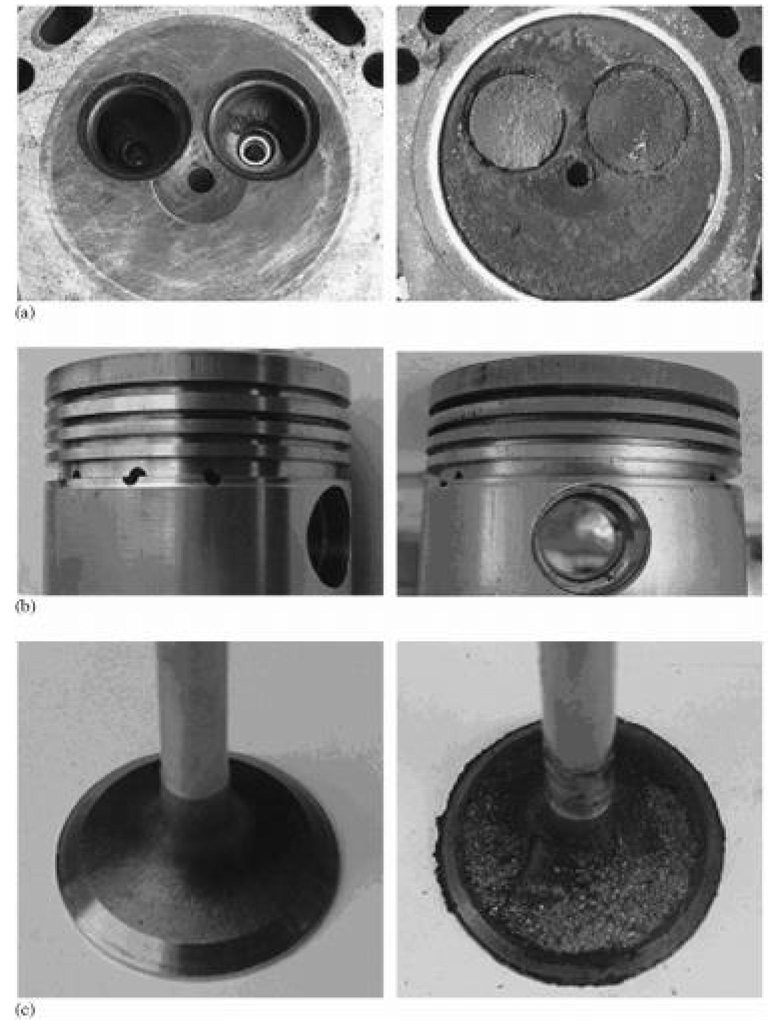


Figure 29: the Comparison between engine components before and after the 2000 h endurance test: (a) cylinder head; (b) piston and (c) exhaust valve.

Appendix 8: the following sections describe the most widely used biogas applications in developing countries. Table provides typical utilization rates of biogas in liters per hour (L/h).

Table 21 : Consumption rates of different biogas appliances

Biogas Application	Consumption Rate (L/h)
Household cooking stove	200–450
Industrial burners	1000–3000
Refrigerator (100 L) depending on outside temperature	30–75
Gas lamp, equivalent to 60 W bulb	120–150
Biogas/diesel engine per brake horsepower (746 watts)	420
Generation of 1 kWh of electricity with biogas/diesel mixture	700

Source: Kossmann and al., undated

Appendix 9: **One-stage 'wet' complete mix systems** this can be represented in Figure 26

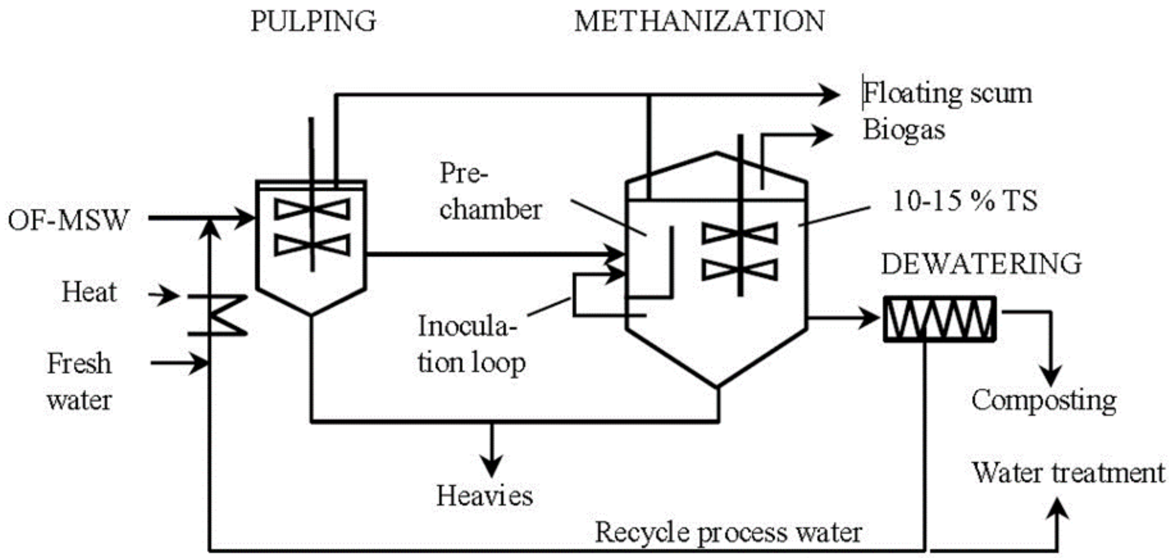


Figure 30: Typical design of a one-stage 'wet' system

Source: Vandevivere and al., 2002

Appendix 10: Table 22 shows examples of calorific value of different fuel sources as compared to biogas as well as the approximate mass of that fuel corresponding to 1 m^3 of biogas.

Table 22 : Calorific value of different fuels

Fuel Source	Approximate Calorific Value	Equivalent to 1 m³ Biogas (approx. 6 kWh/m³)
Biogas	6 – 6.5 kWh/m³	
Diesel, Kerosene	12 kWh/kg	0.50 kg
Wood	4.5 kWh/kg	1.30 kg
Cow dung	5 kWh/kg dry matter	1.20 kg
Plant residues	4.5 kWh/kg dry matter	1.30 kg
Hard coal	8.5 kWh/kg	0.70 kg
Propane	25 kWh/m³	0.24 m³
Natural gas	10.6 kWh/m³	0.60 m³
Liquefied petroleum gas	26.1 kWh/m³	0.20 m³

Appendix 11

Table 23: RUN 2

Year	Waste Accepted (Mg/year)	Waste-in-Place (Mg)	Total Landfill Gas (m^3/year)	Methane (NH_4) (m^3/year)	Carbon dioxide (CO_2) (m^3/year)
2011	36 260	0	0	0	0
2012	36 277	36 260	951700	475800	475800
2013	36 747	72 537	1831000	915300	915300
2014	39 508	109 284	2654000	1327000	1327000
2015	53 002	148 792	3487000	1744000	1744000
2016	58 837	201 794	4610000	2305000	2305000
2017	53 827	260 631	5800000	2900000	2900000
2018	50 210	314 458	6767000	3383000	3383000
2019	47 947	364 668	7564000	3782000	3782000
2020	48 467	412 615	8241000	4120000	4120000
2021	48 467	461 082	8879 000	4440000	4440000
2022	48 467	509 549	9469000	4734000	4734000
2023	48 467	558 016	10010000	5006000	5006000
2024	48 467	606 483	10510000	5257000	5257000
2025	48 467	654 951	10980000	5489000	5489000
2026	48 467	703 418	11410000	5703000	5703000
2027	48 467	751 885	11800000	5901000	5901000
2028	48 467	800 352	12170000	6083000	6083000
2029	48 467	848 819	12500000	6251000	6251000
2030	48 467	897 286	12810000	6407000	6407000
2031	48 467	945 754	13100000	6550000	6550000
2032	48 467	994 221	13370000	6683000	6683000
2033	48 467	1 042 688	13610000	6805000	6805000
2034	48 467	1 091 155	13840000	6918000	6918000
2035	48 467	1 139 622	14040000	7022000	7022000
2036	48 467	1 188 089	14240000	7118000	7118000
2037	48 467	1 236 557	14410000	7207000	7207000
2038	48 467	1 285 024	14580000	7289000	7289000
2039	48 467	1 333 491	14730000	7364000	7364000
2040	0	1 381 958	14870000	7434000	7434000
2041	0	1 381 958	13730000	6863000	6863000
2042	0	1 381 958	12670000	6335000	6335000
2043	0	1 381 958	11700000	5848000	5848000

2044	0	1 381 958	10800000	5398000	5398000
2045	0	1 381 958	9967000	4983000	4983000
2046	0	1 381 958	9200000	4600000	4600000
2047	0	1 381 958	8493000	4246000	4246000
2048	0	1 381 958	7840000	3920000	3920000
2049	0	1 381 958	7237000	3619000	3619000
2050	0	1 381 958	6681000	3340000	3340000

Table 24: RUN 1

Year	Waste Accepted (Mg/year)	Waste-in-Place (Mg)	Total Landfill Gas (m^3/year)	Methane (NH_4) (m^3/year)	Carbon dioxide (CO_2) (m^3/year)
2011	36 260	0	0	0	0
2012	36 277	36 260	537400	268700	268700
2013	36 747	72 537	1034000	516900	516900
2014	39 508	109 284	1499000	749400	749400
2015	53 002	148 792	1969000	984600	984600
2016	58 837	201 794	2603000	1302000	1302000
2017	53 827	260 631	3275000	1638000	1638000
2018	50 210	314 458	3821000	1911000	1911000
2019	47 947	364 668	4271000	2136000	2136000
2020	48 467	412 615	4654000	2327000	2327000
2021	48 467	461 082	5014000	2507000	2507000
2022	48 467	509 549	5347000	2674000	2674000
2023	48 467	558 016	5654000	2827000	2827000
2024	48 467	606 483	5938000	2969000	2969000
2025	48 467	654 951	6200000	3100000	3100000
2026	48 467	703 418	6441000	3221000	3221000
2027	48 467	751 885	6664000	3332000	3332000
2028	48 467	800 352	6870000	3435000	3435000
2029	48 467	848 819	7060000	3530000	3530000
2030	48 467	897 286	7236000	3618000	3618000
2031	48 467	945 754	7398000	3699000	3699000
2032	48 467	994 221	7547000	3774000	3774000
2033	48 467	1 042 688	7686000	3843000	3843000
2034	48 467	1 091 155	7813000	3906000	3906000
2035	48 467	1 139 622	7931000	3965000	3965000
2036	48 467	1 188 089	8039000	4020000	4020000
2037	48 467	1 236 557	8139000	4070000	4070000
2038	48 467	1 285 024	8232000	4116000	4116000
2039	48 467	1 333 491	8317000	4159000	4159000
2040	0	1 381 958	8396000	4198000	4198000

2041	0	1 381 958	7751000	3875000	3875000
2042	0	1 381 958	7155000	3577000	3577000
2043	0	1 381 958	6605000	3302000	3302000
2044	0	1 381 958	6097000	3048000	3048000
2045	0	1 381 958	5628000	2814000	2814000
2046	0	1 381 958	5195000	2598000	2598000
2047	0	1 381 958	4796000	2398000	2398000
2048	0	1 381 958	4427000	2214000	2214000
2049	0	1 381 958	4087000	2043000	2043000
2050	0	1 381 958	3773000	1886000	1886000

Appendix 12

Table 25 : Quantity of Waste Produce at Bertoua City per Year

Year	Quantity of Waste Produces (Tones)
2011	36260.28
2012	36277.20
2013	36746.60
2014	39507.90
2015	53001.70
2016	58826.54
2017	53826.54
2018	50210.41
2019	47946.70
2020	48467.17

Table 26 : Quantity of waste produced per month during five consecutive years

Year / Month	2016	2017	2018	2019	2020
Jan	6247.06 t	4324.48 t	4770.66 t	3978.77 t	4286.51 t
Feb	6782.16 t	4362.5 t	3955.22 t	3595.22 t	3176.56 t
Mar	4656.94 t	4970.24 t	4396.22 t	4134.5 t	4071.7 t
Apr	4611.64 t	5361.56 t	4327.58 t	4294.21 t	4387.31 t
May	4606.04 t”	4606.04 t	4911.36 t	3205.68 t	3248.82 t
Jun	4818.3 t	4818.3 t	4347.82 t	4124.68 t	4286.32 t
Jul	4691.78 t	4691.78 t	4455.64 t	3504.89 t	4262.8 t
Aug	4513.6 t	4649.84 t	3414.47 t	4204.5 t	4178.7 t
Sep	4678.14 t	4678.14 t	2536.42 t	3892.29 t	4322.14 t
Oct	4275.88 t	4275.88 t	4337.00 t	4164.31 t	3868.91 t
Nov	4131.36 t	4131.36 t	4204.95 t	3801.71 t	4025.12 t
Dec	4824.54 t	4824.54 t	4546.07 t	5045.3 t	4627.28 t