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Assesment of Social and Economic Impacts of Biogas Digesters in Rural Kenya

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Abstract

Although biogas technology has been in Kenya for over fifty years, it is only recently that the technology has begun to increase in popularity due to a new subsidy program. In this study, twenty-one households with fixed dome biogas digesters were visited and interviews with plant owners were carried out in order to gauge the social and economic impacts of digester use in addition to understand current challenges relating to biogas technology and the future of the industry. Of the homes visited in Kiambu County and Ngong, the greatest impact of using biogas was deemed financial, due to the monthly savings incured on purchased fuel. In addition, families benefit from improvements in plant growth and crop yield through bio-slurry use. The financial benefits are likely greater when switching from liquid petroleum gas (LPG) to biogas as opposed to changing from collected wood to biogas. Moreover, it is likely more difficult for the second group to invest in biogas due to a lack of financial savings following installation, therefore alternative methods of financing are necessary in order for the majority of Kenya's population with zero-grazing livestock to gain access to biogas technology.

1. Introduction

1.1 *Energy use in Kenya and its impacts*

Currently over 90% of Kenya's rural population relies on biomass, which includes wood, charcoal, and agricultural waste, to meet their energy needs (“Scaling Up Renewable,” 2011). According to the 2008-2009 Demographic and Health Survey (2010), 98% of Kenya's rural population used biomass fuels for cooking, compared to 55% of the urban population. At its current rate, it is clear that the use of wood fuel is not sustainable. At the time of independence in 1963, 10% of Kenya's land was forested, however by 2006 this area decreased to only 1.7%, and the rate of deforestation has only increased (Masinde, 2011). The impacts of this reliance are vast and while some effects are immediate, the full strength of many may not be felt until far into the future.

The consequences of the country's reliance on biomass fuels are far reaching, while the environmental impacts are most notably discussed. Effects of deforestation such as soil erosion and decreasing water tables have lasting impacts, while consequences of climate change are predicted to exacerbate poverty and strongly affect those who are most vulnerable. For instance, it is hypothesized that with climate change, droughts will become more likely throughout sub-Saharan Africa, resulting in as much as a 50% decrease in rain-fed agricultural yields by 2020. This will also have lasting health impacts, as children in Kenya are 36-50% more likely to be malnourished when born during a drought (Cord, 2008). Moreover, Kenya's energy sector will be adversely affected by increasing droughts, as more than half of the country's electricity comes from hydropower ("Scaling Up Renewable," 2011). With decreasing power production, energy demands cannot be met, resulting in widespread power shortages. Evidently, the potential environmental impacts of the current energy use are extensive.

In addition to environmental effects, the reliance on biomass fuels is known to have strong social and health implications, which are agreed to have greater impact on women and children. First, those using biomass fuels to cook within the home double the risk of pneumonia and other respiratory infections for children under five years of age. In addition, women are three times as likely to contract chronic obstructive pulmonary disease (COPD), and cooking with coal doubles the risk of lung cancer ("Fuel for Life," 2006). Women and children are especially at risk as they typically spend more time in the home and are responsible for cooking. In addition to the health impacts of indoor air pollution associated with biomass fuels, women and children are also adversely affected by the time required for fuel collection. This task can be difficult and time consuming as resources are often limited. This results in less time spent on income generating activities and education ("Scaling Up Renewable," 2011). Therefore, it is necessary to target these issues by implementing alternative sources of energy. While government action and policy changes will be required to enact large scale changes towards alternative energy use, small scale initiatives are necessary to aid the 98% of Kenya's rural population relying on biomass fuels in order to provide them with clean, reliable, and sustainable energy.

1.2 *Alternatives to biomass energy*

Wind, solar, and biogas technologies all show potential for small scale use at the household level. Wind and solar technologies may be practical in many areas of Kenya in order to pump water or provide electricity. However, these technologies are less practical for providing energy for cooking which is by far the main energy demand for rural households. Biogas, on the other hand, is a fuel which can be used to supply this need. Produced from the bacterial anaerobic digestion of animal waste in an airtight underground chamber, the gas can be used for cooking, lighting, chicken brooding, hot water heating, electricity generation, and chaff cutting with the correct appliances. Because biogas can practically be used as a cooking fuel, it also helps to address the health issues associated with indoor air pollution while decreasing dependence on biomass fuels. In addition, the byproduct of biogas production known as bio-slurry is a usable fertilizer, a valuable commodity to rural farmers. Because rural farmers keeping cattle and other livestock have access to the raw manure necessary for biogas production, as well as a demand for energy and fertilizer, biogas technology is a feasible solution to rural energy needs.

1.3 *Biogas in Kenya and the developing world*

While growth and development of biogas technology in some regions of the developing world has been slow, its presence in others is quite strong. In 2005 it was estimated that there were 16 million small-scale household digesters around the world, with most of these plants in India and China. In India, 6 million tons of firewood were replaced by the use of biogas in 1996 (Bhat, 2001). Furthermore, 7 million digesters in China contribute to the energy demands of 4% of the country's population (Mwakaje, 2007). While biogas use in Kenya is still in its early stages of development, the technology has been present in the country for over 50 years. The first digester in Kenya was built in 1957 on a rural coffee farm. Its success prompted the owner to begin a commercial venture, resulting in the building of 130 small-scale digesters in addition to 30 larger plants throughout the country from 1960 to 1986. In the late 1980s the Ministry of Energy partnered with a German organization known as GTZ to build 400 floating dome digesters ("Promoting Biogas," 2007). Today it is reported by the Kenya National Domestic Biogas Program (KENDBIP) that 6,748 plants have been built since 1957, however only about a quarter of these plants are believed to be operating by design (KENDBIP, 2012). The KENDBIP program, funded through the Ministry of Energy and the Dutch Ministry of Foreign Affairs, has a goal of building 12,000 high quality, functioning plants in the five years following its commencement in 2009. As an incentive to invest in biogas technology, the subsidy provides a 25,000 KSH subsidy upon completion of the plant. As a result of the program, the biogas industry in Kenya has experienced growth. Knowledge is growing in regards to the technology's potential and it is becoming more popular within the rural community. Therefore, as the technology spreads it is important to contemplate the future of the industry and further study its impacts on the community.

1.4 *Biogas in the current literature*

Biogas use in the developing world is a common topic in today's journals of alternative energy and sustainable development. Much of the literature discusses the various impacts of using biogas, similar to this report. However, the published literature typically draws from experiences of a large number of users in a sizable region. In this way, authors can formulate statistical data relating to users' experiences. A quantitative study is evidently beneficial in understanding the impacts of biogas use. For example, Katuwal and Bohara surveyed 461 biogas users in two districts of Nepal on incidence of eye infection, respiratory disease, cough, and headache before and after biogas installation. It was reported that the incidence of each affliction decreased. They were also able to compare disease rates of women, children, and men separately, determining that the positive health impacts resulting from biogas use more drastically affect women and children compared to men. For example, the study found rates of eye infection and headache to decrease by approximately 40% for women, while only 20% for male respondents. Through this survey, Katuwal and Bohara were able to confirm a common assertion in the literature in which women and children are more adversely affected by indoor air pollution. It is important to consult quantitative data, as found in the previously reviewed study, due to the nature of the study carried out in Kenya which relies on ethnographic accounts of biogas.

In addition to considering applicable literary discussions on the impacts of biogas, it is also important to present a discussion on the failure of biogas plants in developing countries. It is fairly common that plants will be found in disrepair, abandoned, and no longer producing biogas. Because the biogas industry in Kenya is in its embryonic stages, it is necessary to explore the status of biogas in other developing regions so as to learn from others' experience. Bhat, Chanakya, and Ravindranath (2001) reviewed the use of biogas in the Sirsi region of India, and determined that the area experienced a high rate of success compared to other regions. In conclusion, the authors found that this was likely due to particular characteristics unique to the region. This included a large population of livestock, which prevented plant abandonment due to lack of dung. They also found that users living in this region had greater access to free or low cost digester maintenance through intermediate financing institutions, such as agricultural cooperatives. This infrastructure provided greater support to clients, impacting the overall success of biogas in the region.

Bond and Templeton (2011) also discuss the topic of plant failure in their review of biogas use in developing countries throughout the world. They mention the status of biogas use in various Asian countries, including Bangladesh, Sri Lanka, China, and Nepal. After citing failure rates of as high as 70%, the authors similarly assert the importance of infrastructure to support biogas users should plants malfunction. In considering the future of biogas in Kenya, the KENDBIP subsidy program will likely come to an end in the near future. Therefore, it is of great importance that the Kenyan biogas industry focuses on developing the infrastructure necessary for sustainable growth.

In addition to a review of biogas in Asia, the authors also provide a short evaluation of biogas in sub-Saharan Africa. It is reported that of the estimated 850 plants installed in Kenya as of 1995, only 25% were operational, which resulted in a negative view of biogas in the country. It is evident through the KENDBIP program and growing popularity of biogas in Kenya that the country is beginning to move away from this negative view. However, in considering the past histories of biogas in other nations through the literature, it is evident that the biogas industry in Kenya faces many challenges in terms of sustainable development.

2. Objectives

In considering the future of biogas technologies and that of businesses and contractors within the industry, it is necessary to more fully understand the impacts of the plants for those using them. This study will focus on understanding the social and economic effects of using biogas digesters on rural farms in Kiambu County and Ngong and its surrounding communities. In addition, it is important to gain feedback from users about ways in which biogas technology might be improved to suit their needs while understanding what they foresee as the future of biogas in Kenya. Specific objectives are:

1) to investigate the economic and health related implications of using biogas.
2) to understand bio-slurry use, its perceptions, and effect.
3) to determine the time needed to maintain a functioning digester, potential improvements to the technology, and problems encountered by its users.
4) to ascertain the ways in which biogas systems are financed, understand the associated implications, and explore alternative financing options to make the technology accessible to Kenyans without the necessary capital.
5) to discuss the future of biogas in Kenya and requirements for growth.

3. Setting

The study was carried out in Kiambu County and the Ngong are where local homes with small-scale biogas digesters were visited.

3.1 *Kiambu County*

Kiambu County borders Kenya's capital, Nairobi, approximately fifteen kilometers north of the city in the country's Central Province. The land area of the county is fairly large and has a population of over 1.5 million people according to Kenya's 2009 Census, while the region is primarily home to people of Kikuyu ethnicity. One Kiambu resident noted that the county is proud to border the country's capital, and this proximity allows many residents to commute into the city for work and business (Interview 15). The region's fertile lands and climate make it home to many farms, both large and small. These farms are well known for producing tea, coffee, and milk. With so many families taking part in the agricultural and dairy industries, Kiambu County is an excellent environment for biogas. The area providing the necessary manure from cows and the land in which to utilize the bio-slurry byproduct, while also having a demand for cooking energy.

3.2 *Ngong and its surrounding communities*

Approximately twenty kilometers south-west of Nairobi's city center, Ngong sits at the base of the Ngong Hills in Kenya's Rift Valley Province. Within close proximity to Nairobi, many of the area's residents commute to the city for work, similar to citizens of Kiambu. Moreover, many residents work in local business, while small residential farms, known as *shambas*, augment the family's store bought food supply. Many residents also keep cows and other animals to provide supplemental income, and some work in the area's quarry industry. In addition, the region is somewhat unique in that it borders a large Maasai community on the opposite side of the Ngong Hills, bringing that cultural influence to the local community.

3.3 *The rural household*

Visits were made in both regions to private homes. The compounds visited shared many similarities which are important to note in terms of biogas feasibility and application. In addition to the home, each compound also contained at least a small *shamba* containing various crops, some of which include napier grass, maize, beans, coffee, and bananas. The size of these plots ranged from a small front yard to a few acres. In addition to agriculture, almost all families owned livestock, namely cows and occasionally pigs. These animals were zero-grazing, kept in small, enclosed paddocks adjacent to the home, which is required to ensure ample dung for biogas production. The biogas digester was usually placed near to these enclosures to allow for convenient dung addition to the plant.

Particular aspects of the home itself are also important to discuss in relation to biogas usage. All but one home visited received conventional electricity from the grid. In terms of cooking, most homes had both a kitchen inside the home in addition to a second kitchen in a small building outside of the home which could be used when more cooking space was necessary. These details are important to keep in mind in order to more fully understand the addition of biogas to the rural home.

4. Methodology

The study was carried out over the month of April, 2012. The primary method of data collection involved home visits to families using biogas technology. Twenty-one homes with completed digesters were visited, five in Ngong and its surrounding communities, and sixteen in Kiambu County. At twelve of the twenty-one homes, an in depth interview was carried out in English with at least one of the owners of the plant. Due to various reasons and constraints, at five of the nine remaining sites, only informal interviews were carried out with various family members or workers present in the home. These interviews took place in both English and Kiswahili, sometimes with the aid of a second person present in the home, or a biogas contractor in attendance. During each interview, questions were asked regarding current and past fuel use, manure use, system maintenance, cost, issues, and improvements, in addition to other questions relating to their experience with biogas. An extensive list of interview questions can be found in Appendix A. At the four remaining sites, the systems were seen, but no one was home to discuss the biogas plant. However, various observations could still be made at these sites, and the contractor who built the plant, present on the visit, was often able to provide background on the clients' experiences.

Visits were carried out both alone and in the company of the contractor responsible for the building of the plant. Three clients in Kiambu were visited with a local contractor. In addition, clients of a second contractor were visited in his company. Three such visits occurred in the Ngong area while five took place in Kiambu County. These visits in the company of the two contractors also provided an opportunity for extensive discussion relating to the biogas industry.

In addition to carrying out visits to homes with completed digesters, two visits were also made to plants under construction, providing an opportunity to better understand biogas technology and the construction process. Also, in order to gain exposure to the biogas industry, time was spent in the Takamoto Biogas shop in Kiambu Town. This offered a chance to speak with potential clients and hear from those interested in biogas. Lastly, a KENFAP conference was attended in Thika, which provided an excellent opportunity to learn about biogas in Kenya from the point of view of contractors and masons while also learning about the subsidy program currently in place.

5. Results and discussion

5.1 *Fuel use*

At this point in its development in Kenya, biogas fuel is primarily used for cooking, which was confirmed by the study. The vast majority of plant owners used biogas solely for cooking, while a few also utilized the fuel for occasional lighting purposes. This change in fuel use made a tremendous difference for plant owners in various ways, while the main impact was deemed financial.

5.1.1 *Previous fuel use*

Prior to using biogas, plant owners were found to cook with wood, charcoal, and liquid petroleum gas (LPG) fuels. All but three families participating in the study reported using LPG as their main fuel source before switching to biogas. However, few informants reported cooking only with LPG, as most described augmenting this fuel with that of wood and charcoal. For many of these families, it was found that the LPG cooking mainly took place in the home, while cooking with wood or charcoal was done in the exterior kitchen. The average user reported spending 1,200 to 3,000 KSH on LPG per month, in addition to 500 to 1,800 KSH on charcoal, depending on usage. Wood was either cut from trees on the family *shambas* or purchased for anything from 400 to 2,200 KSH per month. In general, the biogas users in the study paid approximately 3,000 to 5,000 KSH on cooking fuel per month.

5.1.2 *Current fuel use and its financial impacts*

The use of biogas was shown to have a large impact on conventional fuel consumption. Of the families who reported cooking with LPG prior to using biogas, only two claimed to be using LPG in addition to biogas. Therefore, of these biogas users with past LPG consumption, cooking with biogas results in an immediate financial savings. While most informants now augment their biogas use with that of wood and charcoal, it is clear that their consumption of these commodities has decreased. For instance, one biogas user noted that the family now purchases wood every two months as opposed to every two weeks, while another estimated that her supply of wood which used to last about three to four months could now be used for well over one year (Interview 7, Interview 10). Most users estimated their total energy savings at approximately 3,000 KSH per month.

Questioning biogas users in regards to where they may invest the money saved solicited varied responses. For example, one biogas user said that he had been able to purchase a second vehicle, and another noted his ability to give more to others (Interview 8, Interview 14). However, when asked what they would do with the fuel savings, an overwhelming majority reported that the money would be invested in the family farm. One was interested in purchasing a milking machine, allowing for greater milking efficiency, higher milk production, and therefore higher income, while another said she was saving to build a drip irrigation system for her *shamba* which would increase her yields and allow her to harvest multiple times per year (Interview 2, Interview 5,). Many others expressed desire to purchase another cow or more pigs. In turn, this will result in greater income due to milk production or meat sales, in addition to potentially greater biogas production due to larger dung output, allowing for even greater fuel savings. Because of the strong links between biogas and farming, an investment in livestock with savings from biogas use has the potential to result in greater income generation compared to its equivalent investment by someone without a biogas plant, further raising the standard of living of the plant owner.

5.1.3 *Kenyan cooking culture and the role of biogas*

As discussed, biogas fuel use was nearly always augmented with traditional biomass fuel use of wood and charcoal. In some cases this was done because the biogas plant did not produce enough fuel to meet a family's energy needs, however in many cases there seemed to be a cultural hurdle preventing full adoption of biogas fuel. For example, many biogas users reported using wood or charcoal to cook particular dishes, including *githiri* and *chapati*. *Githiri*, a dish made from maize and beans, is cooked continuously for about three hours. For someone cooking primarily with LPG it is understandable that they might use wood or charcoal to cook this dish as LPG is an expensive source of fuel. However, it was unclear as to whether or not biogas users cooked *githiri* with wood or charcoal out of habit, or because their biogas plant simply did not produce enough gas to meet this higher demand. Furthermore, many informants also reported using biomass fuel to cook *chapati*. It is known that this dish is also traditionally cooked with wood or charcoal, and unlike *githiri*, it does not take exceptionally longer to cook compared to other dishes. One biogas user explained that when she cooks *chapati* with LPG or biogas it has a tougher consistency compared to when cooked with wood or charcoal (Interview 5). Evidently, the cultural norm in which the dish is made with wood or charcoal is shared among biogas users, preventing the complete adoption of biogas for all cooking needs.

5.1.4 *Biogas stove options*

Because the proper appliances are necessary to utilize biogas produced by a plant, it is important to discuss the consumer's options. Because LPG is in liquid form while biogas is evidently a gas, a standard LPG stove cannot run on biogas without modification. Many biogas contractors recommend purchasing stoves made specifically to run on biogas. A two burner biogas stove is reportedly sold for 8,000 KSH. However, when clients purchase new biogas stoves, their conventional LPG stove becomes obsolete. In many homes, the LPG stove remained in the kitchen, unused. In one kitchen, the family's old, high-end, four burner LPG stove had been covered with a piece of glass, allowing for additional counter space. Biogas stove users who remained in possession of their previously used LPG stove were not questioned as to why they kept the appliance. It is possible that this was done in case of an extended loss of biogas. However, if one wishes to sell their old appliance following installation of the biogas plant, it may be beneficial to both parties if biogas contractors and businesses are able to develop a program in which contractors purchase old appliances from clients for resale.

While many study participants using biogas stoves were observed in possession of their previously used LPG stoves, some users opted for an alternative. Seven of the study participants were observed to be using modified LPG stoves. Stoves can be modified by enlarging the hole through which the gas streams prior to flowing into the burner. One adapted stove user reported that she paid 1,300 KSH for the modification, however her contractors were hesitant of the operation (Interview 5). Another user did the modification himself (Interview 8). It is unknown whether this alteration reduces the life of the stove or perhaps compromises the safety of the appliance, but it appeared that users opting for the modification were pleased with the result. If there are no noted downsides to this procedure it would be beneficial to clients to have better access to this opportunity through biogas contractors, allowing them to save a substantial amount of money at the time of biogas investment. This in turn may aid in making biogas more financially accessible to a greater portion of Kenya's population.

5.1.5 *Health impacts of biogas use*

As discussed, it is well known that using biomass fuels has adverse health effects which can be avoided by using liquid and gas fuels like LPG or biogas. Because nearly all biogas users included in the study had previously used LPG, they were likely already benefiting from this lifestyle change. While the adoption of biogas would not impact their health to the same extent as it would for someone who was previously cooking only with wood, a reduction in the supplemental biomass fuel used can only be beneficial to health. Whether or not people had previously used wood or charcoal inside the home, they felt that their homes were cleaner as a result of less smoke. One woman who previously cook with LPG, wood, and charcoal felt that there was far less smoke in her home since using biogas which causes her a headache when cooking with wood charcoal. This she feels is due to the fact that her body is no longer used to large amounts of smoke and carbon monoxide in the air (Interview 5). Therefore, while the vast majority of study participants may not experience extensive health benefits of biogas, having already switched to LPG fuel, they acknowledge a positive difference in their home environment.

In addition to health impacts relating to air quality, two biogas users also expressed feelings in regards to biogas safety as compared to that of LPG. The informants both felt that biogas does not "explode" like conventional cooking fuel (Interview 2, Interview 8). One explained that this reference was towards the fact that there is no longer a gas canister in the home which could potentially burst if not handled properly. Furthermore, the chemical composition of biogas in comparison to that of LPG may also assist in preventing accidents in the kitchen. When one delays in lighting an LPG stove after turning on the burner, the gas can ignite uncontrollably due to the fact that LPG is more dense than air, causing it to rest on top of the stove. Conversely, biogas is far less dense than air, causing it to disperse rapidly from the burner, reducing risk of an oversized ignition. While the extent of this safety impact is unclear, it is evident that some biogas users are more confident in regards to their family's well being.

5.1.6 *Effect of socio-economic status on biogas impacts*

Due to the area in which the study was carried out and its proximity to Nairobi, it was judged that nearly all study participants would be classified as middle and upper class Kenyans. This was mainly determined through observation of their home and possessions. As noted, the main impact of using biogas for cooking was financial, as users likely did not experience extensive health benefits, having cooked with LPG. Furthermore, because of the area of the country in which the users lived and their close and relatively easy access to fuel, they did not report saving large amounts of time on fuel collection. According to one source, women in Africa spend between two and nine hours each day collecting wood in addition to other cooking related chores (Makhabane, 2002). However, in areas such as Kiambu and Ngong, which are still reasonably close to Nairobi, if one does not have access to trees on their own property, then wood is simply purchased due to its high demand and high population density. Therefore, while biogas clearly has a positive impact for those involved in the study, its effect on those with different energy use backgrounds is likely quite different. Moreover, while a family using biogas in a more rural setting may save large amounts of time previously spent on wood collection, because their monetary investment in fuel is less, they may struggle to recover from the financial investment in the plant. Because this group will experience decisive benefits if they are able to invest in biogas, it is important to discuss alternative financing options to suit their needs. Refer to section 5.4.2 for this discussion.

5.1.7 *Lighting*

Biogas lights are hung from the ceiling like a conventional bulb and produce light equivalent to a standard 60W bulb. When the gas is turned on and flowing through the light, a flip is switched, producing a spark to light the lamp. Imported from China, biogas lamps are sold by Takamoto Biogas for 5,000 KSH, equivalent to approximately 60 USD. Of the twenty-one homes visited, only three used biogas for lighting. It is important to note that these three homes also used conventional electricity. Each family had various feelings and experiences pertaining to their lighting use.

Because all of the families with biogas lighting also used electricity, this new form of lighting was supplementary. Two of the homes had one light that was to be used when the power goes out, however only one client reported using the lamp. The ability to use biogas lighting under these circumstances was acknowledged by many, including those who did not have the lighting appliances. However, in these cases informants often stated that they did not feel investing in a light would be worth it, they did not want to invest the extra money, or their digester did not produce enough gas to use for lighting in addition to cooking. In this case, because lighting was not used to replace electricity there was no financial benefit to using the biogas lighting. It is possible that clients save on items such as candles which they use when there is no electricity, however this was never mentioned, and would likely be considered only a fairly small savings. The presence of biogas light in these homes was mainly seen as an added convenience provided by the biogas.

In contrast, one biogas consumer in the study had four lights which he and his family used on a regular basis. With a 12 m^3 digester and dung from six cows, enough gas is produced so that it may be used for more than simply cooking. The client reported using the lights four days per week from approximately ten in the evening. The lights are used inside the home in addition to outside in the cow paddock. This allows for milking at night which may or may not have been completed without a convenient source of light prior to biogas installation. The client estimates a monthly savings of 500 KSH per month on electricity. He hoped that perhaps with dung from more cows he might be able to produce enough gas to begin using the light at seven o'clock as opposed to ten. Reporting that he was able to give kids nearby some money for everyday expenses and perhaps purchase another cow with the money he saved from cooking fuel, saving more on electricity would allow him to augment these investments (Interview 14). This shows the potential that biogas lighting can have, however based on the homes visited this is not the reality for most. As mentioned, many do not feel compelled to invest in biogas lighting when they experience the convenience of electricity. It might also seem likely that people are hesitant to make a large investment in multiple lights after paying the initial digester cost. Potentially after recuperating their costs from the initial investment and growing their savings, some users might feel inclined to broaden their biogas usage by investing in lighting. Moreover, because some clients reported consuming all of the produced gas while cooking due to the digester size or number of animals feeding the system, they may not be able to use biogas for lighting even if they wished.

While people's feelings on and usage of biogas lighting were discerned from those using electricity, the study did not include any members of Kenya's eighty percent majority who do not have access to electricity in their homes ("Kenya: Demograph and Health," 2010). It would seem likely that for people without electricity, biogas might have a very different impact in their lives, and biogas lighting may be more of a priority and therefore play a larger role.

5.2 *Bio-slurry use*

The byproduct of biogas production, known as bio-slurry, is essentially the mixture of water and dung which was originally added to the system. However, following the anaerobic digestion responsible for biogas production, this material has been partially broken down, making available nutrients in the slurry more accessible to plants, for example, compared to conventional manure. As a result of this difference, crop yield increases of 6-10% and as much as 20% have been reported ("Biogas Digest"). In addition, bio-slurry is immediately ready for disbursal in the *shamba*, as opposed to regular manure which must first be cured. The liquid composition of the manure also allows for easy application to crop fields. While it is generally agreed that bio-slurry is superior to conventional manure, it was important to hear the views and experiences of users themselves.

5.2.1 *Fertilizer replacement*

Of the study participants, eleven reported using the bio-slurry product on their *shambas*. Those who did not report use either did not have much experience with the digester, as it was still fairly new, or the topic was not discussed during the interview. Everyone using bio-slurry claimed that they had previously used conventional manure, while only one user reported augmenting this supply with manufactured fertilizer. This cost the client 4,200 KSH per growing season, however it was unclear whether or not he continued to use fertilizer in addition to bio-slurry (Interview 15). Through this assessment, it is clear that for the majority of biogas users keeping cows, there is no economic impact of using bio-slurry in terms of fertilizer cost.

5.2.2 *Effectiveness*

Of the eleven study participants who noted bio-slurry usage, six identified an improvement in yield, plant health, or growth. The others either did not note any difference or the topic was not discussed during the interview. Although the study did not specifically measure differences in crop yield, users were able to make pertinent comparisons to their past harvests. For example, one woman claimed that the leaves of her spinach and *sikuma wiki* are larger than she has ever seen (Interview 5). One man boasted in regards to his successful yield of three bags of maize on a quarter acre plot (Interview 13). And one biogas user now faces a challenge in that his banana trees have grown so tall as a result of using bio-slurry that they are beginning to fall down (Interview 8). While it is clear that bio-slurry has positively impacted plant growth, the effective changes on yield remain unknown.

5.2.3 *Selling bio-slurry*

In addition to using bio-slurry on their own *shambas*, a few biogas users in the study reported selling the product as well. Prices ranged from 2,000-5,000 KSH per truckload. One informant claimed selling the product once per week, while another mentioned that he previously sold normal manure at the same price (Interview 11). A few study participants also reported giving the bio-slurry away to friends and neighbors. There was no apparent trend in responses relating to the sale of bio-slurry. While some sold the product, one was against it because she felt others would not appreciate the commercialization of something such as cow dung, while another felt people would believe bio-slurry was simply equivalent to dirt (Interview 5, Interview 1). These comments raise questions in regards to cultural perceptions of manure use, which could be the topic of its own study entirely.

5.2.4 *Health and Financial Impacts of Bio-slurry Use*

The most obvious financial impact of bio-slurry use is involved in the sale of the product. To those who did not previously sell manure, this income augments one's fuel savings from using biogas, therefore it may also be invested back into the family farm, as was generally determined. In addition, financial benefits likely also result from improved yield. However, because specific changes in yield were not determined as part of the study, there is no way to provide numerical data regarding increased income due to crop sales or savings as a result of purchasing less food. Moreover, it is likely difficult for families to estimate this financial impact compared to that associated with fuel use changes, as they likely do not track the number of tomatoes they grow or purchase in a year or month, for example. Despite these difficulties, it is probable that one can still assert that biogas users applying bio-slurry to their crops experience a financial benefit.

In addition to the financial impact, it is possible that bio-slurry use also has positive health benefits. While these benefits were not observed in the field, they are still an important aspect of bio-slurry use. First, by processing animal waste in the digester, biogas users likely experience improved sanitation on their farms. This may be especially observed in places where biogas is made from human waste as an alternative to open defecation. Furthermore, people of lower socio-economic standing may experience improved food security as a result of bio-slurry use. If one is unable to purchase much produce due to cost, but is able to keep a *shamba*, increased yields as a result of bio-slurry use may allow them to feed their family a more balanced diet for longer periods during or after harvests. While it was observed that those who participated in the study were of higher socio-economic standing, it may be possible that someone with fewer resources would be given bio-slurry from a neighbor as they may likely be unable to afford their own plant under today's current price or subsidy program. In practice, this may demonstrate that biogas technology is capable of benefiting more than just those who have a digester.

5.3 *System maintenance and improvements*

5.3.1 *System feeding*

Almost all users felt that the work involved in feeding the digester was completely manageable, and they did not feel that this work was too much to take on for either themselves, or a worker. Only one user felt that the work of feeding the digester was too much. She reported that it took approximately 1.5 hours to add the dung and water mixture to the plant, compared to a report of ten to thirty minutes given by all other informants. She complained that it was difficult for her to find workers to consistently complete the job, even with pay, because they felt it was either too messy or difficult (Interview 3). Despite this, the overwhelming majority did not feel that the maintenance detracted from their own or their worker's ability to complete other daily jobs.

While this view was shared by most, one recommendation for improvement to system feeding is important to note. In order to prevent blockage in the system, large, solid pieces of undigested food, such as straw or maize stalks, must be removed from the dung. This is done by hand when the dung is mixed with water in the inlet chamber. This step was observed to be the most time consuming aspect of feeding the digester. In order to improve this job, one user recommended a sieve be placed in the inlet chamber which could easily prevent these solid materials from entering the digester (Interview 10). This would likely aid in making this task cleaner, simpler, and less time consuming.

5.3.2 *System enlargement*

When asked about improvements which could be made to their digesters, six respondents expressed motivation to expand their biogas system in some way. This included purchase of an appliance, enlargement of the digester, or even building a second plant. After experiencing the technology and realizing its potential in their own home, these users were eager and optimistic about the role of biogas in their futures. It also became evident that some users had put much time and thought into ways in which they could make more biogas. Two had similar ideas for connecting a second tank to the first to allow for a larger volume of gas without having to build a completely separate system or destroy the original (Interview 2, Interview 13). One also offered a small structural modification which he felt would allow for a larger volume of gas in the dome without having to increase the size of the plant (Interview 13). This would then allow them to broaden their own biogas usage, or perhaps install a line to their neighbor's home allowing them access to biogas, which was an idea expressed by a few users. Evidently, those included in the study are knowledgeable in regards to the technology and it is important that their ideas play a significant role in the future of biogas in Kenya.

5.3.3 *Gas storage*

Four users in the study expressed a desire to pack and store biogas, allowing them to either sell or use when the plant does not produce enough gas to fulfill their needs. One user even reported plans to begin his own experiments to pack biogas in standard LPG jerry cans (Interview 8). According to one contractor, there is currently research being carried out in China to develop a way in which users can store the gas. Within the scientific community, it is agreed that biogas can only be stored as methane, therefore it is necessary to separate the other gases from the mixture (Kapdi, 2004). Evidently this is difficult and costly, requiring innovative solutions for application in the rural Kenyan setting. However, if the technology can be developed, this will allow biogas users to further augment their savings by selling the gas or storing it for future use. This will also help to expand the biogas industry and lower dependence on biomass fuels as one unable to afford the cost of LPG or a biogas plant may be able to purchase biogas at a lower price.

5.4 *Financing*

5.4.1 *Observed methods of financing*

All participants in the study reported paying for their biogas system with money from savings. It was agreed among many of the informants who had been using the technology for multiple years that it took approximately two years to recuperate costs following the initial investment. No one involved in the study reported taking a loan to finance their investment. One informant noted that people are hesitant to get loans due to high interest rates (Interview 15). Because those who participated in the study had the necessary capital required to pay for a biogas system, it was proposed that all study participants were of middle and upper class. It is well known to most in the biogas industry that the largest hindrance in the widespread adoption of biogas technology is cost. This challenge was certainly observed in the field when users were asked how their neighbors and friends felt about the technology. Many felt that their neighbors appreciated the technology after hearing of their own success, however cost was the main reason given as to why they had not yet invested in the technology themselves. Furthermore, some users believed that their friends and neighbors simply felt that the cost was so high that they could not make a significant return on the investment. Evidently, reducing costs and expanding financing options is necessary for the expansion of biogas technology in Kenya and the developing world.

5.4.2 *Alternative methods of financing*

It was determined that the participants in the study were of middle and upper class and changes are necessary in order to make biogas more accessible to a larger portion of the population. Although KENDBIP currently offers a 25,000 KSH subsidy for digester construction, it appears that many are hesitant or unable to make such a large investment. Because system cost and financing must be a main focus in the future of biogas in Kenya, biogas users in the study were asked about alternative ways in which the technology can be made accessible to those who cannot afford the cost. Some offered alternative methods of financing which may aid in this goal. For example, one user felt that more government and NGO subsidies are required. In terms of a loan system, he offered a unique idea in which loans are given through milk cooperatives. Because the majority of people using biogas are keeping cows and selling milk through the local cooperative, a system could be implemented in which payments for the plant can be made in milk, or milk can be used as collateral (Interview 15). Due to the common participation of biogas users in the dairy industry, it seems logical that perhaps milk cooperatives should play a role in biogas distribution. Lastly, one user considered a system in which the client paid for the plant simply with the money now saved from using biogas. This could be implemented like a conventional loan if the lender is flexible in agreeing on a practical rate of repayment based on the current energy savings. In addition to these suggestions it is also important to note the potential role which microfinance could play in the growth of biogas technology in Kenya. Although this possibility was not explored in the field, it should not be overlooked in the future as a useful financing method.

While these recommendations are given as potential financing solutions, one method was observed in the field as an alternative to acquiring the total capital required for the plant. One biogas user reported that her plant was built over four months, compared to the more common time frame of one to two weeks (Interview 5). It is the client's job to purchase the necessary materials, including cement, gravel, bricks, and piping, however this client chose to take her time making these purchases, distributing her spending over time as opposed to making the investment in one lump sum. If potential biogas users realized this flexibility, they may be more inclined to build a digester, purchasing the materials at their own pace when they financially felt able. If biogas contractors and businesses are willing to work with other institutions to better aid their clients in the financing of plant construction, they may find an increase in business as the payment of construction becomes more manageable for the consumer.

5.5 *The future of biogas in Kenya*

5.5.1 *Cost reduction*

The main obstacle currently preventing substantial growth of the biogas industry is cost. As discussed, this is also a hindrance in allowing biogas to have the greatest possible impact on its users as those who may benefit most from the technology may likely be those who are unable to afford the cost. Therefore, in order to promote biogas in Kenya, effort must be made in reducing plant costs while also improving financing options, as discussed. While it may be challenging for biogas contractors and businesses to aid in the reduction of material costs which is likely out of their domain, one technology shows potential in helping to reduce costs.

The most costly material necessary for biogas plant construction is cement. Therefore, if other less expensive materials can be used in its place, the price of building a digester could be greatly decreased. Currently, KENDBIP is carrying out trials on Interlocking Stabilized Soil

Blocks (ISSB) which are an alternative to cement bricks for biogas construction. The bricks are produced from a mixture of locally available soil and approximately 5% cement ("Interlocking Stabilized Soil," 2012). This has the potential to reduce material costs by 30%, allowing a greater portion of the Kenyan population access to biogas technology through lower costs. Moreover, if biogas masons are able to invest in the brick press necessary for ISSB production, they may be able to augment their income by selling the bricks for other construction purposes. While this technology is still in the developmental stages, it has great potential for the growth of biogas in Kenya.

5.5.2 *The Maasai community*

When discussing the future of biogas technology in Kenya with the study participants, three mentioned the Maasai community as potential beneficiaries of biogas technology. Traditionally pastoralists, the Maasai community mainly resides in two regions in Kenya, Maasailand, south-west of Nairobi, and the Maasai Mara, in the far south-west region of the country. Although cattle and other livestock kept by the Maasai are not zero-grazing, one biogas user felt that due to their large herds it would be possible to accumulate enough dung to produce biogas (Interview 13). Informants mentioning the Maasai community noted that their reliance on wood fuel and exposure to smoke results in a permanent squinting appearance. With the necessary livestock and high exposure to indoor air pollution, it is important for the biogas community to consider the Maasai in their future plans of expansion.

5.5.3 *Education*

While reductions in cost and growth in alternative financing methods is needed to grow the biogas industry in Kenya, ultimately if prospective consumers are uneducated in regards to the potential of biogas, they will not invest. Upon visiting feed stores in Kiambu Town and asking store workers whether or not they knew about biogas, it became clear that while many had heard of the technology, they had little specific knowledge in regards to its function and potential. While visiting plant owners it became evident that very rarely did only one plant exist in the area. Many owners reported at least one neighbor or friend with a digester. And after an initial installation, it appeared that this spurred curiosity and interest from friends. One informant said that it was not until after seeing a friend's plant for himself that he became serious about adopting the technology for his own family (Interview 15). Others thought that many people have difficulty in believing that energy can be made from animal waste. Therefore, education is a key component to ensuring that the biogas industry will continue to grow throughout Kenya and East Africa.

6. Conclusion

Although biogas has been present in Kenya for over fifty years, it has only been within the past five to ten years that the industry has begun to grow. Therefore, today's biogas users should be considered pioneers, and reports of their experience should be an integral part in planning and adapting for the future of biogas in Kenya. It was identified that most of the biogas users participating in the study had very similar experiences with the technology due to their socio-economic standing and access to conventional fuel sources. This most likely indicates that social and economic impacts of biogas use differ in conjunction with this variation in fuel resources used. It was also noted that in order for the biogas industry to succeed in Kenya's future, cost reductions are necessary in order to improve affordability, while education in regards to biogas and its potential must be stressed, so as farmers with the necessary livestock are aware of this opportunity.

7. Recommendations

This study was limited in that the biogas users visited were of similar socio-economic standing and had fairly analogous reports of previous fuel use. In part, this was due to the study setting's proximity to Nairobi and other fairly urban areas. Therefore, it would be highly recommended to further expand the study results by including biogas users from other areas of Kenya where conventional energy use likely differs. Specifically, it would be beneficial to include those who previously cooked only with collected wood prior to biogas installation in addition to those without electricity. This would help to confirm the proposed differences regarding the impacts of biogas use. In studying the impacts of bio-slurry use, it may also be wise to conduct a more thorough study in which differences in crop growth and their economic impact can be determined. Lastly, it is recommended that the study expand to include biogas users who used loans to finance plant installation. This would help to glean the extent to which loans alter the economic impacts of digester use. Overall, these recommendations will help in providing a more complete picture of biogas use in Kenya which will aid in shaping the industry's future.

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Interviews

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2. Kibiko, Ngong. April 14, 2012.
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7. Ndumberi, Kiambu County. April 20, 2012.
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9. Riabai, Kiambu County. April 21, 2012.
10. Riabai, Kiambu County. April 21, 2012.
11. Kiambu, Kiambu County. April 22, 2012.

12. Kiambu, Kiambu County. April 22, 2012.
13. Thika, April 22, 2012.
14. Riabai, Kiambu County. April 24, 2012.
15. Kiambu, Kiambu County. April 25, 2012.

Appendix A

Interview Questions

General information

Name:
Location:
Biogas contractor:
System size and type:
Date of system completion:
Number of people living in the home:
Number of animals feeding the system:
Appliances running on biogas:

Fuel use

- What types of fuel did you use for cooking prior to using biogas?
  - How much per month?
  - Where did they come from?
  - How much did each fuel cost per month?
- What types of fuel do you use now that you have biogas?
  - How much per month?
- How much money do you think you save on fuel each month?
- What do you do with money you save from using biogas?
- Does biogas cook foods any differently than wood, charcoal, or LPG?
- Do you have enough biogas to fulfill your cooking needs?
- If you are still cooking with conventional fuels, why?
- Do you use biogas for lighting?
  - If so, when and for how long each day?

Fertilizer Use

- Are you using bio-slurry on your *shamba*?
  - Why or why not?
- What did you use as fertilizer before bio-slurry?
- Do you notice an improvement in crop yield or growth since using bio-slurry?
- Could you estimate or describe the changes in crop yield you experience?
- Do you ever sell bio-slurry or give extra to friends and neighbors?

System maintenance, problems and improvements

- How much time is spent each day on work relating to the digester?
- Who is responsible for feeding the digester?
- Do they find this work to be manageable?
- Are there any improvements you feel could be made to your plant?
- Have you had any problems with the biogas system?
- Are there any negative things in regards to the plant?

Financing

How much did your biogas system cost?
Were you part of the KENDBIP subsidy program?
How did you finance the cost of your biogas plant?
How long did it take to recover from the initial investment of the plant?
What do you feel can be done so that those who currently cannot afford biogas can gain access to the technology?

Miscellaneous

What is the biggest difference in your life now that you use biogas?
Where did you learn about biogas?
What do your friends and neighbors think of your biogas system?
Do you know other people with biogas?
What do you foresee as the future of biogas in Kenya?