# EVALUATING THE ECONOMIC FEASIBILITY OF ANAEROBIC DIGESTION OF KAWANGWARE MARKET WASTE

by

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**ABSTRACT**

Anaerobic digestion is an alternative solution to organic waste management that offers economic and environmental benefits. The Kawangware open air market in Kenya generates approximately 10 metric tons of organic waste per day as a result of farm produce sold at the market. Fresh fruits and vegetables sold at the market account for more than 80 percent of the organic waste. This organic waste is left uncollected, piling up and therefore becoming pollution to the environment. Instead, this waste can be processed by anaerobic digestion to produce energy, organic fertilizer and greenhouse gas credits.

The main objective of this project is to help investors and members of Kawangware Waste Utilization Initiative (a waste management community based organization in the Kawangware area) answer the following questions: (a) Is it economically profitable to invest in an anaerobic digestion system to convert the market organic waste to methane and fertilizer? (b) Is it economically profitable to burn the methane to generate electricity?

To answer these questions, the study examines the costs and returns of producing methane, electricity, and fertilizer from organic waste under various scenarios using net present value, internal rate of return and payback period analysis techniques.

Three production conditions under various scenarios using the anaerobic digester are examined. The conditions include:

(a) Production of methane and organic fertilizer.

(b) Production of methane, organic fertilizer, and carbon credits.

(c) Production of electricity, organic fertilizer, and carbon credits.

From these three production conditions examined, production of methane, organic fertilizer and carbon credits had the highest net present value of $332,610, internal rate of return of 21.4%, and the shortest payback period of 7.9 years.  If carbon credits could not be sold the next best alternative would be production and selling of methane and organic fertilizer which has a net present value of $246,752, internal rate of return of 19%, and a payback period 9.2 years.

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# CHAPTER I: INTRODUCTION

## 1.1 Background information

The cost of energy in Kenya like most other countries is increasing due to escalating oil prices, peaking of hydropower generated electricity supply due to chronic droughts and impact of deforestation on river water supply. Besides the cost of oil, emissions from the use of non-renewable fossil fuels such as oil, gas and coal also pose economic and environmental challenges (Kenya Ministry of Energy, 2009). Less than 25 percent of Kenyans are currently linked to the electricity grid. With a fast-growing economy and demography, energy demand is climbing by eight percent each year (The Kenya Power and Lighting Company, 2009). Currently, Kenya uses 1,050 MW of electricity at peak hours, just 50 MW shy of the country's maximum capacity. Blackouts across the country are frequent. Therefore, it is necessary to examine new ways of producing energy. Renewable sources may play a role in providing new energy supply at local level where it is produced. Producing biogas from food market waste (organic solid waste) and utilizing it for power generation may play a role in providing this supply without having to construct the expensive centralized electricity grid.

Kawangware open air market is a fresh produce market. The market is located in the suburb of Kawangware which is 7.2 miles west of Nairobi. It is located in a densely populated area of more than 200,000 people. The market generates over 10 metric tons of fruits and vegetables waste each day. As Nairobi continues to grow and modernize, it begs for modern ways of utilizing waste from markets and from other collection sites. With over 1,500 tons/day of waste raised from agricultural markets around Nairobi, strategic and sustainable ways of disposal are needed.

*Picture of Dandora dump site.*

The assumption that the waste can decompose on the only dump ground located at Dandora continues to be strongly challenged by the availability of land and pollution problems. The Dandora dump site is perceived to have reached full capacity beside lack of sufficient financial, technical and institutional capacities to collect, transport and safely treat and dispose of municipal wastes by the Nairobi city council. The failure of city authorities to collect waste leads to unpleasant conditions and decomposing waste heaps at Kawangware and other markets in Nairobi. These conditions pose health risks as they provide breeding grounds for disease linked micro-organisms, insects and rodents and also cause air pollution in the form of stench that emanates from rotten organics.

**1.2 Objectives**

The main objective of this project is to help investors and residents of Kawangware Waste Utilization Initiative (a waste management community based organization in the Kawangware area) answer the following questions. a) Is it economically profitable to invest in an anaerobic digestion system to convert the market organic waste to methane and fertilizer? b) Is it economically profitable to burn the methane to generate electricity?

To answer these questions the study examines the cost and net returns of producing methane, electricity, and fertilizer from organic waste using Net Present Value Analysis techniques. The Internal Rate of Return and Payback period for the investment are also determined. To achieve this requires understanding of the anaerobic digestion process of organic waste and the market values of methane, electricity, and fertilizer. This project may also qualify as a Clean Development Mechanism (CDM) project for greenhouse gas emission reduction based on carbon credits under the Kyoto protocol. Therefore, the value of carbon credits from destroying (combusting) methane as opposed to its release from decomposing food waste in piles or landfills are considered.

# CHAPTER II: REVIEW OF LITERATURE

## 2.1 Anaerobic Digestion

Anaerobic digestion (AD) is a biological process that uses microbes to convert organic waste into different usable end products. The end products of anaerobic digestion are biogas and digestate, a moist solid which can be used as organic fertilizer. The components of the biogas depend on the digestion process, but mainly are methane and carbon dioxide with other minor gas constituents like hydrogen sulphide produced from sulfate reducing bacteria (Speece, 1996). The presence of hydrogen sulphide can be troublesome for some applications. These constituents can be removed by cleaning to make the gas equal to natural gas. Biogas generated from organic waste typically contains 55-65% methane gas and 35-45% carbon dioxide. The digestate obtained after digestion is a thick sludge with a moisture content of about 80% which can be dewatered by simple filtration to capture about 10% liquid before it is sold as semi solid fertilizer. Because the fertilizer has most of the nutrients to enrich the soil it can be used instead of the chemical fertilizers. Elements such as nitrogen, phosphorous and potassium can be found in this fertilizer. Subjecting the fertilizer to specific laboratory tests will determine the elements concentration levels present so as to help in determining application rates. The liquid remaining from dewatering is recycled in a biological process to adjust moisture in the digester.

When biogas is captured and combusted it creates renewable energy which can be substituted for fossil fuel based energy or increase the overall energy supply. If the biogas substitutes for fossil fuel based energy, greenhouse gas emissions associated with energy consumption are reduced. Because methane is a potent greenhouse gas, its combustion results in a decrease in emissions from decomposing piles of organic waste in open dump sites. Anaerobic digestion technology is widely used in Europe; for example in Germany it is used for treating solid waste.

There are various AD technologies each of them designed for a specific feedstock material. The amount of biogas produced from feedstock (Table 2.1) varies from one type of feedstock to another depending on solid content. Therefore, variation in the amount of biogas produced should be expected as is explained in the next section analysis of factors determining biogas production and digester types.

**2.2 Factors determining biogas production**

Anaerobic digestion takes place in air –tight containers. The nature of these containers varies depending on the specific application. The size of container required to handle the waste is dependent upon the amount of organic waste to be converted to biogas and the duration of time the waste must remain in the container. The amount of time the waste remains in the container greatly determines the size requirements of the system. The greater the storage requirement capacity, the greater the capital required to build the system. The container types range from horizontal to upright tanks whose cost is proportional to the space they require. The amount of gas produced from anaerobic digestion is dependent upon temperature, retention time and percentage of total solids in the feedstock.

1) Temperature – Anaerobic digestion can take place at a variety of temperatures. In general, higher temperature results in faster conversion of the feedstock to biogas. As a result systems operating at higher temperatures will require less storage space than lower temperature systems. The optimal ranges for anaerobic digestion are between 125 to 135° F (thermophilic conditions) and between 95 to 105° F (mesophilic conditions). Anaerobic digestion under thermophilic conditions generates gas in a shorter amount of time than anaerobic digestion under mesophilic digestion.

2) Retention time – this refers to the amount of time organic material remains in the anaerobic digestion container. Longer retention times under high temperatures result in higher biogas production.

3) Concentration of total solids (material residue left after evaporation of feedstock) in the feedstock determines the amount of biogas. It is also a function of the amount of volatile solids fed to the digester per day per unit volume of the digester. Volatile solids are a measure of the amount of digestible organic material in a feedstock. If total solids are increased volatile solids increase. Therefore, a higher volume of biogas is produced. The increase of total solids is limited to a range of 11% - 13% before it starts being detrimental to the quantity of biogas produced. As solids levels increase the amount of water decreases and the level of acidity increases (Bouallagui et al, 2004b).

### 2.3 Anaerobic digestion types

Various types of anaerobic digesters exist and can be used depending on how convenient it is to handle the solid content. The varieties include covered lagoon, fixed film, complete mix and plug flow digesters. Covered lagoon digesters also known as ambient temperature covered lagoon are commonly used for animal manure. They produce biogas from dilute wastes with less than 2% total solids (98% moisture) such as flushed dairy manure, dairy parlor wash water, and flushed hog manure. Fibrous solids are removed prior to digestion. The lagoons are not heated and the lagoon temperature and biogas production varies with ambient temperatures. When designing they are fitted with a floating gas cover that traps methane. Fixed film digester immobilizes bacteria on a packing material within the reactor vessel, thereby preventing microbial biomass washout. The system handles solids content of less than 2% and can operate at ambient or higher temperatures. The system is suitable for flush manure operations.

Complete mix digesters are constructed with a tight gas cover whose contents are mixed by mechanical agitation, effluent recirculation or biogas recirculation. Complete mix digesters are constructed with reinforced steel or concrete and are heated to keep the temperature at the desired level. The digester works best with a manure slurry or organic solids content of 3 to 10 percent.

A plug flow digester consists of long horizontal tanks, built underground, with a gas cover on the top. The digesters function horizontally, displacing old material with new material. The new material is usually pumped in, displacing an equal portion of old material, which is pushed at the other end of the digester. Solids content handled in this type ranges from 11 to 13 percent (Lusk 1998).

Because the organic waste from Kawangware market has a high solids content, a system that allows maximum digestion is preferred. The digestion system considered for this project is a model developed by Bhabha Atomic Research Center (BARC) in India, (Figure 2.1). The system is a blend between a floating dome digester and a plug flow digester. In this system, the market waste goes through several steps before finally producing biogas and fertilizer as illustrated in figure 2.2 which is step by step flow of the system. The waste gets hydrolyzed in the first phase and in second phase methane is produced. The digester is constructed underground, thus reducing building costs and the reactor contents flow under gravity by volume displacement. As the digester is fed, an equal amount of reactor content will leave the digester. The anaerobic digester is fed with food waste which is digested to produce biogas and fertilizer. The biogas is water scrubbed under high pressure to remove carbon dioxide and hydrogen sulphide thus yielding methane. The methane is then dried to remove water vapor and is compressed to generate electricity or is directly sold as methane at centralized metered locations to market users and neighboring residents for cooking.

The digester effluent utilized as fertilizer is first separated into solids and liquids over gravel/sand bed. The liquid drains through the sand into a holding tank. The solids are moved by the backhoe to an open air holding area where they are air dried to reduce the moisture content before being sold. The separation process is as illustrated in Figure 2.2.

### 2.4 Anaerobic digestion benefits

Anaerobic digestion has several benefits that make it worth consideration. The benefits range from economic, to environmental, to social. Anaerobic digestion affords the option of treating or biodegrading organic waste into useful end products. In most cities, waste collection and disposal services are provided by municipal or private entities and can be costly. The city of Nairobi is supposed to provide the Kawangware market and residents a service that collects and disposes of organic waste. Unfortunately, this service is not currently being provided. The anaerobic digestion option to decompose the market waste has potential to provide the following benefits:

1) Replacement of fossil fuel. The production of biogas from of biodegradable solid waste can replace consumption of liquefied petroleum gas (LPG) and other energy sources used for cooking, lighting or electricity production. The local fruit and vegetable waste source may prove to be more economical for producing energy in the long run than use of imported fuel.

2) Nutrient rich organic fertilizer. Because anaerobic digestion degrades organic waste at high temperatures, it kills germs. Therefore the residue which is a semi solid form can be applied as organic fertilizer for agricultural purposes. The residue is rich in nutrients (ammonia, phosphorous, potassium and more other nutrients) that can be used as a soil conditioner. The degradation of the biomass makes the nutrients readily available to plants compared to inorganic fertilizer. Specific nutrients of this fertilizer will be determined by doing laboratory tests in order to determine concentration levels of elements available.

3) Employment creation. Both skilled and unskilled labor can be used in operating and maintaining the anaerobic digester.

4) Greenhouse gas (GHG) emission reduction revenue. The project has to demonstrate that it actually does reduce greenhouse gases for it to be certified under the clean development mechanism (CDM) project based credits. Project based credits also referred to as "offset credits" can be generated from projects that sequester carbon or reduce GHG emissions (Williams, et al. 2009). Anaerobic digestion of biodegradable solid waste to generate energy reduces greenhouse gas emissions if it substitutes for a fossil fuel or if used instead of open landfill biodegradation. Digestion of the solid waste will capture the methane that would otherwise be released from decomposing food waste in piles or landfills. This methane can then be destroyed by combustion for heat or generation of electricity. Under the Kyoto protocol such a project can sell its credits as a source of revenue in the carbon trading market if emission reduction units are certified. Carbon credit trading is a market oriented system that provides incentives to control the emission of carbon dioxide.

5) Saving landfill space. Fruit and vegetable waste used in an anaerobic digester reduces the solid waste that ends up in landfills. With less waste to be disposed of, space will be saved and the landfill lifespan will be extended.

### 2.5 Previous Economic Analysis of Anaerobic Digesters

Anaerobic digester system costs vary widely and so does the economic feasibility. The variation in cost depends on type of construction materials and labor cost; otherwise the standard factors to consider when building a digester are cost, size, local climate, availability and type of organic feedstock material used.

Because user needs for anaerobic digesters differ several studies have been conducted that examine their profitability and determine the right size or type of digester. Depending on the primary purpose of the digester, the economics are determined at different levels of operation and production of end products. For example in the United States, digesters are used for biogas production, waste treatment and odor reduction especially on large scale livestock operations such as dairies, feedlots and slaughterhouses, overriding its economic value as a fuel source. In many developed countries, inexpensive fossil fuels make it harder to compete with fossil fuel generated electricity. Considering cost- size relationship for dairy farm plug flow digesters, an economic analysis by Ag star in 2006 found that high installation costs are prohibitive in most cases but the interest for bio digesters is increasing (www.rurdev.usda.gov).

Further, a study on economics of anaerobic digesters in Europe comparing costs between countries found that there were clear differences between countries. For example Switzerland and Austria have higher plant costs than in Italy or Germany. The differences are attributed to technical approaches. In Germany many anaerobic digesters are custom constructed whereas in countries like Switzerland and Austria the plants are commercially supplied equipment (Ian Higham, AEA technology environment, 1998). In comparing farm scale and centralized digester producing electricity the study found the average payback period of more than fifteen years and less than three percent internal rate of return. In both cases these are long payback periods and low internal rate of return, therefore, making it an unattractive economic investment. However, as these economic indicators show poor returns there is opportunity to improve the economics. Given the considerable investment costs of the technology, additional income from selling effluent from the plant as organic fertilizer and participating in the clean development mechanism (CDM) program of the Kyoto protocol could potentially increase the economic viability of anaerobic digestion. Growing interest in digester technology increases the incentives to reduce technology costs.

**Table 2.1: Biogas Production and Retention Time from Various Feedstocks**

| Material | Biogas produced (L/kg TS) | % methane in biogas | Suitable RT |
|---|---|---|---|
| Banana (fruit and stem) | 940 | 53 | 15 |
| Potato (tuber) | 880 | 54 | 15 |
| Sugar beet ( root) | 620 | 65 | 15 |
| Meat waste ( paunch, offal) | 600 | 59 | 25 |
| Lucerne | 450 – 600 | 56 – 64 | 20 |
| Kale | 440 – 560 | 47 – 58 | 20 |
| Grass | 450 – 530 | 55 – 57 | 20 |
| Maize (whole plant) | 350 – 500 | 50 | 20 |
| Oats (whole plant) | 450 – 480 | 51 – 55 | 20 |
| Hay | 350 – 460 | 54 – 65 | 20 |
| Straw (ground) | 350 – 450 | 54 – 58 | 25 |
| Poultry manure (fresh) | 300 – 450 | 57 – 70 | 20 |
| Pig manure (fresh) | 170 – 450 | 55 – 65 | 20 |
| Sugar beet (leaves) | 380 | 66 | 20 |
| Garbage (organic fraction) | 380 | 48 | 25 |
| Lake weed (lagarosiphon) | 380 | 56 | 20 |
| Straw (chopped) | 250 – 350 | 58 | 30 |
| Newspaper | 240 | 52 | 30 |
| Cattle manure | 190 – 220 | 68 | 20 |
| Sheep manure | 180 – 220 | 56 | 20 |

*TS = Total solids or dry matter, * RT = Retention time in days, * L = Liters, *Kg = Kilogram.
Source: www.rise.org.au/info/Tech/waste/index.html

**Figure 2.1: Schematic Description of Bhabha Atomic Research Center (BARC) Biogas Plant**

source: http//www.eawag.com

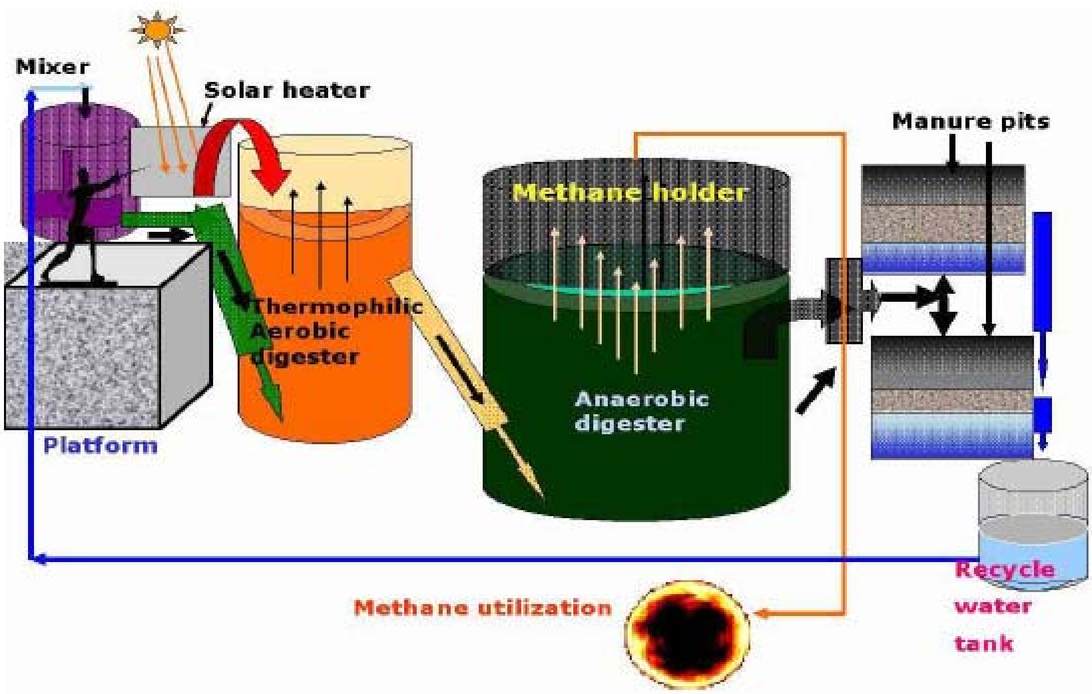
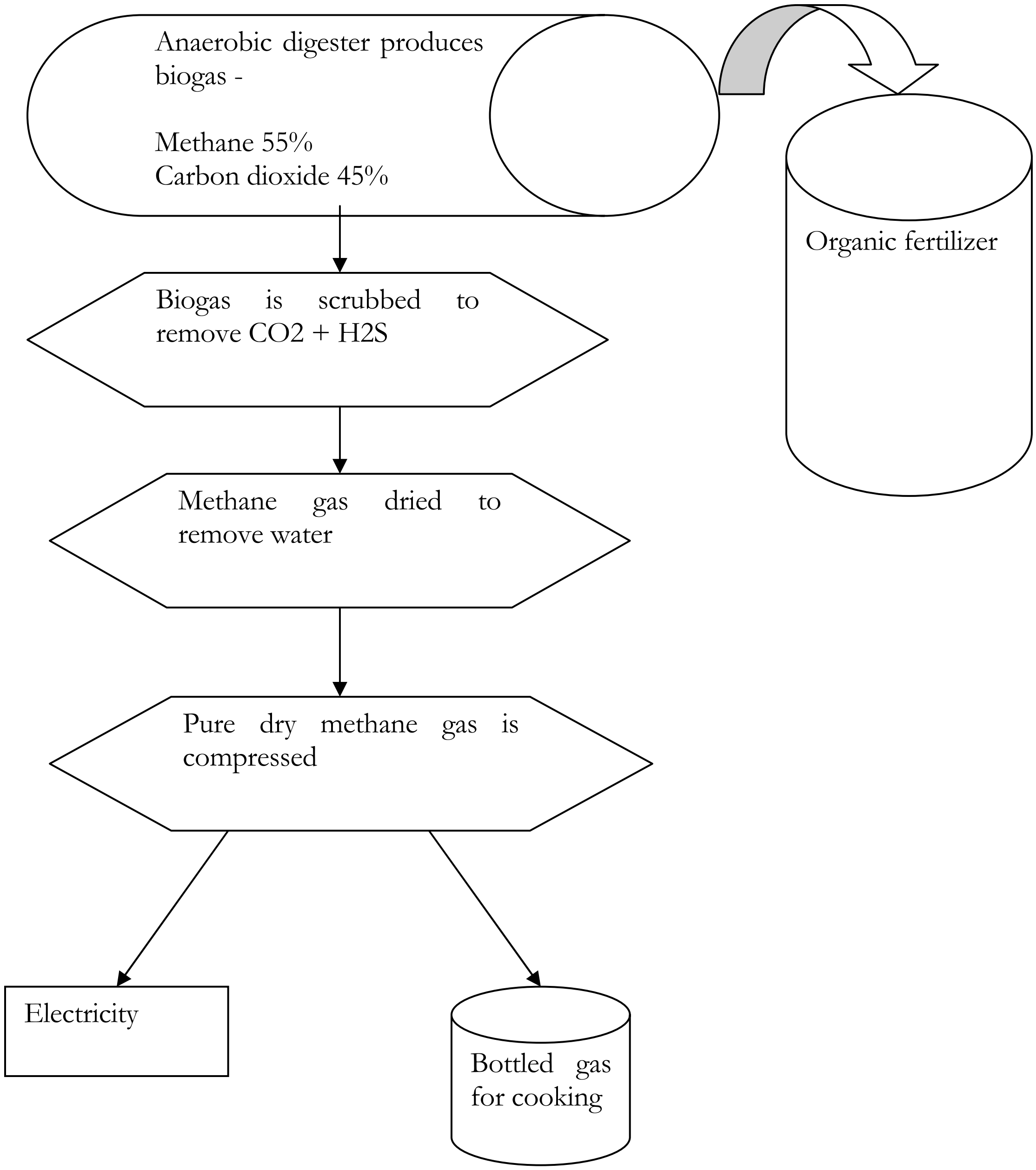


**Figure 2.2: Methane and Fertilizer Production Process.**



# CHAPTER III: METHODS AND DATA

The objective is to conduct Net Present Value (NPV) and Internal Rate of Return (IRR) analyses using discounted cash flows to determine if using an anaerobic digestion process to convert organic waste to methane or electricity, fertilizer, and obtain carbon credits outweighs the costs. The cash flows for the initial investment, labor, repairs and maintenance, sale of methane, electricity, organic fertilizer and carbon credits are estimated over a 15 year period and discounted after taxes to present dollars at 12.6 per cent.

## 3.1 Methods

The economic assessment is carried out using an after tax discounted cash flow analysis. Although the NPV analysis model adopted is applicable for a variety of investments, the results presented in this study are based on processing 10 tons of organic food waste per day into methane, electricity, organic fertilizer and carbon credits.

Both Net Present Value and Internal Rate of return are referred to as discounted cash flow methods because they factor the time value of money into the capital investment project evaluation. Both methods are based on a series of cash flows. Investment costs used in the analysis include the construction of biodigester, purchase of electric generator, shredder, backhoe, dump truck and land. Operating costs (cash outflows) include labor, water, repairs and maintenance. Cash or income received from sale of methane electricity, organic fertilizer and carbon credits account for the project revenue (cash inflows).

The net present value (NPV) is the sum of the expected net cash flows, measured in today's dollars. Today's dollars implies the present value (PV) of receipts and expenditures (cash flows). Present value is calculated by multiplying future expenditures and receipts by the appropriate discount rate. The difference between the present value of the receipts and the present value of the expenditures is the net present value (NPV). Higher NPV values represent greater economic benefit. A net present value (NPV) greater than zero dollars indicates that the digester is profitable than the next best alternative at the same rate of return on investment.

The following formula is used to calculate the NPV.

(3.1)

$$NPV_N = -C_0 + C_N(1+r)^{-N} + (1-T)\sum_{k=1}^{N}\left(MR_k + ER_k + FR_k + CC_k\right)(1+r)^{-k} + T\left[\sum_{k=1}^{N} D_K(1+r)^{-k}\right]$$
$$-(1-T)\left[\sum_{k=1}^{N}\left(LC_k + RM_k + W_k\right)(1+r)^{-k}\right]$$

where:

| | | |
|---|---|---|
| $NPV_N$ | = | Net present value of solid waste digester investment. |
| $C_0$ | = | The original investment required for construction, installation of the solid waste digester and related equipment. |
| $C_N$ | = | The salvage value of the digester and other equipment at the end of the $N^{th}$ year. This term is discounted to present value by $(1+r)^{-N}$. |
| r | = | An after-tax discount rate. |
| T | = | Marginal income tax rate. |
| $MR_k$ | = | Methane revenue in $k^{th}$ year. |
| $ER_k$ | = | Electricity revenue in the $k^{th}$ year. |
| $FR_k$ | = | Fertilizer revenue in the $k^{th}$ year. |
| $CC_k$ | = | Carbon credit revenue in the $k^{th}$ year. |
| $D_k$ | = | Depreciation in $k^{th}$ year. This term is discounted and then multiplied by the tax rate to arrive at the effective tax deduction for depreciation. |
| $LC_k$ | = | Labor cost in the $k^{th}$ year. |
| $RM_k$ | = | Repair and maintenance cost in the $k^{th}$ year. |
| $W_k$ | = | Water cost in the $k^{th}$ year. |

$MR_k$, $ER_k$, $FR_k$, and $CC_k$, are discounted and multiplied by (1-T) to arrive at the after-tax revenue. $LC_k$, $RM_k$, and $W_k$ also are discounted and multiplied by (1 – T) to arrive at the after-tax costs. These costs are deductible expenses, therefore, the effective rate is found by multiplying the costs by (1 – T).

Internal rate of return (IRR) is also used in this study to measure the yield of the project. The IRR is the annualized rate of return that is possible to earn on the newly invested capital. It is the yield created from the investment. A project is considered to be a good investment if its IRR is greater than the rate of return that could be earned by alternative investments. Mathematically, the IRR is defined as the discount rate that results in a NPV of zero.

The last measurement used in this analysis is the Payback Period of the project. Payback Period measures the length of time required for a project's cumulative revenues to return its investment through the annual cash flow. A more attractive investment is one with a shorter payback period. This method has a weakness because the cut off criteria for the project is arbitrary and it does not consider the return on the investment after the payback period. It cannot be used to compare alternative investments.

The spreadsheet constructed to perform the calculations can be found in Appendix A.

**3.2 Data**

Although no published report could be found that strictly considers biogas production from fruit and vegetable waste in Kenya, studies elsewhere have generally confirmed that majority of biomass can potentially be used as substrate as long as they contain carbohydrates, proteins, fats, cellulose and hemicellulose as main components. Except for lignin, a wood component, all other plant fiber degrades well under anaerobic conditions (Mata-Alvarez, 2003). Beside type of feedstock used for the anaerobic digester, particle size of influent can also determine performance of digesters operating on solid wastes. Therefore, reducing the particle size can increase the surface area of the feedstock thus increasing the degradation yield and accelerating the digestion process. Because of such varying factors a wide range of data exists. These data are based on study reports from various anaerobic digesters operating under different conditions and therefore different results. For example, dry matter content and biogas production volume used in this study is from a presentation reviewing biogas potential in New Zealand (Table 3.3) (http://www.bioenergy.org.nz/documents). The daily outputs are based on digesting ten metric tons of fruit and vegetable waste per day. This waste is comprised of the items listed in Table 3.1. Dry matter content of the collected waste is estimated at 15 percent based on average total solids for various items listed in Table 3.2. Production of $46m^3$ biogas per ton is assumed for this project based on the potential yield for various feedstock listed on Tables 2.1 and 3.3.

Labor, water, operation and maintenance costs used in this study were obtained from personal interviews in November 2008 with a Nairobi city council official and a Kawangware youth group representative.

*3.2.1 Investment costs*

Investment costs include land, complete digester installation, shredder, generator, and backhoe (Table 3.4). Investment costs are based on a project life of 15 years for them to depreciate to zero salvage value. A 12.5% deductible is applied to all project investment assets when depreciating according to Kenya tax law (www.kra.go.ke). Processing of waste through anaerobic digestion normally produces about 90% residue which includes solid and liquid content. For the chosen digester type, it is estimated to produce 70% residue daily because some material may settle at the bottom of the tank. This estimate is based on the same floating dome design used for digestion of organic waste in India and China. The daily processing of 10 metric tons of waste will produce an estimated 7 metric tons of residue per day (www.barc.net). Therefore 17 tons of material will be moved each day. A multipurpose 80 horsepower backhoe loader will be used for excavating, moving, and loading the waste to a dump truck for delivery to and removal from the digester. The option of producing electricity will require an 80KW electric generator whose cost is $ 291,100. In most systems with electrical generation, this type of engine will produce about 2kWh of hot water and

1.7kWh of electricity from each cubic meter of reasonably good quality biogas (Cuellar and Webber, 2008). A shredder will be used to cut the waste material into smaller sizes before feeding into the digester. Given the foregoing interest rates charged by banks for borrowing money, a similar project of capital requirement like this would be subjected to long term borrowing rates. These rates are in the range of 14 – 18 percent. Therefore, before tax discount rate of 18% is selected and is further adjusted to an after tax discount of 12.6% that is used in the analysis. The after tax discount rate accounts for the impact of depreciation and expense deductions from income. After tax discount rate is calculated using the following equation: $r = i\ (1 - T)$

where:

$r$ = after tax discount rate

$i$ = before tax discount rate

$T$ = marginal tax rate

The marginal tax rate is the sum of the marginal federal income tax rate, state income tax rate, and self employment tax rate. In this case since the project business is recognized as a corporation in its organization structure, 30% tax rate for corporations is used as marginal tax rate. The analysis assumes a zero salvage value for all the investment at the end of 15 years.

### *3.2.2 Labor, operation, maintenance, and water costs*

These are recurring costs over the life of the operation. They help sustain the operation process as discussed below. The individual items and cost calculation spreadsheet can be found in appendix A.3.

### *3.2.3 Labor costs*

Labor cost will be paid in the form of a monthly salary. The salary scale used in this project is based on assessment of income in Nairobi city for informal employment. Full time employment in this project refers to employees who will work eight or more hours a day and will be paid when on vacation. Part time employees will work between four and eight hours a day but cannot claim vacation compensation. A staff of four full time people will be needed to operate and monitor the installation on a daily basis. Two part time people will be employed to remove the non-digestible waste like cans and bottles from the food waste. One of the full time employees will administer the project. A second full time employee will assist with administration and be in charge of sales and marketing of the energy and fertilizer. Two full time employees will operate the digester, maintain the equipment, move the digestate, and service buyers. The project administrator will earn $1.45/hour. The assistant administrator and two full time operators will earn $1.35/hour. Part time employees will each earn 1.15/hour. The two full time employees on the administrative staff will each work 2496 hours/year. The two full time employees on the operation staff will each work 3120 hours/year. Each part time employee will work 1768 hours/year. Refer to Table 3.5 for the itemized labor costs.

*3.2.4 Operation and maintenance cost*

Annual operation and maintenance cost of 5% on the initial total capital investment cost excluding land of $537,875 will be considered for this project. The 5% allocation to cover recurring operation and maintenance of the installation and equipment is the average allocation for most investments of this nature.

*3.2.5 Taxes and tax deductible expenses*

According to the Kenya Income Tax act, a corporate tax rate of 30% is levied on corporate income (www.kra.go.ke). The act specifies other tax rates and deductible expenses. Deductible expenses are those expenses incurred wholly and exclusively in the production of income and are not of a capital nature. Depreciation of capital investment on equipment is a deductible expense at different rates. The act specifies rates of depreciation deductible at 37.5 percent for heavy equipment. This includes the backhoe and dump truck that weigh more than 3 tons each. A 12.5% rate for plant, machinery and other equipment is allowed.

Financing of the project will depend on donations from development donors like the United Nations Environmental Program, United States Agency for International Development, World Bank, European Union. These agencies have been approached by the Kawangware youth group representative and have asked to see a proposal of the project. Securing bank loans will not likely be feasible at the moment because the group does not have any savings or equity which the banks can use to guarantee a loan.

*3.2.6 Water cost*

Water is needed to balance the moisture content of the raw material above 75%. Fifty percent of the total amount required will come from water recycled from the digester and waste water collected from the market after cleaning. The rest will be purchased tap water at a cost of $0.01 per cubic foot. A total of 128,918.00 cubic feet water will be used in a year therefore 64,459 cubic feet will be bought from the water company costing US$644.59 (Table 3.5).

*3.2.7 Methane, fertilizer, and electricity*

The breakdown of organic waste to various products is illustrated in the following equations.

(3.2) Annual Biogas ($m^3$) = $46m^3$/ton waste × 10 tons waste/day × 365 days/year = $167{,}900m^3$.

Biogas is approximately 55% methane ($CH_4$) and 45% carbon dioxide ($CO_2$). Thus, this corresponds to approximately $25.3m^3$ $CH_4$/ton of work and $20.7m^3$ $CO_2$ per ton of waste.

(3.3) Annual Methane ($ft^3$/year) = $25.3m^3$/ton waste × 10 tons waste/day × 365/days/year = 92,345.

(3.4) Annual Fertilizer (tons) – 0.7 tons/ton waste × 10 tons waste/day × 365 days/year = 2555 tons.

An electric generator will produce about 1.7kwh of electricity from each cubic meter of biogas (Cuellar and Webber, 2008). Methane conversion to electricity by use of an 80KW electric generator can potentially yield 285, 430 kwh per 78.2 tons of waste.

(3.5) Annual Electricity (kwh) = 78.2kwh/ton waste × 10 tons waste/day × 365 days/year = 285,430.

The constructed spreadsheet for electricity, methane and fertilizer can be found in appendix A.4, A.5, and A.6 respectively.

*3.2.8 Greenhouse gas abatement*

Anaerobic digestion produces biogas which contains methane ($CH_4$) and carbon dioxide ($CO_2$). The 10 tons per day of waste when digested will produce 75,555$m^3$ of $CO_2$ and 92,345$m^3$ of $CH_4$ per day. Since 1 volume of methane when combusted yields 1 volume of carbon dioxide ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$), the total volume of $CO_2$ already present in the organic waste of 75,555$m^3$ plus the 92,345$m^3$ of $CO_2$ produced on complete combustion of the $CH_4$ from the digester equals 167,900$m^3$ of $CO_2$.

If the organic waste is left to decompose in a pile or in a landfill it will produce 45% carbon dioxide and 55% methane gas. Assuming the 10 tons of organic waste is not digested, it will produce 207$m^3$ of $CO_2$ and 253$m^3$ of $CH_4$ respectively. This is equivalent to 75,555$m^3$ of $CO_2$ and 92,345$m^3$ of $CH_4$ per year. Methane has 23 times the global warming potential (GWP) as carbon dioxide (IPCC, 2001). Therefore, the $CO_2$ equivalent of 92,345$m^3$ of $CH_4$ equals 2,123,935$m^3$ $CO_2$ per year. When this is added to 75,555$m^3$ $CO_2$ the yearly production of $CO_2$ equivalent equals 2,199,490$m^3$. Therefore, the difference between 2,199,490$m^3$ and 167,900$m^3$ of 2,031,590$m^3$ is the reduction in $CO_2$ equivalent emissions due to the project. Equation (3.5) describes how this is converted to metric tons.

(3.5) Annual $CO_2$ abated (metric tons) = 2,031,590 × 1.83kg/$m^3$ ÷ 1,000kg = 3,717.81.

Kenya is a signatory to the Kyoto protocol, and is currently formulating and formalizing GHG emission monitoring and verification procedures for CDM projects. Hopefully, these procedures shall be published and become effective by the launch of this project in 2010. The constructed spreadsheet for greenhouse emission and abatement can be found in appendix A.7.

*3.2.9 Revenue*

There are four potential revenue sources from the project. These are (1) methane sales, (2) electricity sales, (3) fertilizer sales, and (4) carbon credits. The outputs and market prices used to estimate revenue are listed in Tables 3.6 and 3.7. The methane sales price of $0.95/kg unit is based on the price of natural gas.

The true fertilizer price will be determined after doing sample analysis of effluent from the digester once in operation to help determine the exact nutrient content. For the analysis, a conservative price of $25.64 per ton is used, far lower than the price of inorganic fertilizers. The current price for calcium ammonia nitrate chemical fertilizer is $512.82 per ton. A price of $25.64 per ton for fertilizer from the digester is realistic given the rising demand for organic fertilizers at the expense of inorganic fertilizers. A brief market survey conducted by a representative of Kawangware youth group in October 2008 bears evidence for a potential market for organic fertilizer. The representative surveyed the demand for organic fertilizer by market attendees, plant nurseries and landscapers within Dagoreti and Westlands locations in Nairobi city. These two locations are within a reasonable distance for transportation of the fertilizer from the project site. The survey covered the price paid for chemical fertilizers and compost

Most participants that sell their produce at the market, plant nurseries and landscapers would be willing to buy the organic fertilizer if it is of good quality. Because the fertilizer will be air dried to reduce the moisture content, it is possible that the produce delivery trucks will haul the fertilizer back to the buyers' farms and for landscapers to conveniently transport it within residential sites where they do their work.

Since the carbon credit market is new and therefore experiencing some price volatility, the project uses a conservative sale price of $5 per ton of $CO_2$.

*3.2.10 Depreciation Schedule*

Table 3.8 shows the depreciation used for this project. It is for 15 years period and based on double declining balance method. In this method the depreciable balance is subjected to twice the straight line rate hence why the method is also referred to as accelerated method. The method assumes the project assets will lose majority of their value in the first few years of their useful life. The method considers the current book value and useful life of the digester, electric generator, shredder, backhoe and dump truck whose depreciable expense is higher during the early years of the project and less expense towards the later years.

Additional details regarding the data used for analysis is reported in Appendix A.1.

**Table 3.1: Agricultural Wastes from the Kawangware Market.**

| |
|---|
| Bananas |
| Pears |
| Onions |
| guava |
| Pineapple |
| Oranges |
| Avocado |
| Kales |
| Citrus |
| Tomatoes |
| Cabbage |
| French beans |
| Mangoes |
| Carrots |
| Papaws |
| Pasfruit |

**Table 3.2: Solid Waste Content Analysis**

| Fruit/ Vegetable | Moisture content (%) | Total Solids (%) | Volatile solids (%) | Fixed Solids (%) | N (%) | P (%) | K (%) |
|---|---|---|---|---|---|---|---|
| Banana, fresh | 84 | 16.0 | 13.9 | 2.1 | 0.53 | | |
| Broccoli, leaf | 86.5 | 13.5 | | | 0.30 | | |
| Cabbage, leaf | 90.4 | 9.6 | 8.6 | 1.0 | 0.14 | 0.034 | |
| Cabbage, core | 89.7 | 10.3 | | | 0.38 | | |
| Carrot, top | 84.0 | 16.0 | 13.6 | 2.4 | 0.42 | 0.03 | |
| Carrot, root | 87.4 | 12.6 | 11.3 | 1.3 | 0.25 | 0.04 | |
| Cassava, root | 67.6 | 32.4 | 31.1 | 1.3 | 1.68 | 0.039 | |
| Corn, Sweet | 79.8 | 20.2 | 19.0 | 1.2 | 0.67 | | |
| Kale, top | 88.4 | 11.6 | 9.7 | 1.9 | 0.22 | 0.06 | |
| Lettuce, top | 94.6 | 5.4 | 4.5 | 0.9 | 0.05 | 0.027 | |
| Onion, top | 8.6 | 91.4 | 84.7 | 6.7 | 1.37 | 0.02 | |
| Orange, flesh | 87.2 | 12.8 | 12.2 | 0.6 | 0.26 | | |
| Orange, pulp | 84 | 16.0 | 15.0 | 1.0 | 0.24 | | |
| Parsnip, root | 76.3 | 23.7 | | | 0.47 | | |
| Potato, top | 12.8 | 87.2 | 71.5 | 15.7 | 1.22 | | |
| Potato, tuber | | | | | 1.60 | 0.25 | 1.9 |
| Pumpkin, flesh | 91.3 | 8.7 | 7.9 | 0.8 | 0.12 | 0.037 | |
| Rhubarb, leaf | 88.6 | 11.40 | | | 0.20 | | |
| Rutabaga, top | 90.0 | 10.0 | | | 0.35 | | |
| Rutabaga, root | 89.5 | 10.5 | | | 0.20 | | |
| Spinach, stems | 93.5 | 6.5 | | | 0.065 | | |
| Tomato, fresh | 94.2 | 5.8 | 5.2 | 0.6 | 0.15 | 0.03 | 0.30 |
| Tomato, solid waste | 88.9 | 11.1 | 10.2 | 0.9 | 0.22 | 0.044 | 0.089 |
| Turnip, top | 92.2 | 7.8 | | | | 0.20 | |
| Turnip, root | 91.1 | | | | | 0.34 | |

*N = Nitrogen, *P = Phosphorous, *K = Potassium

Source: http://tammi.tamu.edu/pdf%20pubs/chap4-toc.pdf (210-vi-AWMFH, rev. 1, July 1996)

**Table 3.3: Biogas Production and Energy Output for Each Metric Ton of Input.**

| Feedstock | No of animals to produce 1 metric ton/day | Dry matter content | Biogas yield (metric/ton feedstock) | Energy value ($mJ/m^3$ biogas) |
|---|---|---|---|---|
| Cattle slurry | 20-40 | 12 | 25 | 23-25 |
| Pig slurry | 250-300 | 9 | 26 | 21-25 |
| Laying hen litter | 8000-9000 | 30 | 90-150 | 23-27 |
| Broiler manure | 10,000-15,000 | 60 | 50-100 | 21-23 |
| Food processing waste | - | 15 | 46 | 21-25 |

Source:
http://www.bioenergy.org.nz/documents/Christchurch%20Workshop/1_Bioenergy%20Opportunities%20in%20NZ%20paper.pdf September 20th, 2009

**Table 3.4: Investment Expenses (2009 US$)**

| Capital Investment Expense | | | |
|---|---|---|---|
| Item | Description | US $ | Years of Life |
| Land | ½ acre | 14,500 | |
| Biodigester construction & engineering | 200 cubic meter | 210,350 | 15 |
| Shredder | 9FH-80 | 7,000 | 15 |
| Electric Generator | 80 kw | 181,100 | 15 |
| Backhoe loader with bucket and fork | 80 hp | 75,650 | 15 |
| Dump Truck | $10m^3$ | 49,275 | 15 |
| Total | | 537,875 | |

**Table 3.5: Labor, Operation, Maintenance, and Water Costs (2009 US$)**

| Item | Capacity | Annual cost |
|---|---|---|
| Labor | Administrator<br>Assistant Administrator<br>Two Full time Operators<br>Two Part time Operators<br>Total | \$ 3,619.20<br>\$ 3,369.60<br>\$ 8,424.00<br>\$ 4,066.44<br>\$19,479.20 |
| Operation and maintenance | 5% of capital cost | \$26,893.75 |
| Water | $353.2ft^3 \times 365$ days $\times .5 = 64{,}459ft^3$ | $64{,}459ft^3 \times \$.01/ft^3 = \$644.59$ |

**Table 3.6: Project Output**

| Output | Daily capacity | Annual capacity |
|---|---|---|
| Methane | $253m^3$ | $92,345m^2$ |
| Fertilizer | 7 tons | 2,555 tons |
| Electricity | 460 × 1.7kw/day (782 kwh) | 285,430 kwh |
| Greenhouse gas abatement ($CO_2$ equivalent) | 10.19 tons | 3,717.81 tons |

**Table 3.7: Revenue**

| Item | Daily revenue ($) | Annual revenue ($) |
|---|---|---|
| Methane | $253m^3$ × 0.717kg × $0.95/kg=$172.33 | 62,900.80 |
| Electricity | 782 kwh × $0.03/Kwh = $23.46 | 8,562.90 |
| Fertilizer | 7 tons × $25.64/ton = $179.48 | 65,510.20 |
| Carbon credits | 10.19 tons × $5/ton = $50.93 | 18,589.05 |

Exchange rate: $1= kshs 78

**Table 3.8: Depreciation Expense Deductible for Taxes**

| Year | Digester | Electric generator | Shredder | Backhoe | Dump truck | Total |
|---|---|---|---|---|---|---|
| 2010 | $24,540.83 | $21,128.33 | $816.67 | $6,304.17 | $4,106.25 | $56,896.25 |
| 2011 | $21,263.41 | $18,306.64 | $707.60 | $5,462.25 | $3,557.86 | $49,297.76 |
| 2012 | $18,428.99 | $15,866.37 | $613.28 | $4,734.13 | $3,083.60 | $42,726.36 |
| 2013 | $15,972.41 | $13,751.38 | $531.53 | $4,103.07 | $2,672.55 | $37,030.94 |
| 2014 | $13,843.29 | $11,918.32 | $460.68 | $3,556.13 | $2,316.30 | $32,094.72 |
| 2015 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2016 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2017 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2018 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2019 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2020 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2021 | $12,703.70 | $10,564.16 | $408.34 | $3,152.08 | $2,125.63 | $28,953.90 |
| 2022 | $0.00 | $3,542.31 | $136.90 | $1,056.94 | $0.00 | $4,736.15 |
| 2023 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 2024 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |

# CHAPTER IV: ANALYSIS

The project will be 100 percent donor funded since the community based initiative does not have any equity to inject into the operation. The net present value analysis of the project is calculated for a 15 year period beginning from year 2010 through year 2024 when most capital investments are depreciated to zero salvage value. In analyzing the cash flows for this project it helps to answer the principal economic objective: whether it is of economic value to invest in anaerobic digester to produce methane or electricity, fertilizer and carbon credits using organic waste collected from Kawangware market

The projections used are based on full capacity operation of the digester year round. To help understand the practical side of the operation, twelve scenarios are analyzed by comparing the net present value (NPV), internal rate of return and payback period for each of three different production conditions. The sensitivity of NPV evaluation is examined by varying inflation rates, product selling price, tax rates, production levels and combinations of methane, organic fertilizer, carbon credits and electricity. The current inflation rate in Kenya is 9% for underlying inflation and 18% for general inflation. Underlying inflation in this case refers to annual rate which excludes food items from the consumer price index (CPI) basket whereas general inflation is the overall rate at which prices of goods and services rise (Kenya National Bureau of Statistics, February 2009). Underlying inflation of 9 percent is applied to prices for organic fertilizer, electricity, methane and cost for operation and maintenance of the system. Water cost is inflated using the overall inflation rate of 18 percent.

### 4.1 Sensitivity Conditions

The three production conditions that are evaluated are:

1. Methane and organic fertilizer are produced.

2. Methane, organic fertilizer, and carbon credits are produced.

3. Electricity, organic fertilizer, and carbon credits are produced.

The following are sensitivity scenarios used in assessing viability of the project under each of the production conditions.

A. 100 percent production and sale of methane at $0.95 per metric ton, electricity at $0.03 per Kwh, organic fertilizer at 25.64 per metric ton , carbon credits at $5.00 per metric ton, when corporate tax is 30 percent and 18 and 9 percent overall and underlying inflation rates respectively. The after tax discount rate is 12.6%

B. 90 percent production and sale of end products.

C. 100 percent production and sale of end products at 10 percent price reduction equivalent to $0.86 per kilogram of methane, $23.08 per metric ton of organic fertilizer, $4.50 per metric ton of carbon credits, and $0.027 per Kwh of electricity.

D. 100 percent production and sale of end products at 20 percent price reduction equivalent to $0.76 per kilogram of methane, $20.51 per metric ton of organic fertilizer, $4.00 per metric ton of carbon credits and $0.024 per KWh of electricity.

E. 100 percent production and sale of end products if the inflation rates are 20 percent for overall and 11 percent for underlying.

F. 100 percent production and sale of end products if the inflation rates are 16 percent for overall and 7 percent for underlying.

G. 100 percent production and sale of end products with an after tax discount of 11.6 percent.

H. 100 percent production and sale of end products if both overall and underlying inflation is zero percent.

I. 100 percent production and sale of end products if the corporate tax is 35 percent.

J. 100 percent production and sale of end products if the corporate tax is 25 percent.

K. 100 percent production and sale of end products at 5 percent increase in initial total operation costs (labor, repairs and maintenance, and water).

L 100 percent production and sale of end products at 5 percent decrease in initial year total operation costs.

The scenarios are considered under each condition only if they apply in that case. Specific output combinations, sale price, inflation and tax rate variations are applied depending on the specific production conditions

**4.2 Results**

Each scenario result is calculated under the three production conditions. When a condition does not apply in a particular scenario, for example, to produce electricity, organic fertilizer and carbon credits, methane is set to zero value.

Table 4.1 shows the results when methane and organic fertilizer are produced under different scenarios. Table 4.2 shows the result when methane, organic fertilizer, and carbon credits are produced. Table 4.3 shows the results when electricity, organic fertilizer, and carbon credits are produced.

Comparison of the three Production Conditions shows that Production Condition 2 that includes production of methane, organic fertilizer, and carbon credits has the highest NPV for each of the 12 scenarios. Production Condition 1 has the second highest NPV and shows that even if carbon credits are not available the project is still feasible under the current stated production and sale prices. Scenario (H) has a negative NPV for all the three Production conditions. Production condition 3 in which the methane is used to produce electricity is not economically feasible. The low returns from producing electricity could be due to low gas yields, inefficient generator set or low energy prices. It is important to note that the option can earn better returns if for example low cost digester is installed, higher energy prices are available or gas yields are improved.

Operating the digester to produce methane, organic fertilizer and carbon credits (Production Condition 2) has the highest NPV, IRR and shortest payback periods with a significant difference in NPV compared to Production Conditions 1 and 3. The carbon credit revenue accounts for 35 percent increase in NPV over Production Condition 1 that only sells methane and organic fertilizer.

**Table 4.1: Sensitivity Analysis for Production of Methane, and Organic Fertilizer (Production Condition 1)**

| Scenario | NPV ($) | Annualized NPV($) | IRR (%) | Payback(Years) |
|---|---|---|---|---|
| A | $246,752 | $37,397 | 19% | 9.2 |
| B | $141,757 | $21,484 | 16.5% | 11.0 |
| C | $141,757 | $21,484 | 16.5% | 11.0 |
| D | $36,763 | $5,572 | 13.7% | 13.7 |
| E | $373,527 | $56,610 | 21.6% | 8.3 |
| F | $139,319 | $21,115 | 16.7% | 10.6 |
| G | $299,401 | $43,024 | 19.1% | 8.8 |
| H | ($121,498) | ($18,414) | 7.7% | NA |
| I | $207,366 | $31,428 | 18.2% | 9.7 |
| J | $286,138 | $43,366 | 20.0% | 8.8 |
| K | $245,271 | $37,172 | 19.1% | 9.2 |
| L | $248,234 | $37,621 | 19.2% | 9.2 |

Note: The IRR% result is less than the after tax discount rate of 12.6% when the NPV value is negative (Scenario H).

**Table 4.2: Sensitivity Analysis for Production of Methane, Organic Fertilizer, and Carbon Credits. (Production Condition 2)**

| Scenario | NPV ($) | Annualized NPV($) | IRR (%) | Payback(Years) |
|---|---|---|---|---|
| A | $332,610 | $50,409 | 21.4% | 7.9 |
| B | $219,030 | $33,195 | 18.6% | 9.4 |
| C | $219,030 | $33,195 | 18.6% | 9.4 |
| D | $105,449 | $15,981 | 15.6% | 11.6 |
| E | $459,385 | $69,623 | 23.7% | 7.3 |
| F | $225,177 | $34,127 | 19.1% | 8.8 |
| G | $389,953 | $56,037 | 21.4% | 7.6 |
| H | ($35,640) | ($5,401) | 11.2% | NA |
| I | $287,092 | $43,512 | 20.4% | 8.4 |
| J | $378,129 | $57,308 | 22.4% | 7.5 |
| K | $331,129 | $50,185 | 21.3% | 8.0 |
| L | $334,092 | $50,634 | 21.4% | 7.9 |

Note: The IRR% result is less than the after tax discount rate of 12.6% when the NPV value is negative (Scenario H).

**Table 4.3: Sensitivity Analysis for Production of Electricity, Organic Fertilizer and Carbon Credits. (Production Condition 3)**

| Scenario | NPV ($) | Annualized NPV($) | IRR (%) | Payback(Years) |
|---|---|---|---|---|
| A | ($113,075) | ($17,137) | 8.9% | NA |
| B | ($185,973) | ($28,185) | 6.2% | NA |
| C | ($185,973) | ($28,185) | 6.2% | NA |
| D | ($261,625) | ($39,651) | 3.0% | NA |
| E | ($51,413) | ($7,792) | 11.1% | NA |
| F | ($165,256) | ($25,046) | 6.7% | NA |
| G | ($86,395) | ($12,415) | 8.9% | NA |
| H | ($291,030) | ($44,107) | -0.9% | NA |
| I | ($127,091) | ($19,261) | 8.4% | NA |
| J | ($99,059) | ($15,013) | 9.4% | NA |
| K | ($115,191) | ($17,458) | 8.8% | NA |
| L | ($110,959) | ($16,816) | 9.0% | NA |

Note: The IRR% results are less than the after tax discount rate of 12.6% because the NPV values are negative (Scenarios A through L).

# CHAPTER V: SUMMARY AND CONCLUSIONS

The thesis analyzed production of methane, electricity, organic fertilizer and greenhouse gas credits from organic food market waste. Net cash flows were determined and used to calculate NPV, IRR and payback period for the biodigester project under three production conditions. Twelve scenarios under each of the three production conditions were analyzed.

The NPV analysis indicates that production of methane and organic fertilizer with and without carbon credits is economically feasible using the current output prices. The use of methane from the biodigester to produce electricity is not economically feasible at current costs and electricity prices. However, while there currently are negative NPV in production Condition 3, if electricity prices increased above $0.077 per Kwh, the project can break even. Alternatively, electricity production from biogas would have to increase from 782 Kwh per day to over 2029 Kwh per day for the project to break even under Condition 3 if the electricity price is held at $0.03 per Kwh. The NPV is negative under all three production conditions if there is zero inflation in the value of methane and organic fertilizer for the sale (Scenario H).

Besides the positive NPV of this project, other socio-economic benefits include reduction of air pollution and stench from open decomposition of organic waste, job creation for project operators, relief of the burden for the city council for the cost of operating and maintaining garbage collection vehicles which are not effectively completing the task. Other benefits of the project that could not be estimated in dollar values for inclusion in the net present value analysis but would have a positive affect on it include reduced public and environmental health concerns. Implementation of the project will immediately reduce environment pollution (air, water courses and land), and also reduce niches for disease vectors such as mosquitoes, rodents, houseflies and cockroaches.

Implementation of this project within Kawangware market area of Kenya will not only provide the above mentioned benefits but also will help improve living standards of the community through use of the valuable products it creates. Given the very poor conditions of roads and poor infrastructure network in Nairobi city and Kenya in general, distribution of products from a much larger project may not be feasible due to substantially increased costs of transportation and distribution to distant markets. The project will not only help overcome transportation and disposal costs of the organic waste at distant sites but also will make good use of the readily available local resource.

### 5.1 Further Considerations

The figures for methane, electricity, fertilizer, carbon credits, and costs used in this study are estimates. Therefore, if this project is constructed, it will be useful to examine the operating performance by measuring the quantity and quality of output. Use of an independent laboratory, such as Kenya Agricultural Research Institute (KARI), can be used to analyze dry matter content of feedstock and fertilizer quality.

Proper training in data recording and monitoring will be necessary to ensure full compliance with emission reduction requirements under the Kyoto treaty as well as non - emission related data needed for performance analysis. Necessary data needed for performance analysis include the following items:

1. Total gas volume out of the bio-digester.

2. Biogas breakdown to provide percentage of methane, carbon dioxide and trace gases.

3. Total volume of fertilizer from the bio-digester.

4. Sales price and amount sold of each output.

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# APPENDIX A

**Table A.1 Depreciation expenses**

| Year | Digester | Electric generator | Shredder | Backhoe | Dump truck | Total |
|---|---|---|---|---|---|---|
| 2010 | $24,540.83 | $21,128.33 | $816.67 | $6,304.17 | $4,106.25 | $56,896.25 |
| 2011 | $21,263.41 | $18,306.64 | $707.60 | $5,462.25 | $3,557.86 | $49,297.76 |
| 2012 | $18,428.99 | $15,866.37 | $613.28 | $4,734.13 | $3,083.60 | $42,726.36 |
| 2013 | $15,972.41 | $13,751.38 | $531.53 | $4,103.07 | $2,672.55 | $37,030.94 |
| 2014 | $13,843.29 | $11,918.32 | $460.68 | $3,556.13 | $2,316.30 | $32,094.72 |
| 2015 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2016 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2017 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2018 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2019 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2020 | $12,883.94 | $10,564.16 | $408.34 | $3,152.08 | $2,155.78 | $29,164.30 |
| 2021 | $12,703.70 | $10,564.16 | $408.34 | $3,152.08 | $2,125.63 | $28,953.90 |
| 2022 | $0.00 | $3,542.31 | $136.90 | $1,056.94 | $0.00 | $4,736.15 |
| 2023 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| 2024 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |

**Table A.2 Investment Costs**

| Initial investment requirements | |
|---|---|
| Land | $14,500 |
| Digestor | $210,350.00 |
| Electric generator | $181,100.00 |
| Shredder | $7,000.00 |
| Backhoe | $75,650.00 |
| Dump truck | $49,275.00 |
| **Total initial investment cost ($)** | **$537,875.00** |

## Table A.3 Recurring Expenses

| | |
|---|---|
| **Labor** | |
| Project administration and accounting cost/month ($) | $301.60 |
| Marketing, project administration and operation cost/month ($) | $280.80 |
| Project operators cost/month ($) | $702.00 |
| Part time workers cost/month ($) | $338.87 |
| Monthly labor cost($) | $1,623.27 |
| Months of labor | 12 |
| Initial annual labor cost | $19,479.20 |
| Annual wage inflation rate | 5% |
| | |
| **Operation and Maintenance** | |
| O&M % of total investment cost | 5% |
| Initial Operation and Maintenance cost | $26,893.75 |
| Operation and Maintenance cost annual inflation | 9.00% |
| | |
| **Water** | |
| Daily use of water (ft3) | 353.20 |
| Days of production per year | 365 |
| Water use per year (ft3 ) | 128,918.00 |
| 50% purchased water per year ((ft3) | 64,459.00 |
| Initial water cost/ ft3 ($) | $0.010 |
| Initial annual water cost | 1289.18 |
| Annual water inflation rate | 18.0% |

## Table A.4 Electricity production

| **Electricity production** | |
|---|---|
| Initial Kwh price ($) | $0.030 |
| Daily volume of biogas m3 | 460 |
| Kwh/biogas m3 | 1.7 |
| Electricity production per day (Kwh) | 782.00 |
| Electricity sales/day ($) | $23.46 |
| Days of production/year | 365.00 |
| Gross annual income from electricity generation | $8,562.90 |

## Table A.5 Methane Production

| **CH4 production** | |
|---|---|
| CH4 price ($/Kg) | $0.950 |
| Daily volume of biogas m3 | 460 |
| % CH4 in biogas | 55% |
| Daily volume of CH4 produced(m3) | 253.00 |
| Mass of CH4 (kg/m3) | 0.717 |
| Days of production/year | 365.00 |
| Volume of CH4 per year (kgs) | 66211.37 |
| Gas (CH4) sales per year | $62,900.80 |

### Table A.6 Fertilizer production

| Fertilizer production | |
|---|---|
| Fertilizer price/metric ton ($) | $25.64 |
| Daily volume of fertilizer (metric ton) | 7.00 |
| Fertilizer sales/day ($) | $179.48 |
| Days of production/year | 365.00 |
| Fertilizer production per year | 2555.00 |
| Fertilizer sale per year($) | $65,510.20 |

### Table A.7 Greenhouse gas emissions

| **Greenhouse gas impacts of status quo** | |
|---|---|
| Daily volume of biogas produced(m3 ) | 460.00 |
| % CH4 in biogas | 55% |
| Volume of CH4/day (m3) | 253.00 |
| % CO2 in biogas | 45% |
| Volume of CO2/day (m3) | 207.00 |
| CO2 equivalent of CH4 (23 times) | 23.00 |
| Days of production/year | 365.00 |
| CO2 equivalent of CH4 per year (m3) | 2123935.00 |
| Volume of CO2/year (m3) | 75555.00 |
| Total volume of CO2/year (m3) | 2199490.00 |
| Mass of CO2 at 25 deg celcius(kg/m3) | 1.83 |
| Mass of CO2 per year (kgs) | 4025066.70 |
| Mass of CO2 per year (metric tons) | 4025.07 |
| | |
| **Greenhouse gas impacts with project** | |
| Daily volume of biogas produced(m3 ) | 460.00 |
| % CH4 in biogas | 55% |
| Volume of CH4/day (m3) | 253.00 |
| % CO2 in biogas | 45% |
| Volume of CO2/day (m3) | 207.00 |
| Days of production/year | 365.00 |
| Total volume of CO2/year (m3) | 167900.00 |
| Mass of CO2 at 25 deg celcius(kg/m3) | 1.83 |
| Mass of CO2 per year (kgs) | 307257.00 |
| Mass of CO2 per year (metric tons) | 307.26 |
| | |
| Greenhouse gas abated per year (metric tons) | 3717.81 |
| Carbon credit sale price ($/metric tons) | 5.00 |
| Carbon credit sales per year | $18,589.05 |