Journal of Energy Technologies and Policy www.iiste.org
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.4, No.12, 2014

Acceptance, Operational Challenges and Conceptual Optimization of Biodigester System in Embu Prison

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Abstract
This research was conducted within the Kenyan context in Embu prison on a pioneering and fully operational, since 2011, biodigester system. After three years of operation it was imperative to assess the functionality of the system and also the acceptance level by the users and beneficiaries. This research was significant as it synthesizes the true-life experiences from Biodigester utilizing rare input-human excreta. The study was a cross-sectional descriptive research which sought to examine the operational practices and challenges of the biodigester, alongside with factors influencing the adoption of biogas technology. To achieve this, the study conducted regular field visits to Embu prison, administered interviews and distributed questionnaires (designed in English and in Kiswahili language). The data was organized, edited, coded and analyzed using the Microsoft Excel and Statistical Package for Social Sciences (SPSS). Response rate of detainees was 76%, while for staff it was 43%. To address the issue of gas accumulation at night hours and fully utilize the potentials of human excreta, the study proposed to incorporate microbial fuel cells (for electricity production). Conceptualization and preliminary design of optimized system was conducted according to fundamental engineering design principles. To select the best alternative design a pair-wise comparison known as the *drop and re-vote* (D&R) method was used in this study. The study confirmed that biodigester in Embu prison is an appropriate solution to produce clean renewable energy. Therefore it is recommended to pursue and replicate this approach in prisons in other areas and in different public institutions of Kenya. The study also identified several directions for further research; the most important one is to conduct detailed structural design of the proposed configuration including economical evaluation of the system. The results and discussions may be also applicable to other countries or regions with similar conditions.
Keywords: biogas, biodigester, human excreta, Kenya.

1. Introduction

Energy is a major component in all forms of human activity. Today's world is dependent on fossil fuel for up to 80% for its total primary energy demand. From 1990 to 2010, global energy demand as well as the utilization of fossil fuels increased by 45% (IEA, 2012a). Combustion of fossil fuels also represents more than 50% of global anthropogenic emissions of greenhouse gases affecting the climate and contributing to global warming (IEA, 2012b). The shift of the global energy industry to renewable energy sources is one of the major challenges of this Century.

The use of renewable energy from solar, biogas and wind is very low in Kenya with 3%, 0.2% and 0.1% respectively (KIPPRA, 2010). Continued over-dependence on unsustainable wood fuel and other forms of biomass as the primary sources of energy has contributed to uncontrolled harvesting of trees and shrubs leading to deforestation. Kenya's forest cover is only around 1.9 %, which is a great deal lesser than recommended by UN minimum of 10% (NEMA, 2005). In addition, continued consumption of traditional biomass fuels contributes to poor health among users due to excessive products of incomplete combustion and smoke emissions in poorly ventilated houses.

Many public institutions (prisons, boarding schools and colleges among others) in Kenya are facing challenges with regard to the provision of safe and adequate sanitation services. Only 18% of the total population is covered by the sewer system (Onyango, 2009). Due to the high cost of energy relatively cheap wood fuel is used in large quantity for cooking in the kitchens. This is causing stress on the already decaying forest cover of Kenya. It has been reported by UNEP in an article which appeared in the Standard Newspaper of 2nd March, 2009 that Kenya as a country is tottering towards environmental disaster due to the destruction of forests (Onyango, 2013).

Kenya prison service has 108 prison institutions of which 18 are women's prisons, 87 are for male offenders, while the remaining 3 are for juvenile male offenders-two Borstal Institutions and one Youth Corrective Training Centre (YCTC). The current inmate population is about 55,800 against established design capacity of 18,600. There are in total 18,400 members of staff out of which 4,812 are female officers. It costs about 15 million shillings ($180,000) daily to sustain the prison population (Onyango-Israel, 2013). Severely overcrowded confinement and existing old and poorly maintained infrastructures lead to very poor water, sanitation and environmental conditions harshly affecting the detainees. Above all, safe and hygienic way of disposal of human waste is an increasing problem particularly in over populated prisons.

Biogas is an energy technology that has the potential to counteract many adverse health and environmental impacts connected with traditional biomass energy and with poor sanitation in Kenya. The worldwide interest in Anaerobic Digestion (AD) in biogas plants in recent time is due to current issues such as global warming, demand for renewable energy, landfill tax on wastes, high fossil fuel and inorganic fertilizer prices, legislation relating to the treatment and disposal of organic wastes (Lukehurst et. al*.,* 2010), on-site sanitation systems associated with faecal sludge management (FSM) especially in relation to difficulties with emptying, transportation and disposal (Boot, 2008).

This study was focused on Biogas digester system based on Anaerobic Digestion from human excreta, with the emphasis on prison environment.

2. Materials and methods

2.1. Study area

The research was conducted within the Kenyan context in Embu prison. Kenya is an East African country with a population of 41.8 million people. Embu prison is situated in Embu County (former Eastern Province), Manyatta Constituency of Kenya. Embu County had a population of 516,212 in 2009 census with an area of 2,555.9 km^2 (Web article 1). Figure 1shows the position of Kenya in the African continent and the map of Kenya and the position of Embu County (*marked in green)*

Embu prison situated at the outskirts of Embu town and has an elevation of 1,350 meters (4,429 ft) at longitude 37.45 and -0.538 latitude, located on the foothills of Mount Kenya. For a long time, it was the main economic centre for the Embu and Mbeere communities, as well as other communities from central Kenya.

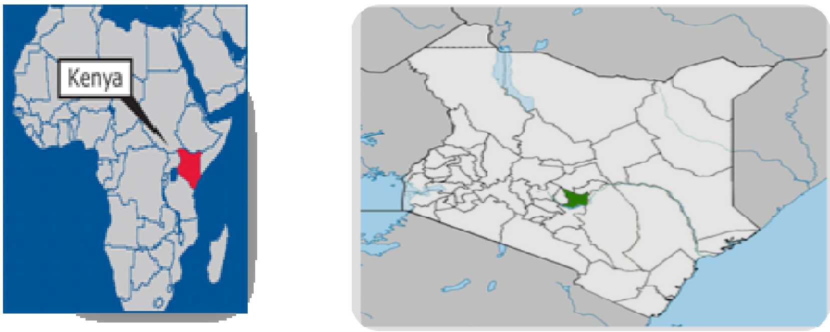


Figure 1. Kenya in African continent (left) and map of Kenya showing Embu County (Web article 1)

This study was a cross-sectional descriptive research which sought to examine the operational practices and challenges of biodigester installed in Embu prison, alongside with factors influencing the adoption of biogas technology. The study was performed under short Hydraulic Retention Time (HRT) and under mesophilic temperature. In order to develop an understanding of biogas digester operational practices, performance and challenges encountered the study conducted regular field visits to Embu prison. To generate various information regarding acceptance of the project which utilizes the rarely used resource, the human waste, the benefits of the project and the challenges which the project is facing detainees and operational staff of the prison were requested to fill questioner (designed both in English and in Kiswahili languages). The targeted population of the prison was 1000 detainees and 300 staff. A 10% sample of 100 detainees and 30 staff members was selected through systematic random sampling. However, 76 of detainers responded giving a response rate of 76%, while for staff only 13 responded giving a response rate of 43%. The data was organized, edited, coded and analyzed using the Microsoft Excel and Statistical Package for Social Sciences (SPSS).

Critical evaluation of Biogas digester system was conducted, including analyses of potential improvements of performance of the biodigester. The conceptualization and preliminary design of optimized system, incorporated microbial fuel cells (for electricity production) was performed according to fundamental engineering design principles. To select the best alternative design, a pair-wise comparison known as the *drop and re-vote* (D&R) method was used in this study. In D&R, the members of the design team each order alternative concepts in a *weak order*, an ordinal ranking with no level of preference. The weak orders are then compared to some common filtering criterion (such as “choose the best of the best” or “avoid the worst of the worst”) (Filippo, 2012) and the most poorly ranked concept are dropped from further consideration. The process is then repeated until only one alternative remains.

3. Results

3.1. Biodigester specifics and Observation of operational practices

Biogas digester of Fixed Dome type (124m^3) was constructed at Embu prison in September, 2010 by the trained prisoners. It started its operation after six months and afterwards it was opened officially on 11th March, 2011. The construction was funded by the Kenyan government at a cost of four million Kenya shillings. The main aims of the biodigester were to improve the poor sanitary conditions and waste water treatment of the prison, reduce the health risks of the detainees, provide a smoke-free source of cooking fuel, provide a renewable energy source to the jail to reduce the use of traditional fuels (wood and kerosene) which in turn improve the kitchen environment (reduction of indoor air pollution) and finally to produce a biogas slurry which is to be used as fertilizer in the prison's vegetable garden. Farm activities such as cultivation, fertilizer/manure application, planting and harvesting are done by around 40 inmates. Five inmates have been assigned to carry out daily operations of the digester under supervision. The biodigester details are shown in Figure 2. The biogas plant has been fully operational since the start and produces biogas from human excreta mixed in the ration 3:1 with the cow dung (from the prison's zero grazing livestock). The biodigester is of continuous type, where the feed material must be flow able, continuous and uniform. Approximately one liter of water is used by an inmate daily to flush toilets.

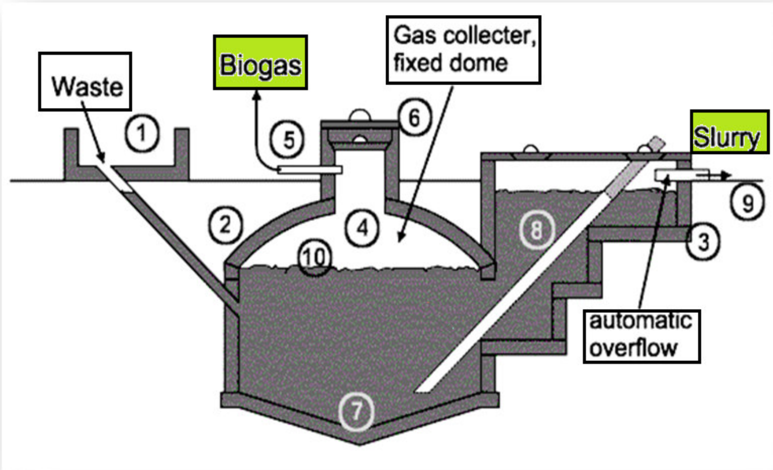


Figure 2. Fixed dome type biodigester.

Key:

1. Mixing tank with inlet pipe and sand trap
2. Digester
3. Compensation and removal tank
4. Gasholder
5. Gas pipe
6. Entry hatch, with gastight seal
7. Accumulation of thick sludge
8. Outlet pipe
9. Reference level
10. Supernatant scum, broken up by varying level

The biodigester operates under short HRT/fermentation time of about 30-40 days and under mesophilic temperature (below 35^{0}C). Current and proposed operations involved in biogas and slurry production are shown in Figure 3.

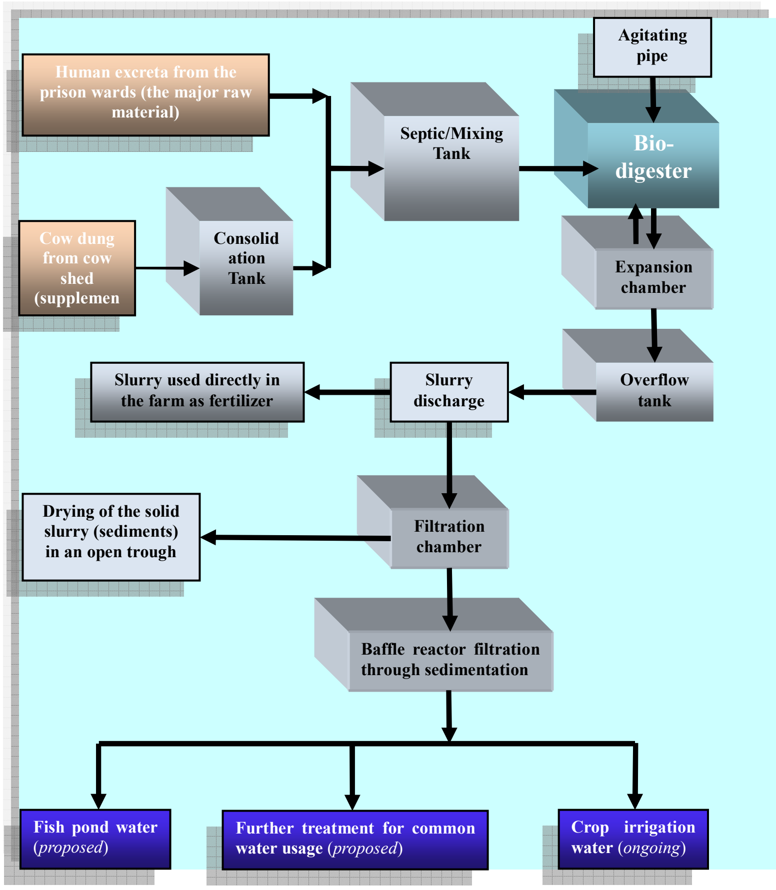


Figure 3. Flow-chart of biodigester processes at Embu prison

Bio-gas at the time of the study fuelled three boilers in the prison kitchen, and firewood costs have been cut down by about a third hence saving around KSh. 500,000 annually.

The slurry from the digester is applied in the prison's farm either in liquid or solid (dried slurry) forms; it helps to improve soil condition hence increasing crop production. Crops grown in the farm include: local vegetables, French beans, nappier grass, eggplant, mango and avocado trees among others. The manure is applied to the crops once in six months. Products from the farm are bought by exporting company Makindu Limited. The highest recorded annual earnings from the farm products are about KSh. 250,000(around US$ 2,900).

During several visits to the project site it was revealed that at evening hours (when biogas is not utilized for cooking) the biogas accumulates and as a result pressure builds up inside the digester which then displaces a lot of waste which are not fully digested. In addition, the built up pressure is a potential explosion hazard. During one of our visits the biodigester had been maintained in the morning after it had clogged and waste was being forced to move backwards and out through checkpoints.

3.2. Evaluation of responses to the questionnaires

The questionnaires were targeted at detainees and operational staff of the prison. There was a discrepancy between the number of questionnaires planned to be administered and the number evaluated. Critical analysis suggests that the contributing factors to this discrepancy could be the following: time constrains, restriction of researches' movement within prison for security reasons, unwillingness of some prisoners to spend time on this exercise, some detainees wanted to use the paper given to them for other purposes, and some although took the questionnair, returned it empty and, as we later were shed light on, probably were not proficient in any of the languages the questionnaires were offered in. In addition, 4 questionnaires were incomplete and therefore excluded from evaluation exercise. In total, duly filled questionnaires of 76 detainees and 13 operational staff of the prison were evaluated. These figures correspond to a response rate of 76% and of 43% respectively.

3.2.1. Evaluation of the responses from the detainees

All of the respondents were male, between 19-64 years old. 93.4% of the inmates had knowledge of the use of human excreta as a source of energy and only 6.6% had no idea of this. 37% of detainees expressed their initial skepticism towards a system which transforms human faeces into cooking fuel. These detainees admitted having feared transmission of diseases through biogas and a worse taste of the food. However, after no such negative changes were observed or reported, they cautiously tried out biogas-cooked food themselves. It can be thus concluded that experiencing no negative effects after consuming "biogas-food" led to a change of perception and eventual acceptance of a beneficial system. The highest population of detainees uses firewood and charcoal in their homes i.e. 76.3% and 13.2% respectively and this confirms the previously referenced high prevalence rate of biomass use in Kenya. Only a smaller percentage uses other sources of energy but still in combination with firewood or charcoal, 10.4% while none of them use electricity in their homes. 94.7% of the population was positive that human excreta can help to conserve our forests when used as a source of energy. 2.6% were negative about it whereas the remaining 2.7% did not have any idea. 69.7% confirmed that they have used the human waste to benefit them in areas such as: production of biogas for cooking, fertilizer, additive to compost manure, producing electricity and ripening bananas among others. On the other hand, 26.4% had never been involved with the use of human excreta and gave some of the explanations as: lack of knowledge about its use, lack of resources to handle the waste and smaller amounts of the excreta which cannot be beneficial. 3.9% had no idea of this fact. 85.5% have the knowledge of the health hazard caused by improperly disposed human excreta and mentioned the following: pollution of the environment e.g. bad smell, unsightly surrounding, may cause diseases such as cholera, typhoid amoebic dysentery and diarrhea, and contamination of water resources especially during rainy seasons. 9.2% and 5.2% did not know any health hazard caused by human excreta and did not have any idea respectively. 78.9% of the population embraces the use of human excreta in production of biogas for use in the kitchen for cooking while 10.5% did not agree to this and the remaining 10.5% did not have any idea of the same. 80.3% of the population would like to install biogas systems in their homes when they get out of prison and they plan to use the following as their raw materials: cow dung, cow dung and human waste and other organic wastes. 6.6% would not be able to get involved but some of whom can participate when taught on how to use the biogas system. 13.2% did not have any idea of what they may or may not do. Only 30.3% had learnt about the biogas facility in Embu prison's facility or elsewhere, 50.0% had not learnt about the system in the prison, 17.1% had no idea while 8.7% gave out irrelevant answers to the question.

Some of the changes which have been experienced in the Embu prison's kitchen since the start of the biogas plant and the experienced advantages from the biogas were stated as: food is cooked faster, less use of firewood hence minimized air pollution by reduction in the smoke produced, economizes on the use of firewood, saves/conserves forests by limiting the use of firewood, cheaper fuel, easy to handle the gas, among others.

3.2.1. Evaluation of the responses from the operational staff

84.6% of the staff correspondents were men (32-56 years old) while the remaining 15.4% were women (29-43 years old). The composition of respondents were as follows: prison Constables (53.8%), Corporals (15.4%) while each of the following: Senior Sergeant, Deputy Officer-in-charge, Officer and General Duties Officer represented 7.7% of the total number of the staff respondents. 84.6% of the staff embraced the use of human excreta as a source of energy while the remaining 15.4% didn't have any idea, that they have a biodigester and moreover that the biodigester uses human excreta. Only 46.2% agreed that the project has benefitted them and gave the following reasons: it has reduced the cutting of trees, no use of firewood and this conserves the environment, saves government some funds among others. The gas produced from the system is generally used for cooking in prison kitchen. A third of the spending on firewood is being saved and this is not used directly in prison since it's a government project therefore the money goes to the government treasury. 38.5% claimed to have participated in the maintenance of the facility especially as administration, 46.2% have never participated in any maintenance work while the remaining 15.4% didn't have any idea. 92.3% of the members of the staff confirmed that there has been an improvement in the sanitation in the prison since the start of the biogas project and only 7.7% disagreed to that fact. Possible major challenges that the project might/have encountered are as listed as: maintenance cost, lack of enough exhaust pipes, small quantity of biogas, blockage of main pipe to the digester, air pollution in case of biogas leakage, lack of enough raw material, maintenance practices and breakdown. 69.2% of the members of staff were willing to improve the system, 23.1% were not willing to improve the system and the rest 7.7% had no idea of the kind. The following are some of the areas proposed for improvement: to expand for generation of more biogas, to use storage balloon for accumulated gas, and use of alternative supplementary raw materials for biodigester. 84.6% were agreeing to the generation of electricity by the use of Microbial Fuel Cell (MFC) and the other 15.4% did not have any idea. The following are some of the changes experienced in the kitchen since the start of the biogas system in Embu prison: less firewood is used, cooks faster, cleanliness, no smoke, reduced expenditure on firewood, and cooking is done on large scale among others.

3.3. Conceptual optimization of the system

Scientists have long known about the connection among chemistry, biology, and electricity. In the late 1700s, Luigi Galvani, an Italian anatomist, noted that a detached frog's leg twitched due to the electrical charges in the atmosphere. His findings helped create the field of electrochemistry. In 1911, scientists in England published one of the first papers on electricity generation by bacteria. Today *Microbial Fuel Cells* (MFCs) are receiving more attention because they are a potential part of the solution to our energy demands and could provide a clean and renewable source of energy.

3.3.1. Microbial Fuel cells

To overcome the problem of accumulated gas, and to reduce the potential danger of explosion, the study suggested generating electricity from the accumulated gas. The generation is based on the noble principle of Microbial Fuel cells, which converts chemical energy, available in a bio-convertible substrate, directly into electricity. To achieve this, bacteria are used as a catalyst to convert substrate into electrons. Bacteria are very small (size approximately 1 µm) organisms which can convert a huge variety of organic compounds into CO_2, water and energy. The micro-organisms use the produced energy to grow and to maintain their metabolism. However, by using a MFC we can harvest a part of this microbial energy in the form of electricity. A MFC consists of an anode, a cathode, a proton or cation exchange membrane and an electrical circuit (Web article 2). Figure 4 shows the schematic diagram of MFC.

Several factors affect electrical energy generation by MBFC system are as follows: its electrical parameters, mass transfer, Ohmic losses, activation losses and electron quenching reactions and energy efficiency. (Semionov, 2013; Web article 3)

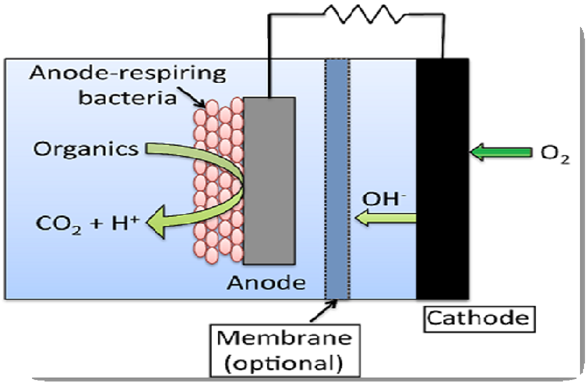
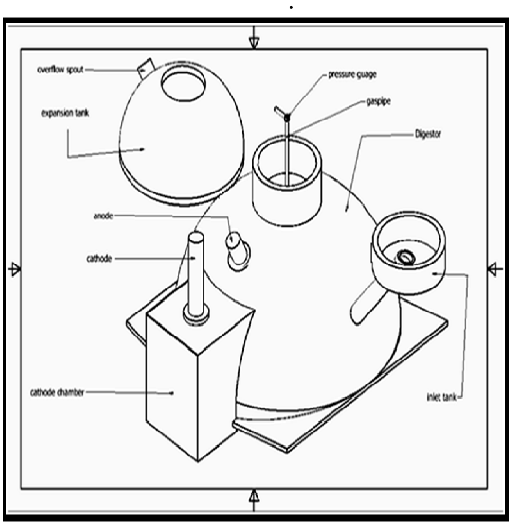


Figure 4. Schematic diagram of MFC

3.3.2. Preliminary design

Pair-wise comparison of 4 design alternatives was conducted and the best design alternative was chosen, which is shown in Figure .5, while Figure 6 shows 3D view of the same (made via Autodesk 2014 software). In addition video simulation of the operation of the proposed system was prepared.



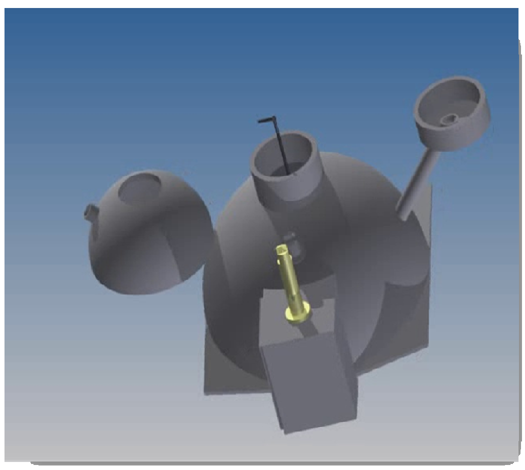


Figure 5. Labeled diagram of the proposed system Figure 6. 3D view of the proposed system

The current digester system is proposed to be modified by having an additional chamber known as cathodic chamber. The following are the design criteria involved in coming up with the conceptual design:

1. Construction of the cathodic chamber; the chamber should not be airtight and electrode which receives the electrons is placed inside the chamber (electrons receptor or cathode).
2. Construction of salt bridge; this helps in the transfer of protons from where they are produced in the digester to where they are reduced in the cathode chamber. Constructing the cathode chamber in a way

that it will share the wall with the digester and then allowing an opening which is then sealed with a salt bridge membrane (as considered in the design drawing)

3. Electrodes; these are two types of electrodes i.e. cathode and anode electrodes. Cathode electrodes are placed in the cathodic chamber where they receive the electrodes while the anode electrodes are made in the form of electrochemical cells and are placed in the digester suspended in the digestrate.

4. Discussions

To address the energy crisis, the government of Kenya enacted the Energy Act No. 12 in December, 2006 which offers regulatory stewardship to electricity, petroleum and new and renewable sub-sectors. As indicated in Part V of the Energy Act section 103, the act provides for promotion of the development and use of renewable energy technologies which include biomass, biodiesel, bio-ethanol, charcoal, biogas and municipal waste. On the other hand, the National Biomass Energy Policy objective is to promote development of appropriate local capacity for manufacture, installation, maintenance and operation of basic renewable technologies such as biodigesters (The Energy Act, 2006). Energy provision and environmental stewardship are key elements of Kenya's Vision 2030 blueprint for development (World Bank, 2014). In 2008, Kenya became the first country in sub-Saharan Africa to introduce the "Feed-in Tariff Policy" (FiT), which guarantees investors fixed rates for power from eligible renewable energy projects. Despite the availability of renewable energy sources and encouraging policies, potential project developers in Kenya face many challenges, including complex regulatory requirements. The recent "Inventory of Regulatory Requirements to Start and Operate a Renewable Energy Project in Kenya" conducted by the Energy Regulatory Commission (ERC) and supported by International Finance Cooperation (IFC), revealed up to fifteen separate clearances from nine different government agencies required to develop a renewable energy project. Information about each of the clearances was dispersed and often difficult to find (FUAS, 2012).

The study recommends that the process of clearance to start and operate renewable energy project in Kenya need be *streamlined* (the procedure should be clearly articulated and should be made available on line), also the process should be *centralized* (instead of nine different government agencies it should be just one) and finally the process should be *simplified* (fifteen separate clearances should be re-designed and compressed into single comprehensive all-inclusive clearance certification).

Initial capital investment for medium and large scale biodigesters has been reported as one of the major reasons behind rather slow spreading and promotion of biogas technology. In this regard, the study recommends the Government to subsidize or sponsor the initial capital investment, especially for a large scale projects, such as biogas digesters for institutions. Kenya National Domestic Biogas Program (KENDBIP)-a component of African Biogas Partnership Program (ABPP) funded by the Dutch Ministry of Foreign Affairs, Netherlands and managed jointly by Hivos and SNV could be a capable stakeholder to achieve this. Another approach is to look for the new techno developments in the area of biodigesters. One of such developments is innovative type of biogas system, manufactured in Kenya, is Flexi Biogas, a flexible above-ground system that is much simpler and less costly to build and operate. This system does not require agitation and the digester is not a sealed tank but simply a 6m x 3m plastic bag made of PVC tarpaulin. The smallest system now costs US$410 (KSh 35,000), including installation (FBS, 2013).

From the field observations it was realized that only breakdown maintenance on the boidigester was carried out. The study therefore recommends shifting to preventive maintenance approach, which can be scheduled and condition-based maintenance. It can be performed after a predetermined number of operating hours or as a result of a planned inspection revealing need for maintenance.

As shown in Fig.3 the biogas plant is not only a supplier of energy. The digested substrate, digestrate, is a source of high quality fertilizer. Human excreta is a rich source of nitrogen and other nutrients necessary for plant growth. All the plant nutrients in the raw materials digested are preserved in the digesrtrate. In many ways it is better than artificial fertilizers, as it encourages the formation of humus (decomposed vegetable matter) which is essential for optimum soil structure and water retention; it contains trace elements (chemical fertilizers do not) which help protect the plant from parasites and disease; it promotes the development of small organisms (microbes) which convert the minerals to forms that the plants can use; and it improves the soil structure, making it easier to cultivate and to resist the effects of erosion (Mshandete, 2009). It is a valuable soil fertilizer, rich in nitrogen, phosphorus, potassium and micronutrients. Compared to raw animal manure, digestrate has improved fertilizer efficiency due to higher homogeneity and nutrient availability and better Carbon-Nitrogen (C/N) ratio. One main advantage of biogas production is the ability to use "wet biomass" types as feedstock, all characterized by moisture content higher than 60–70% (e.g. sewage sludge, animal slurries, flotation sludge from food processing etc.). Slurry provides positive effects on soil fertility and food productivity can also improve the nutritional status (Ahring, 2003) of detainees. Additional benefits of slurry include that fact that it is almost odorless and the remaining ammonia odors disappear shortly after application as fertilizer. It does not attract flies or insects as does manure, and it reduces weed growth by 50 percent, compared to manure, because seeds are destroyed in the digester (ISE, 2010). AD can therefore allow for recirculation of plant nutrients in waste products, and potentially reduce or eliminate completely the demand for chemical fertilizers. It can also diversify and enrich the diet of prisoners, as variety of vegetables lucratively grows on well conditioned soil. However at Embu prison, all produce is exported as organic fruits and vegetables, without even giving some of the exotic vegetables to detainees to test. The study recommends to the administration of Embu prison to request the appropriate government agencies to reconsider their current practices and allocate at least small proportion of harvested organic fruits and vegetables to enrich the modest diet of detainees and to enable the detainees literately to test the fruits of their labor.

At the prison biodegradable kitchen waste is disposed of inappropriately-it is just thrown away. According to Red Cross, Nepal, 2009 adding organic kitchen waste to human excreta increases biogas production from 27L(on pure excreta) to 62L biogas per person per day, with a methane content ranging from 57% to 78%. The study therefore recommends adding kitchen waste to the biodigester input, as on one hand the biogas production will increase significantly and on the other hand it would solve the problem of kitchen waste inappropriate disposal.

Biogas plant at Embu prison operates at short Hydraulic Retention Time (HRT) and under mesophilic temperature. They have been utilising digestrate as a soil conditioner on their vegetable garden. Many studies reveal that under fully mixed mesophilic conditions, excreta pathogens are not completely inactivated (Strauss, 2000; Razak, 2010). The transmission of disease through the use of untreated or partially treated excreta can be widespread. Parasitic eggs and cysts may remain viable in soil, water and on plants for many months, creating a hazard for operators (Razak, 2010). In order to prevent the spread of disease the study recommends conducting a periodic assessment of the level of pathogens in the effluent. According to the WHO (1989) guidelines for coliform bacteria, limit of ≤1000FC/100ml is recommended for unrestricted application (that is crops likely to be eaten uncooked, sports fields, public parks, flood irrigation or when children are exposed) but for restricted application (that is irrigation of cereal crops, industrial crops, fodder crops pasture and trees), ≤ 105/100ml is recommended when adult farm workers are exposed to spray irrigation. For unrestricted application, no detectable faecal coliform bacteria are allowed in ≤100 ml and for commercially processed and fodder crops, the guideline limit is ≤200 faecal coliform bacteria/100 ml (Blumenthal *et al.,* 2000). Also, for biogas effluent to be sanitised, *salmonella* and *clostridium* should be absent in 50g and 1.0g digestrate respectively (Biological Treatment of Waste, 2001). Also, helminth eggs should be ≤ 1.0/litre (WHO, 1989; WHO, 2006).

78.9% of detainees and 92.3% of the members of the prison staff favor the biodigester and report a general improvement of living conditions. Given the use of biogas for cooking, the vast majority of the interviewed inmates and staff appreciated less smoke in the kitchen (and hence lower upper respiratory tract infections and eye ailments that are normally associated with the smoke). The other benefits mentioned the improved sanitary and hygienic conditions and that the consumption of wood fuel reduced to up to 1/3, giving saving of about KSh. 500,000 annually. More than 60% of prisoners and 15.4% of the prison staff didn't have any idea, that they have a biodigester in the prison and moreover that the biodigester uses human excreta. Taking into consideration that social and cultural constraints/stigma is very context specific; some level of secrecy is understandable, however, the importance of keeping the public fully informed about the benefits of human excreta for acceptability has been identified.

There are around 108 correctional institutions in Kenya. Nearly all correctional institutions rely on firewood as an energy source for cooking, making correction sector a major firewood consumer. Such heavy dependence causes environmental problems in the form of deforestation as well as placing a financial burden on the institution itself due to rising firewood prices.

5. Conclusions and recommendations

On a national scale, based on the 4 considerations: (1) the statistics, indicating 108 prisons in Kenya with a population of more than 55,800 prisoners and over 23,200 operating staff, (2) almost all prisons use wood fuel for cooking, (3) pioneering Embu prison (biodigester) saving on wood fuel KSh 500,000 annually, and (4) that the Kenyan diet does not vary essentially throughout the country, and therefore the results of Embu prison are considered to be representative for the other jails. It should be concluded that biogas technology as a source of renewable energy can drastically reduce Kenya's dependence on firewood as a main source of fuel for cooking and also reduce heavy expenditure on wood fuel.

The study established that biogas plant at Embu prison is an appropriate solution for a co-digestion of human excreta and cow dung to produce biogas and rich in nutrients digestrate (successfully applied as soil conditioner, and according to the prison plans for the near future will be used also as a feedstock to fish farming). Biogas holds the greatest promise as an economical energy source because it is renewable, simple to generate, convenient to use, and relatively cheap. Biogas is a unique energy technology because it offers multifunctional and simultaneous benefits in public health, agricultural productivity, environmental sustainability and economic development. Furthermore, by reducing the use of wood for fuel, biogas technology can reduce the challenges associated with deforestation and wood scarcity. In addition, biogas is environmentally friendly: biogas plants lower the greenhouse gas effect in the earth's atmosphere by recycling the methane gas in the bio-degradable matter to be used in cooking instead of being released into the earth's atmosphere to result in global warming.

Notwithstanding the biogas benefits, however, biogas potential is still under-exploited and the widespread verdict "a technology is only as good as its operation and maintenance" also applies in the biogas system at prison context. The best promotion of a technology is its proper functioning and the respective acceptance by its users. As it has been in the case of Nepal (Lohri, 2009), a country with a similar population and GDP but with national biogas framework that has fostered the uptake of over 260,000 biogas units resulting in 11,000 jobs and reducing wood use by an estimated 500,000 tons per year and CO_2 emissions by 750,000 tones.

Following the positive experience with biodigester in Embu prison it is recommended to pursue and replicate this approach in prisons in other areas of Kenya and also encourage promotion of biogas plants for other institutions such as boarding schools and hospitals in order to improve their sanitary conditions and provide renewable and clean energy. The results and discussions may be also applicable to other countries or regions with similar conditions.

The major previously mentioned (under discussions section) numerous recommendations are summarized as follows:

1. The process of clearance to start and operate renewable energy project in Kenya should to be streamlined, centralised and simplified.
2. Following successful example of pioneering project in Embu prison, the GoK should continue to build biodigesters in institutions (as when operational, biodigesters will give reduction of expenditure on woof fuel and on chemical fertilisers), and also to find ways to subsidise the initial capital investment for biodigesters for medium and small private owners.
3. The Embu prison should shift their breakdown maintenance practices to preventive maintenance approach, which can be scheduled and condition-based maintenance.
4. Biodegradable kitchen waste should be added to input, as the amount of biogas increases significantly.
5. To conduct a periodic assessment of the level of pathogens in the effluent (particularly in the light of proposed fish farming at the prison) and also take precautionary measures for biodigester's operating staff when in contact with raw effluent (by use of personal protective equipment).

In this concise study the proposal of generation of electricity from biogas reached only the stage of conceptualization and preliminary design. If implemented, however the proposed system is expected to have the following additional, to already existing, potential benefits:

1) Complete utilization of human waste to produce biogas, electricity and fertilizer.
2) Improved sanitation in the prison environments and consequently elimination or reduction of high sewage bill paid to municipal council.
3) Generation of electricity from human excreta and organic matter to reduce the cost of power consumption and maintenance in the prisons.
4) To improve general wellbeing of prisoners (e.g. by providing hot water for showers)

The study therefore recommends conducting detailed structural design of the proposed configuration including economical evaluation of the system.

As a final point, the study also suggests the following directions on future research: The stability of AD process and treatment efficiency of the biodigester system should be tested, monitored and analyzed, and Finding ways of reducing soluble electron acceptor nitrates, sulfate, iron and manganese oxides so that anode is the only electron acceptor in the digester this help to improve electricity generation in microbial fuel cells.

6. Acknowledgements

The authors would like to thank all staff and detainees of Embu prison for their willingness to share their experiences with honesty, directness and appealing sense of humor, which made this study possible and an unforgettably revealing experience. In a special way, we acknowledge the help of Senior Superintendent (SSP) Mr. Mutembei and the Deputy Officer-in-charge Michael Kitheka, Corporal Benard Kariuki and Christopher Weru, who worked together with us to facilitate the accomplishment of this study. Particular gratitude goes to the Deputy Officer-in-charge Benjamin Ngaria for his true dedication, time, expert explanations and enthusiastic willingness to improve the biodigester's performance in the future. Appreciation also goes to Okoth Kwenya and Catherene Chebet for their invaluable assistance in data collection in the field.

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