IMPACT OF BIOGAS DIGESTERS ON HEALTH AND QUALITY OF LIFE MEASURES OF KENYAN FARMWOMEN

by

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ABSTRACT

Women living in rural Kenya rely on wood for cooking and are exposed to elevated amounts of wood smoke. The objective of this thesis was to assess the health and quality of life benefits of installing biogas digesters on rural Kenyan dairy farms. Thirty-one farms with biogas digesters and 31 farms without digesters (referent group) were assessed for wood utilization practices, basic respiratory and self-reported health, and exposure to volatile organic compounds (VOCs). Women with biogas digesters spent less time and money acquiring wood, and less time exposed to wood smoke ($p<0.01$). Multivariable linear regression showed associations between daily wood consumption and having a biogas digester, family size, and number of cows. Individual VOCs were lower in cookhouses on biogas farms ($p<0.001$) and women with biogas digesters reported fewer respiratory symptoms. Biogas digesters are one technology that can reduce reliance on wood fuel and reduce exposures to harmful wood smoke.

LIST OF ABBREVIATIONS USED

ARI	Acute Respiratory Infection
ATD	Automatic Thermal Desorption
BG	Biogas
CI	Confidence Interval
CO_x	Oxides of Carbon
COPD	Chronic Obstructive Pulmonary Disease
EPA	Environmental Protection Agency
FEF	Forced Expiratory Flow
FEV_1	Forced Expiratory Volume in 1 Second
FHF	Farmers Helping Farmers
FVC	Forced Vital Capacity
GC	Gas Chromatograph
GOLD	The Global Initiative for Chronic Obstructive Lung Diseases
KSH	Kenyan Shilling
NO_x	Oxides of Nitrogen
O_2	Oxygen
OR	Odds Ratio
PEFR	Peak Expiratory Flow Rate
PM	Particulate Matter
RESPIRE	The Randomized Exposure Study of Pollution Indoors and Respiratory Effects
SO_x	Oxides of Sulfur
TDT	Thermal Desorption Tube
TP	Tubular Plastic
UN	United Nations
UNDP	United Nations Development Programme
UPEI	University of Prince Edward Island
US	United States
VOC	Volatile Organic Compound
WDL	Wakulima Dairy Limited
WHO	World Health Organization
WS	Wood Smoke

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Air quality is a major problem affecting the health of billions of people all over the world(1). Outdoor air pollution has been a main feature in the media recently, with the increased public concern for health problems associated with environmental damage. In North America, the concern about indoor air quality is less widely discussed and is mainly related to tobacco smoke exposure(2). However, exposure to indoor air pollutants in developing countries is primarily a function of biomass combustion for heat and cooking and is often less recognized as a large public health concern.

The majority of women living on smallholder farms in rural Kenya use solid fuels, primarily wood, for cooking. The cookhouses in which they work are usually separate from the primary house structure and are poorly ventilated. Consequently women, and children in their care, are exposed to elevated amounts of toxins and respirable particles released from the inefficient combustion of wood. Negative health outcomes, such as pneumonia, lung cancer, chronic obstructive pulmonary disease (COPD), acute respiratory infections (ARIs) and cataracts, have been associated with elevated exposure to wood smoke(3-5). Reducing wood smoke exposure levels has been shown to decrease negative health outcomes for both women and children in their care(6-9).

Improving stove quality and improving ventilation of the smoke generated (e.g. installation of a chimney) are both ways to decrease exposure to wood smoke(10). One technology that has not been evaluated well for reducing wood smoke exposure is the use of biogas digesters. Biogas digesters convert cow manure, or other organic compounds, into methane gas for cooking and consequently reduce the amount of wood consumed as fuel(11).

The aim of this study was to assess the health and quality of life benefits that arise from installing biogas digesters that reduce the need for wood as fuel, on rural Kenyan smallholder dairy farms. To do so, we used portable air samplers to analyze and compare the volatile organic compound (VOC) exposure in the cookhouses of farms with and without biogas digesters. Basic respiratory function tests and survey information were also used to compare wood utilization and the respiratory health of women on farms with and without digesters, as well as to compare changes in self-perceived health after the installation of a biogas digester.

This study was conducted in collaboration with Farmers Helping Farmers (FHF), a not-for-profit organization based in Prince Edward Island whose principal mandate is to help African farmers become more self-reliant in agricultural food production. Over the past 30 years the organization has participated in more than 100 projects in Tanzania and Kenya. One of the organization's largest endeavors was the partnership with the Wakulima Dairy Limited (WDL). This company started out as a cooperative self-help group of 35 farmer members in 1993, and has grown to become an incorporated company to which more than 8000 smallholder dairy farmers in central Kenya hold membership. In 2008 and 2009, the WDL and FHF group installed biogas digesters on 31 of the member farms in an effort to demonstrate the reduction of wood consumption, negative environmental practices and human exposure to wood smoke(12). The member farms of the WDL served as the study population for this research project.

1.2 OBJECTIVES

The goal of this research project was to assess the health and quality of life benefits for women of installing biogas digesters – used to reduce the need for, and dependence on, traditional wood-burning stoves – on rural Kenyan smallholder dairy farms.

The four main objectives of this study were:

(a) to compare wood consumption and time spent collecting wood for women in rural Kenyan homes with and without a biogas digester;

(b) to compare exposure to smoke and its toxic volatile organic compounds for women in rural Kenyan homes with and without a biogas digester;

(c) to compare respiratory function in women in rural Kenyan homes with and without a biogas digester; and

(d) to assess self-perceived respiratory function and quality of life in women in rural Kenyan homes with and without a biogas digesters.

Until this point, there have been no scientific studies conducted to evaluate the benefits of reducing wood smoke exposure through the installation and utilization of biogas digesters. This research project took advantage of the opportunity to collect data from a group of women living on smallholder dairy farms that have received biogas digesters from the FHF organization in order to determine the benefits attributable to the use of this technology. For the scope of this study, the health and quality of life benefits were assessed for women but not children.

1.3 Review of Literature

1.3.1 Background

The combustion of solid biomass fuels constitute the primary source for domestic energy needs, such as cooking, light, and warmth, for more than 50% of the world's population(13). Of those people relying on solid biomass fuels, a large disparity exists between affluent urban families and poorer rural families – up to 90% of all rural households in developing countries rely on solid biomass for domestic energy production(13). The use of solid biomass fuels produces emissions of harmful particulate matter and VOCs that cause indoor air pollution levels well exceeding national and international standards for safe exposure(14).

The World Health Organization (WHO) estimated in 1997 that as many as 2.2 to 2.5 million deaths annually result from indoor air pollution in developing countries(15). This equates to approximately one death every 20 seconds. The percentage of global burden of disease that is attributable to indoor air pollution was estimated to be 2.6% to 4%, with nearly all of that arising in developing countries(16,17). The issue of disease burden and poor quality of life from indoor air pollution is becoming increasingly recognized among developing nations, however, solutions to mitigate this problem are not developing fast enough(18).

In rural Kenyan cookhouses, women generally cook using a three-stone fire, which is a form of open combustion stove. Open combustion stoves are commonly made with three large stones that are arranged in a triangle, to support pots and cookware, while the wood fuel is burned in between the stones. These are the cheapest form of cooking stove available and are used predominantly in developing countries(10). This method of burning wood is inefficient and smoky, and consequently, the women, and any children in their care, are directly exposed to the wood smoke for extended periods of time while cooking. In previous work by the FHF organization, it was established that approximately 74% (of 111 families surveyed) have no means of smoke reduction (i.e. no chimney, no hood, no ventilated ceiling) in their cookhouses(19).

1.3.2 Wood Smoke Exposure

Biomass fuels can include wood, animal dung, and agricultural waste. The combustion of such fuels results in the release of VOCs and respirable particles that can cause significant negative health outcomes to people directly exposed to the smoke(17,20,21).

Solid biomass fuels are organic compounds with an abundance of vegetable protein and carbohydrates, including elements such as carbon, nitrogen, oxygen and hydrogen. The combustion of such fuels generates toxic compounds along with respirable particles, both of which can be hazardous to humans. The compounds produced in the largest amounts and of most significance to negative health outcomes are respirable particles, oxides of sulfur (SO_x), oxides of nitrogen (NO_x), hydrocarbons, benzene, carbonyls (including formaldehyde) and carbon monoxide (CO)(10,22). Respirable particles are often referred to as particulate matter (PM) and are classified based on their median aerodynamic diameter. The two most important classes for respiratory health are PM_{10} and $PM_{2.5}$. PM_{10} refer to particles suspended in the air with a median aerodynamic diameter of less than 10 microns (μm) while $PM_{2.5}$ refer to particles with a diameter of less than 2.5 μm. The particle size fraction between 2.5 μm and 10 μm is referred to as the coarse fraction and is mostly occupied by PM from natural sources such as wind-blown soil, sand, and sea salt. $PM_{2.5}$ is more dangerous to respiratory health than PM_{10} because the particles can penetrate deep into the lungs upon inhalation, while PM_{10} particles generally remain in the upper airway(23,24). Both particle sizes can however, cause serious respiratory illness(25-27).

The exposure to indoor air pollutants is related to both the amount of time spent in an area and the pollutant concentration in the area. Air quality monitoring can act as a suitable proxy for individual exposure, and can be most accurate if associated with activity time sheets that provide the amount of potential exposure time(28).

Passive air samplers offer a cheap, practical method for assessing air quality in outdoor spaces, indoor areas, and personal exposure monitoring for environmental epidemiological studies(29). Passive samplers require no power source, can be transported long distances, and require little training to operate. Simply remove the airtight seal from the passive sampler at the start of sampling and re-attach it at the end of sampling. The only other requirement in order to calculate the average concentration of the air quality metric being measured is the duration of sampling(30,31).

Evidence exists that exposure to indoor particulate matter, in many parts of Kenya, well exceeds international safe exposure guidelines. Studies conducted in the Kajiado and Western areas of Kenya measured the mean 24-hour exposure levels of respirable particles to be 5526 $\mu g/m^3$ and 1713 $\mu g/m^3$, respectively. These levels are more than 10 times greater than the safety guidelines established by the US Environmental Protection Agency (EPA). According to the EPA, levels of safe exposure are estimated to be 150 $\mu g/m^3$ in a 24-hour period (not to be exceeded more than 2% of the time)(22,32). A similar Kenyan project found that the average 24-hour exposure to respirable suspended particles, resulting from using biomass as fuel for cooking in kitchens, was 1400 mg/m^3, with peak exposures exceeding 3600 mg/m^3 (33). The World Energy Assessment, a joint publication of the United Nations Development Programme (UNDP), the UN Department for Economic & Social Affairs, and the World Energy Council, found that burning 1 kg of wood per hour produced emissions of 3.3 mg/m^3 of particles (allowable standard is 0.1 mg/m^3), 0.8 mg/m^3 of benzene (allowable standard is 0.002 mg/m^3), 150 mg/m^3 of CO (allowable standard is 10 mg/m^3) and 0.7 mg/m^3 of formaldehyde (allowable standard 0.1 mg/m^3)(34).

It is clear that combustion of biomass for fuel, in Kenya, produces amounts of respirable particles that well exceed the safe amounts for human exposure, and that mechanisms for reducing the exposure to wood smoke are essential for improving the quality of life of many people. There is, however, little scientific knowledge about the VOC exposure concentrations created during the combustion of biomass fuel in Kenyan cookhouses. In order to determine the need for an intervention and the impact it could have, it is important to accurately quantify toxin exposure levels at the individual, community, and national level(35).

1.3.3 Negative Health Outcomes and Respiratory Function

The exposure to indoor air pollution has many documented negative effects on the health of people, particularly on women and children who typically spend more of their time in the indoor environment. Researched health problems range from eye problems and headaches to respiratory problems and cardiovascular problems that can lead to premature loss of life. The exposure to high levels of indoor air pollution has been attributed to health outcomes such as COPD, respiratory infections, asthma, pneumonia, tuberculosis, cataracts, headaches, high blood pressure and chronic bronchitis(4,5,17,20,21,36).

The WHO report by Bruce et al. in 2002 summarizes the health outcomes associated with these toxic wood smoke products. Inhalation of PM can contribute to wheezing in asthma and the incidence of COPD, respiratory infections and chronic bronchitis. These particles cause bronchial irritation and inflammation, and reduce the macrophage response, all of which can contribute to increased susceptibility to microbial infections. Carbon monoxide exposure can cause low birth weight in infants, as well as increase perinatal death, as insufficient amounts of oxygen are being delivered to the developing fetus. Formaldehyde is a known carcinogen, and benzene causes mucous coagulation and cilia toxicity. Finally, inhalation of nitrogen and sulfur dioxide has been attributed to exacerbating asthma and COPD, as well as contributing to ARIs(13,25). Also included are headaches, cataracts, and reduced lung function in children(7,37).

A meta-analysis of evidence conducted by Smith et al. in 2004 identified that the strongest evidence for negative health outcomes that exists due to wood smoke exposure is for women greater than 15 years old. Studies conducted in Asia, and South and Central America indicate that in this group, the relative risk of developing COPD, because of the use of solid fuels for cooking, was 3.2 (95% CI 2.3, 4.8) compared to control women who did not use solid fuels for cooking. The analysis also found strong evidence for the incidence of acute lower respiratory infection in children less than 5 years of age. Studies conducted in South America, Asia, and Africa indicate that the relative risk was 2.3 (95% CI 1.9, 2.7) in children exposed to the use of solid fuels for cooking, compared to controls(38).

The evidence that supports exposure to wood smoke as an important risk factor for asthma symptoms and pneumonia in children is inconclusive at this time(36). Similarly, there is only suggestive evidence for other health outcomes being caused by the use of wood for cooking, such as eye problems, headache, back pain(4,7), chronic bronchitis(39) and cardiovascular problems(9). It is difficult to accurately measure exposure and health outcomes in rural, developing countries where access to sophisticated health services, diagnostic equipment, and laboratories may be limited. Self-reporting for health problems is often heavily relied on in this kind of investigation, but can lead to problems with reporter (recall) bias and misclassification bias due to a lack of understanding of health symptoms. Also, it is often difficult to tease out relationships between exposure to indoor air pollution and health because of confounders such as co-morbidities and poor nutrition.

One method of empirically evaluating lung function is to perform spirometry on those people exposed to elevated amounts of indoor air pollution. Common measures resulting from spirometry testing are: (1) forced vital capacity (FVC), the maximum volume of air that can be forcibly exhaled in one breath (measured in liters); (2) forced expiratory volume in 1 second (FEV_1), the volume of air forcibly exhaled in the first second of exhalation (measured in liters); (3) forced expiratory flow (FEF), the speed of air coming out of the lung during the middle portion of a forced expiration (measured in liters/second); and (4) peak expiratory flow rate (PEFR), the maximal speed (flow) achieved during a forced expiration (measured in liters/minute). For all of these measures, individual values are compared to predicted values for a population of similar age, sex, height, weight, and ethnicity in order to generate percent-predicted values for the individuals. The most important measures for obstruction in lung function are FEV_1 and the ratio of FEV_1/FVC. FEV_1 should be $\geq$80% predicted and the fraction of FEV_1/FVC should not be <0.7(40).

1.3.4 Strategies to Reduce Wood Smoke Exposure

There are two main strategies that can be employed to reduce the effects of indoor air pollution. Families and communities can be encouraged to use cleaner burning fuels, or safer and more efficient systems for burning fuel can be installed to reduce exposure to wood smoke(16).

There are a variety of fuels that burn cleaner than biomass, and produce fewer harmful emissions. Fuels increase in cleanliness from dung, crops, and wood to charcoal, to coal and kerosene, to liquid petroleum gas and natural gas, and finally to electricity. However, as these energy sources increase in cleanliness, they also increase in cost(41). Few people who rely on biomass fuels have funds to afford cleaner burning fuels. Consequently, the best option to lessen indoor air pollution immediately is to reduce the production of and exposure to wood smoke.

The majority of studies that have investigated the benefits of reducing wood smoke exposure in rural houses have focused on installing improved stoves or ventilation systems in the homes. Examples of improved stoves used in parts of Central America are the Patsari or plancha stove. These are similarly designed closed combustion stoves, with flues that ventilate wood smoke from the building. The stoves were designed to provide affordable alternatives to traditional stoves, which also meet the cooking practices of local populations. Bricks surround a closed combustion chamber, with a small metal door in the front to add wood for fuel. Cooking surfaces are integrated into the top of the stove and a flue ventilates smoke to the exterior of the house. These stoves reduce the amount of wood smoke exposure among family members and reduce the amount of wood consumed for cooking(9,42).

A large (n=800) randomized control trial for improved stove intervention, to reduce wood smoke exposure and negative health outcomes in women and children, was conducted from October 2002 to December 2004 in the Guatemalan highlands. The Randomized Exposure Study of Pollution Indoors and Respiratory Effects (RESPIRE) study compared the use of traditional wood burning stoves with the improved plancha stove(35). The study produced many clinically and statistically significant results regarding women and children's health and exposure levels. Passive diffusion tubes were used to measure CO levels, at baseline and post-intervention, in the kitchens of intervention and control groups, as well as the exposure levels of the women and children in the study. The implementation of the intervention stove significantly reduced women's CO exposure by 60%, children's exposure by 50%, and kitchen CO levels by 90%(35).

Questionnaires to assess eye discomfort, headache and back pain were administered to 504 women from both the intervention and control groups of the RESPIRE study. The questionnaires were administered to both groups of women at baseline and then again at 6, 12 and 18 months post-intervention. Differences in all the self-reported ailments were reported at all follow-up times. The odds of having sore eyes and headache were substantially reduced for the intervention group compared to the control group (OR=0.18 and 0.63, respectively)(7). The questionnaires administered to the women at baseline, and every 6 months for follow-up also evaluated respiratory symptoms of women. Questions included in the questionnaire assessed cough, wheeze, phlegm, and chest tightness. Standard COPD and asthma questions were also included in the survey and all the women's lung function was tested using spirometry techniques. The investigators found that the plancha stove intervention had a protective effect on all self-reported symptoms, however the only statistically significant result was for wheeze. They also found that there was no significant difference in FVC between the intervention and control groups(8).

Another study that was conducted in Mexico compared the type of fuel used with respect to respiratory health and lung function among exposed women. This group found that cooking with gas, a cleaner burning fuel, was significantly protective for self-reported wheeze and phlegm problems and that FVC was slightly decreased in women who were using biomass for fuel(43).

Finally, the RESPIRE project also collected data on the self-perceived changes in the health of women and children in both the intervention and control groups. Of the women who received the intervention, more than 50% reported improvements in health. Of the women that reported health improvements, 88% of them attributed the improvements to the reduction in wood smoke. Fifty-seven percent of these women also attributed the reduction in smoke to improvements in the health of their children(6).

Evidence exists that reducing indoor air pollution, primarily through the reduction of wood smoke exposure, has beneficial impacts on the health and quality of life of women and children living in rural developing countries. Based on this evidence, investigating other technologies to reduce wood smoke exposure in similar settings will be important in addressing this health and quality of life issue.

1.3.5 Biogas Digesters

Biogas digesters anaerobically decompose organic material, such as livestock waste, to generate gas to be used for cooking and to produce safe, high quality compost that can be used as fertilizer. The principal gas produced is methane, the primary constituent of natural gas, with small amounts of ammonia, hydrogen sulfide, and carbon dioxide (CO_2) also produced. The decomposition of livestock waste produces high methane content (70%) gas, which burns cleanly and at high temperatures(11).

There are different types of biogas digesters, including the float-drum, fixed dome and tubular plastic (TP) types. All types of digesters work on the same principle but differ greatly in cost; the TP digester installation costs only 10% of the other two kinds of digester(11).

The tubular plastic type of digester is what was installed on the Kenyan dairy farms in 2008 and 2009. These are long tubes of black plastic that have ports at each end. Manure and water are added at the input end and the decomposed compost is removed from the output end. As the manure is digested, methane is produced, which exits the biogas digester by a hose that is connected to a burner in the cookhouse. Typically, the digesters work best at higher ambient temperatures when the black plastic is heated up and the manure decomposes at a faster rate, generating more methane. For a family of four, with two cows fueling this type of biogas digester, it is suggested that enough methane is generated to reduce wood fuel consumption by approximately 40%(11).

The benefits attributable to installing biogas digesters include: 1) the production of a cheap, alternative source of energy, which leads to less wood burning, a reduction in wood smoke exposure, a reduction in deforestation, and a reduction in time spent searching for and collecting wood for fuel; 2) the generation of a safe, high nutrient content fertilizer; and 3) the conversion of methane, a greenhouse gas that absorbs much more infrared radiation per molecule relative to CO_2, into the combustion products water and CO_2 which contributes to the reduction of harmful greenhouse gas emissions(11,44). However, quantification of these benefits in a scientific manner for biogas digesters in Kenya has been limited.

Although biogas digester technology is more than 30 years old, it has not been widely adopted because little has been done to evaluate the health and quality of life benefits of installing this technology on smallholder farms(11,12).

CHAPTER 2: WOOD CONSUMPTION DATA

2.1 Abstract

The majority of women living on dairy farms in rural Kenya rely on solid biomass fuels, primarily wood, for cooking. Consequently, these women spend large amounts of time searching for and collecting wood for fuel. Biogas digesters anaerobically convert livestock manure into methane for cooking – potentially reducing the reliance on wood as fuel. The objective of this study was to assess the benefits of installing biogas digesters on rural Kenyan dairy farms. A total of 62 farms (31 biogas, 31 referent) participated in interviews to determine reliance on wood as fuel and the impact of biogas digesters on this reliance. The measured amount of wood consumed (lbs/day), self-reported time spent collecting wood (min/week), and self-reported money spent on fuel (KSH/week) were significantly lower ($p<0.01$) for the biogas group, compared to the referent group as well as when comparing before and after the installation of digesters among the biogas group members. Multivariable linear regression analysis showed that current wood consumption increased by 2 lbs/day for each additional family member, and having a biogas digester was associated with reduced wood consumption by 3 lbs/day for each cow that a family had. Biogas digesters are one technology that can reduce reliance on wood as fuel and improve quality of life for rural Kenyan dairy farmers.

2.2 Introduction

Of the 6.8 billion people living in the world, it has been estimated that more than 50% rely on the combustion of solid biomass fuels (e.g. wood) for domestic energy needs, such as cooking, light, and warmth(13). There is also a large disparity in the use of biomass fuels between affluent urban families and poorer rural families. Up to 90% of all rural households in developing countries rely on solid biomass fuels for domestic energy production(13). It has been estimated that in Sub-Saharan African countries, more than 70% of the entire population relies on wood as fuel(45).

A large proportion of the population living in rural Kenya relies on wood as fuel. The women generally cook using a three-stone fire, which is a form of open combustion stove. Open combustion stoves are commonly made with three large stones that are arranged in a triangle, to support pots and cookware, while the wood fuel is burned in between the stones. These are the cheapest form of cooking stove available, but they are inefficient for burning wood, and are used predominantly in developing countries(10).

There are two strategies that can be employed to reduce the consumption of wood as fuel. Families and communities can be encouraged to use alternative fuel sources, or safer and more efficient systems for burning wood can be implemented(16). Biogas digesters, as an example of an alternative fuel source, anaerobically decompose organic material, such as livestock waste, to generate gas to be used for cooking, and to produce safe, high quality compost that can be used as fertilizer. The principal gas produced is methane, the primary constituent of natural gas, with small amounts of ammonia, hydrogen sulfide, and carbon dioxide also produced. The decomposition of livestock waste produces high methane content (70%) gas, which burns cleanly and at high temperatures(11). There are different types of biogas digesters, including the float-drum, fixed dome and tubular plastic (TP) types. All types of digesters work on the same principle but differ greatly in cost; the TP digester installation costs only 10% of the other two kinds of digester(11). The tubular plastic type of digester is what was installed on some rural Kenyan dairy farms in 2008 and 2009. These are long tubes of black plastic that have ports at each end. Manure and water are added at the input end and the decomposed compost is removed from the output end. As the manure is digested, methane is produced, which exits the biogas digester by a hose that is connected to a burner in the cookhouse. Typically, the digesters work best in warm ambient temperatures when the black plastic is heated up and the manure decomposes at a faster rate, generating more methane. For a family of four, with two cows fueling this type of biogas digester, it is suggested that enough methane is generated to reduce wood fuel consumption by approximately 40%(11).

The benefits attributable to installing biogas digesters include: 1) the production of a cheap, alternative source of energy, which leads to less wood-burning, a reduction in wood smoke exposure, a reduction in deforestation, and a reduction in time spent searching for and collecting wood for fuel; 2) the generation of a safe, high nutrient content fertilizer; and 3) the conversion of methane, a greenhouse gas that absorbs much more infrared radiation per molecule relative to carbon dioxide (CO_2), into the combustion products water and CO_2, which contribute to reducing harmful greenhouse gas emissions(11,44). However, quantification of these benefits in a scientific manner for biogas digesters in rural Kenya has been limited.

The descriptive objectives of the study were to compare wood consumption, money spent on fuel, and time spent collecting wood: 1) between biogas and non-biogas farms; 2) before and after the installation of the biogas digesters; and 3) between warm and cool ambient temperature conditions, to understand seasonal variation in these factors for farms with biogas digesters. The analytical objectives were to determine the factors associated with the amount of wood consumed on Kenyan smallholder dairy farms, and the factors associated with self-reported back pain by Kenyan farmwomen.

2.3 METHODS

2.3.1 Study Population

All participants included in the study lived on member dairy farms of Wakulima Dairy Limited (WDL), located in the Mukurwe-ini area of central Kenya. There were 31 farms identified with biogas digesters installed recently (with assistance from a non-governmental organization called Farmers Helping Farmers (FHF) – "biogas" farms) and 31 referent farms without biogas digesters, matched to the biogas farms based on age of the participant, family size, and number of cows. The referent farms were selected using a chain referral sampling method(46). In this method, the study sample is created through referrals made among people who know others who possess the 'characteristics of research interest'(47). A list of non-biogas digester farms was created by referral from farms with digesters. A non-biogas digester farm was randomly selected from the created list for participation in the survey; in the event a non-biogas digester farm chose not to participate in the survey, the next family on the list was approached.

2.3.2 Data Collection

Data collection took place in February 2010 and again in June and July 2010. At each phase of data collection, participants in the biogas farms completed a survey on self-perceived health and quality of life. Measures of cookhouse size (m^3) and wood consumption (lbs/day) were also collected for each farm at both phases of data collection. To measure wood consumption, each woman was asked to make a pile containing the amount of firewood she used in an average day. The wood was then weighed with a hand held scale. The repeat measures (February and June/July) for the biogas farms were taken to investigate seasonal variation in wood consumption potentially due to changes in methane production. The referent farms completed a similar health and quality of life survey in the second phase of data collection (June/July) only. Measures of cookhouse size and wood consumption were also taken for referent farms.

For logistics reasons, referent farms could not be visited in February 2010. Also, two biogas farms did not participate in the study after the February data collection and were replaced for the June/July collection with WDL member dairy farms that recently had biogas digesters installed.

A 43-question survey (Appendix A) was administered in Kikuyu (local language), through a translator, to study participants with biogas digesters in February and to all study participants in June/July. The questionnaire was designed to collect information on self-reported wood consumption, money spent on fuel, time spent collecting wood for fuel, historical and current health, as well as quality of life indicators. Survey information on whether the participants currently had a diagnosed (by a physician) back problem and whether or not they experienced back pain during the last 6 months was gathered for all participants. There were 10 questions specifically related to biogas digesters that were omitted from the referent farm surveys. This paper focuses on the survey questions involving wood utilization, and self-reported back pain.

2.3.3 Data Analysis

Basic descriptive analyses were conducted for each variable, and normality was assessed graphically and using the Shapiro-Wilk test(48). For descriptive statistics, square-root transformations were applied to variables, in some cases, to achieve a normal distribution. Standard paired (between time points among biogas farms) and unpaired (between biogas and referent farms) t-tests, testing for equal variance according to Levene's test (continuous data), and chi-square tests (categorical data) were used to compare survey and measured variables.

Multivariable linear and logistic regression models were used to determine the important predictors of wood consumption and self-reported back pain for the participants. Univariable analyses were first conducted, and variables were retained for model building if $p \leq 0.2$. Following univariable analysis, potential explanatory variables were tested for collinearity using Pearson correlation coefficients for continuous variables, chi-square tests for dichotomous variables, and two sample t-tests for continuous variables with dichotomous variables. A possible causal diagram was also created for the potential explanatory variables to avoid the inclusion of intervening variables during the model building process(49). Forward selection was used to determine the main predictors in the models. Variables were initially included in the model building process at a significance level of $p \leq 0.1$. Intervening variables (e.g. time spent collecting wood) were then removed and only main effects were retained in the final model at a significance level of $p \leq 0.05$. The final model generated was compared to an automated stepwise model building process (variable entry at $p \leq 0.05$), which generated the same model. Potential interactions of main effects were also assessed through forward selection with a $p \leq 0.05$.

Linearity between continuous predictor variables and wood consumption was assessed using a scatter plot of the variable and outcome, with a Lowess smoother line fitted to the plot. Quadratic terms of the predictor variables were added to the model to test for significance, if necessary. Scatter plots of the standardized residuals and predictor variables were also generated to test goodness-of-fit. Constant variance was assessed using the Cook-Weisberg test for heteroscedasticity. Influential observations, for all models, were identified using Cooke's distance.

All data were analyzed using Stata/IC 11.1 for Mac (StataCorp 4905 Lakeway Drive, College Station, Texas, 77845, USA).

2.4 RESULTS

2.4.1 Population Characteristics

Table 2.1 indicates the summary characteristics for each participant group. The women participating in the study ranged in age from 22 to 72 years; the mean age was 45 years for women on farms with biogas digesters and 44 years for women on referent farms. There were no differences in age between the biogas and referent groups. There were also no significant differences between the family size and number of cows per farm. The two participant groups also did not significantly differ in education level, employment, or smoking status. The group of participants with biogas digesters was more likely to have an employed husband than the referent group but the difference was not statistically significant. Women on the referent farm were more likely to report having back pain in the last 6 months, compared to women with biogas digesters ($p<0.01$).

Table 2.1. Population characteristics for women participants living on farms with and without biogas digesters, June data.

Variable	Biogas farms n=31			Referent farms n=31		
	Mean (95% CI)	Median	Range	Mean (95% CI)	Median	Range
Age[1]	45 (42, 49)	45	22, 63	44 (40, 48)	44	24, 72
Number of cows[2]	3.7 (3.0, 4.4)	3	2, 12	3.3 (2.7, 4.1)	3	1, 10
Family size[1]	3.5 (2.9, 4.2)	3	1, 7	3.9 (3.3, 4.5)	3	1, 8

	Percent (number) n=31	Percent (number) n=31
Education[3]		
None	6 (2)	10 (3)
Standard 4	13 (4)	6 (2)
Standard 8	48 (15)	61 (19)
Form 4	19 (6)	19 (6)
Technical college	13 (4)	3 (1)
Employed[3]	39 (12)	35 (11)
Married[3]	74 (23)	84 (26)
Husband employed[3]	74 (17)[§]	50 (13)[±]
Smoker[3]	3 (1)	0 (0)
Self-reported back pain*[3]	39 (12)	71 (22)

1 parametric test performed on raw (normally distributed) data
2 parametric test performed on square root transformed data; means, 95% CIs, medians & ranges presented were back-transformed
3 categorical test performed on raw data
* $p \leq 0.01$
[§] n=23; [±] n=26
CI: confidence interval

2.4.2 Wood Consumption and Collection

The group of participants without biogas digesters consumed 79% more wood per day, on average, compared to the group with biogas digesters. The referent group also spent 2.9 times more time collecting wood and spent 3.4 times more money purchasing wood as fuel, on average, compared to the group of participants with biogas digesters (Table 2.2). There was no significant difference in the proportion of participants that spent money on other fuels (e.g. charcoal, liquid petroleum gas) between the two groups (biogas group, 10%; referent group, 19%).

Table 2.2. Comparison of wood consumption and other measures between biogas and referent farms, June data.

Variable	Biogas farms n=31			Referent farms n=31			p value
	Mean (95% CI)	Median	Range	Mean (95% CI)	Median	Range	
Wood consumption (lbs/day)[1]	14 (9, 19)	13	0, 48	25 (21, 31)	23	9, 57	<0.01
Time spent collecting wood (min/week)[1]	57 (18, 117)	30	0, 1440	166 (95, 253)	150	0, 1260	0.02
Money spent on wood (KSH/week)[1]	112 (59, 185)	100	0, 1500	384 (286, 511)	300	27, 1500	<0.01
	Percent (number) n=31			Percent (number) n=31			
Purchased other fuels[2]	10 (3)			19 (6)			0.28

1 parametric test performed on square-root transformed data; means, 95% CIs, medians & ranges presented were back-transformed
2 categorical test performed on raw data
CI: confidence interval; KSH: Kenyan shilling

Among the farms with biogas digesters there was a significant difference in time spent collecting wood, as well as money spent on wood as fuel, before and after the biogas installation. Participants reported, on average, an 83% reduction in time spent collecting wood and 75% reduction in money spent on wood, after the installation of biogas digesters. There was no significant difference in the proportion of participants than spent money on other fuels (Table 2.3).

Table 2.3. Comparison of time spent collecting wood and funds spent on fuel before and after the installation of biogas digesters for biogas farms, June data.

Variable	After biogas installation n=30			Before biogas installation n=30			p value
	Mean (95% CI)	Median	Range	Mean (95% CI)	Median	Range	
Time spent collecting wood (min/week)[1]	42 (15, 85)	30	0, 1050	243 (132, 388)	270	0, 2100	<0.01
Money spent on wood (KSH/week)[1]	94 (54, 144)	100	0, 500	372 (282, 475)	300	71, 1500	<0.01
	Percent (number) n=30			Percent (number) n=30			
Purchased other fuels[2]	10 (3)			50 (15)			0.07

1 parametric test performed on square-root transformed data; means, 95% CIs, medians & ranges presented were back-transformed
2 categorical test performed on raw data
CI: confidence interval; KSH: Kenyan shilling

The potential effects of seasonal variability in fuel use, for farms with biogas digesters, were investigated. The comparisons show that there were no significant differences (p>0.2) in wood consumption, time spent collecting wood or money spent on fuel between February and June (data not shown). Numerically, on average, biogas farms spent 20% more money on wood in June (186 KSH/week) than in February (155 KSH/week), and spent 18% more time collecting wood in June (139 min/week) than in February (118 min/week). Measured wood consumption was slightly higher in February than in June, which was likely a function of a few farms using substantially more wood in February than in June.

There was no difference in the self-reported time spent collecting wood, or money spent on wood as fuel, between farms with biogas digesters (before the installation) and referent farms currently (data not shown). Numerically, on average, the biogas group reported spending 55% more time collecting wood before the installation (362 min/week) compared to the referent group currently (233 min/week). The biogas group also reported spending 8% less money on wood as fuel before the installation (415 KSH/week) than the referent group currently (450 KSH/week). However, participants on biogas farms reported spending money on other fuels before the installation of the biogas digester (50% spent money on other fuels) significantly more often than referent participants reported (19% spent money on other fuels) at the time of data collection (p=0.01).

The results from the univariable regression model of wood consumption are presented in Table 2.4 and the results from the multivariable linear regression model of wood consumption are presented in Table 2.5. The multivariable model includes the following predictors: biogas farm status, the number of people living on the farm, and the number of cows on the farm, as well as the interaction term between biogas farm status and the number of cows (R^2=0.40).

Table 2.4. Univariable linear regression model of wood consumption (lbs/day – outcome), using June data (n=62 farms).

Variable	Coefficient	Standard error	95% CI	P value
Age	0.13	0.16	-0.20, 0.46	0.44
Family size	1.87	1.03	-0.18, 3.92	0.07
Biogas farm status	-10.6		-17.1, -4.04	<0.01
Number of cows	9.3	3.41	2.49, 16.2	0.01
Time collecting wood (min/week)	0.51	0.19	0.14, 0.88	0.02
Cookhouse size (m^3)	0.13	0.25	-0.37, 0.63	0.60
Education				1.00
no formal education	reference	reference	reference	reference
standard 4	-1.14	8.64	-18.4, 16.2	0.90
standard 8	1.02	6.83	-12.7, 14.7	0.88
form 4	1.56	7.59	-13.6, 16.8	0.84
technical college	-0.16	9.02	-18.2, 17.9	0.99
Employment	3.63	3.63	-3.62, 10.9	0.32
Husband employment	-5.92	4.25	-14.5, 2.62	0.17
Condition of wood (wet/dry)	-7.53	13.6	-34.8, 19.8	0.58
Other fuel use	4.40	5.24	-6.09, 14.9	0.41

CI: confidence interval

Table 2.5. Multivariable linear regression model of wood consumption (lbs/day – outcome), using June data (n=62 farms).

Variable	Coefficient	Standard error	95% CI	P value
Family size	2.00	0.85	0.30, 3.69	0.02
Biogas farm status	1.84	5.76	-9.71, 13.4	0.75
Number of cows	4.35	0.98	2.38, 6.31	<0.01
Biogas farm status*number of cows	-3.34	1.33	-6.02, -0.67	0.02
Constant	3.53	5.42	-7.32, 14.4	0.52

CI: confidence interval

With the significant interaction variable between biogas farm status and cow number, the interpretation of the two variables depend on the value of the other variable, and therefore the coefficients of the main effect variables in Table 2.5 should not be interpreted in isolation. Figure 2.1 represents the effect of the number of cows on wood consumption for both biogas and referent farms. As the number of cows a family had increased, wood consumption increased, but this association was much weaker for farms with biogas digesters compared to referent farms. Specifically, for an average family of 3 people, an addition of one cow causes wood consumption to increase by 1.0 lbs/day on biogas farms but by 4.4 lbs/day on referent farms. There was also, not unexpectedly, an increase in wood consumption by 2 lbs of wood per person per day, as the number of people living on the farm increased, controlling for all other factors in the model. An average family of 3 people, with 3 cows will consume, on average, 14.5 lbs/day of wood if they have a biogas digester and 22.6 lbs/day if they don't have a biogas digester.

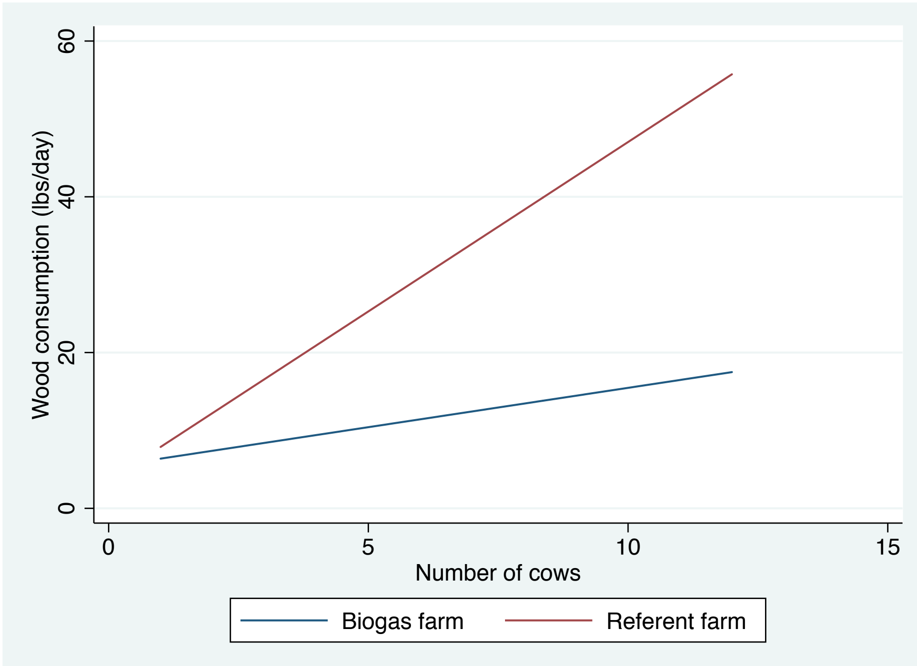

Figure 2.1. Graph of the outcome (wood consumption) for different numbers of cows, by biogas digester status (biogas or referent).

The final model was tested for linear regression model assumptions. A histogram of the standardized residuals and a quantile-quantile plot were used to assess normality. The Cook-Weisberg test showed no violation of heteroscedasticity and all potentially influential observations or outliers were assessed using Cooke's distance, with no important observations being identified (modified Cook's distance=8.87).

2.4.2 Self-Reported Back Pain

During the individual interviews, participants also answered questions on self-reported health. Participants in the referent group reported having back pain, some time in the last 6 months, more often than the biogas group (71% versus 39%, respectively) (Table 2.1). The multivariable logistic regression modeling was not able to determine a model with more than one significant predictor of self-reported back pain for the farmwomen.

Consequently only the crude, univariable associations between self-reported back pain and the predictors are presented (Table 2.6).

Table 2.6. Univariable logistic regression model for self-reported back pain among Kenyan farmwomen, June data (n=62 participants).

Variable		Coefficient	Standard error	95% CI	P value
Biogas farm status		-1.4	0.54	-2.4, -0.29	0.01
Age		0.02	0.02	-0.03, 0.07	0.46
Family size		0.16	0.16	-0.14, 0.47	0.30
Number of cows		-0.19	0.13	-0.45, 0.07	0.15
Education					0.30
	≤standard 4	reference	reference	reference	reference
	standard 8	-1.10	0.76	-2.59, 0.39	0.15
	>standard 8	-0.62	0.84	-2.27, 1.02	0.46
Milk income					
	<5000 KSH/mo	reference	reference	reference	reference
	≥5000 KSH/mo	-0.30	0.53	-1.35, 0.74	0.57
Employment		-0.45	0.53	-1.49, 0.59	0.40
Husband employment		0.05	0.63	-1.18, 1.28	0.94
Wood consumption (lbs/day)		0.03	0.02	-0.01, 0.07	0.15
Time collecting wood (min/week)		0.001	0.001	-0.001, 0.003	0.29

CI: confidence interval

According to the crude association (OR=0.26), having a biogas digester was associated with a reduction in the odds of reporting back pain by almost 75%, compared to the referent group. There were no other predictors or confounders that remained in the multivariable logistic regression model to account for the rest of the variation in back pain reporting among Kenyan farmwomen.

2.5 Discussion

Women with biogas digesters consumed significantly lower amounts of wood as fuel compared to the referent group (14 lbs/day and 25 lbs/day, respectively). The referent group also spent, on average, 2.9 times more time collecting wood (min/week) for fuel and spent 3.4 times more money on wood for fuel (KSH/week) (Table 2.2). The generation of methane from the biogas digester, which was then used as fuel for cooking explains the reduction in wood fuel use and the time collecting wood and money spent on wood. There was no difference in the proportion of participants who spent money on alternative fuels between the two groups, which is likely due to the fact that few families actually used fuels other than wood or methane (if they had a biogas digester on their farm). The women with biogas digesters also spent time cooking with wood as fuel (Table 2.2). This is likely a result of either not having enough methane to satisfy their fuel needs, thus supplementing with wood fuel use, or the use of wood for cooking certain traditional dishes, such as githeri, that could require more heat than that provided by the methane burner.

While little literature exists on wood consumption, or the impact of biogas digesters on wood consumption in developing countries, the average amount of wood consumption for referent farms (25 lbs/day or 750 lbs/month) is similar to levels of consumption in other areas, such as, Bangladesh where the average consumption of wood fuel was 760 lbs/month(50). The reduction in wood fuel consumption due to implementation of biogas digesters has been shown to cause a 40% reduction in wood energy use in families in two rural areas of China. This reduction in wood energy use was due to replacement with biogas; total energy requirements for families remained the same with and without biogas digesters(51). This result is on par with the 40% reduction in wood consumption seen in Kenyan dairy farms (Table 2.2), consequently demonstrating the similar functionality of biogas digesters in reducing reliance on wood fuel in other situations.

No important differences with respect to age, family size, and cow numbers were found between the two groups of women that participated in the study (Table 2.1), demonstrating that the matching process was effective. Further, there were no significant differences between groups in education, income, or employment of the participant or her husband, and therefore these other variables were unlikely to be confounders of any relationship between biogas farm status and wood consumption.

Since methane production in biogas digesters has been shown to be temperature dependent in some situations, the seasonal variation (February vs June/July) in wood consumption, time spent collecting wood, and money spent on fuel was compared for the group of women with biogas digesters. There were no significant differences observed in the mean wood consumption, mean time spent collecting wood, mean amount of money spent on wood as fuel, or use of alternative fuels between the February (average maximum temperature 26°C) and June/July (average maximum temperature 21°C)(52). Because it appears that the digesters function equally well in both seasons, it would appear that the effects of the biogas digesters were not being limited to the warmer period of the year, but rather apply to the entire year. A lack of statistically significant differences may also be a function of the fact that the farm locations were near the equator where they experience only small changes in hours of sunshine and temperature between February and June/July.

The before installation data for self-reported time spent collecting wood, and money spent on fuel, were also collected from the women on farms with biogas digesters (Table

2.3). The women reported spending significantly more time collecting wood and more money on wood as fuel before the installation of the biogas digester. However, there was only a borderline significant difference in the number of women that spent money on alternative fuels. More women reported spending money on alternate fuel sources before the installation of the biogas digester compared to after. One possible explanation for the decrease in alternate fuel use could be that the amount of methane produced by the biogas digesters was enough to mitigate the need for other fuels. However, the proportion of women in the referent group purchasing other fuels was lower (19%) than the biogas group prior to biogas digester installation (50%). There may be something different about the biogas farms compared to the referent farms that allowed, or required them to purchase fuel more often, prior to biogas installation, compared to the referent farms.

Self-reported data were partly used to assess the changes in wood consumption before and after biogas installation. To test the reliability of the self-reported data for before installation, the answers from the women on farms with biogas digesters about time spent collecting wood and money spent on fuel before the installation of the biogas digester were compared to the answers of the referent women. If the women with biogas digesters were answering accurately, there should have been no significant differences between the two groups. This was true for the average time spent collecting wood and money spent on wood for fuel, however, there were more women who had biogas digesters that reported spending money on other fuel sources than the referent women. This difference possibly resulted from the type of farms receiving biogas digesters. The first group of biogas digesters installed (n=12) went to more affluent farmers, according to tribal customs. It is possible that the farms spending money on alternate fuel sources were of those that had higher incomes to begin with and could afford to do so.

According to the wood consumption multivariable model (Table 2.5), there was a mean increase of approximately 2 lbs per day of wood consumption for each additional family member living on the farm, controlling for all other factors in the model. Essentially, more people living in the family means more food must be cooked, resulting in increased fuel consumption. The interaction between the cow number and biogas farm status, as represented in Figure 2.1, shows that as the number of cows on the farm increased, the effect of a biogas digester on wood consumption also increased. Since biogas digesters are fed with cow manure, more manure being supplied to the digester will result in increased methane production. Increased production of methane for fuel consequently reduced the reliance on, and consumption of, wood as fuel. Presumably, this increase in methane production, with increasing numbers of cows on the farm, would only increase to the point of maximum methane production for the biogas digester, at which point the interaction would no longer occur.

The univariable associations for reported back pain (Table 2.6) showed that the odds of reporting back pain were lower for women living on a farm with a biogas digester (crude OR =0.26) compared to the referent group. Presumably, the lower odds of reporting back pain among women with a biogas digester, versus those without a digester, were a result of the decrease in time spent carrying heavy loads of wood. The women in the referent group consumed almost 79% more wood per day and spent 2.9 times more time collecting and transporting wood per week (Table 2.2). The majority of back problems that were diagnosed were the result of continuous strain on the back from carrying heavy loads, so it is intuitive that having a back problem would be a strong indicator of back pain and that reducing the strain (by reducing the amount of time spent carrying heavy loads) would also decrease the odds of reporting back pain.

2.5.1 Limitations

One limitation to this study is the reliance on self-reported data, particularly for the period of time prior to the installation of the biogas digesters. However, researchers were able to acquire measurements of daily wood consumption, for all participants, at the time of data collection. For the quantification of the amount of time spent collecting wood and the amount of money spent on fuel, the researchers relied on self-report data from the study participants. One concern was that participants with biogas digesters would exaggerate the beneficial effects of the digesters. However, comparing the results from the questions related to before the installation of the biogas digester with the questions from the referent farms, there were no significant differences in the responses, suggesting that the women with biogas digesters were answering questions reasonably accurately. Ideally, some of the reliance on self-report data could have been avoided with a before and after evaluation of the digesters, however, this was not possible since the digesters were installed before the initiation of the study.

A second limitation of the study was the small number of farms that had biogas digesters installed on them. The study was limited to the 31 biogas farms that had biogas digesters and their referent farms (n=62). However, despite the small sample size, a highly statistically significant difference in wood consumption was found, showing that large and meaningful differences existed and could be detected.

2.5.2 Conclusions

Biogas digesters installed on rural Kenyan dairy farms are a viable option for a sustainable fuel alternative to wood. The digesters function equally well during both phases of data collection, and were associated with a reduction in wood consumption, time spent collecting wood, and the amount of money spent on wood as fuel. The digesters were also associated with a decrease in reported back pain among the participants. This alternative fuel source may not be ideal for all situations (geographic location, etc.), but it has the potential to reduce reliance on wood as fuel and improve quality of life. Further investigation into the impacts of biogas digesters in other rural areas would strengthen the evidence for their use, as would larger scale before and after studies.

CHAPTER 3: VOC DATA

3.1 Abstract

The use of solid biomass for fuel produces huge emissions of harmful respirable particulate matter and volatile organic compounds (VOCs). The majority of women living on smallholder farms in rural Kenya use wood as fuel for cooking and are consequently exposed to elevated amounts of harmful combustion products. The objective of this study was to evaluate the differences in VOC exposure for women living on farms with and without biogas digesters – a technology that reduces reliance on wood by generating methane, from livestock waste, for cooking fuel. Women living on Kenyan dairy farms (n=31 biogas farms, n=31 referent non-biogas farms) wore passive thermal desorption VOC sampling tubes for 7 days, while cooking, and recorded activity time sheets corresponding to those days. Results showed that women with biogas digesters spent less time exposed to wood smoke ($p<0.01$) compared to the referent group, and that cookhouse VOC exposure levels were lower for the women on the biogas farms than referent farms, specifically for trans-1,3-dichloropropene, bromoform, and 1,4-dichlorobenzene. Total VOC concentrations did not differ significantly between the two groups ($p=0.14$), although the composition of VOC species between the groups was significantly different. This study shows that passive VOC sampling can be used to assess biogas digesters' impact on the emissions of VOCs in cookhouses of rural Kenyan dairy farms.

3.2 Introduction

The use of solid biomass for fuel produces huge emissions of harmful respirable particulate matter (PM) and volatile organic compounds (VOCs) that push indoor air pollution concentrations well in excess of national and international exposure standards(14). Fifty percent of the world's population relies on the combustion of solid biomass fuels for domestic energy needs, such as cooking, light, and warmth, and up to 90% of all rural households in developing countries rely on solid biomass fuels for domestic energy production(13). The World Health Organization (WHO) estimated in 1997 that as many as 2.2 to 2.5 million deaths annually result from indoor air pollution in developing countries(15).

The majority of women living on farms in rural Kenya rely on solid biomass fuels, primarily wood, for cooking. The cookhouses they work in are separate from the primary house structure and are poorly ventilated(53). Consequently, women, and children in their care, are exposed to elevated amounts of PM and VOCs released from the process of wood combustion(54), although no research in Kenya has quantified this exposure. Negative health outcomes have been associated with exposure to wood smoke, such as pneumonia, lung cancer, chronic obstructive pulmonary disease (COPD), acute respiratory infections, and cataracts(3-5,13,36). Reducing exposure to harmful wood smoke has been shown to decrease the risk of negative health outcomes in women and children(6-9,42,55).

Biogas digesters represent an alternative and accessible technology that has the potential to reduce wood smoke exposure in cookhouse operations common in low and middle-income countries(56). Biogas digesters anaerobically decompose organic material, such as livestock waste, to produce combustible gas that can be used for cooking. The principal combustible gas produced is methane, the primary constituent of natural gas. Small amounts of ammonia, hydrogen sulfide, and carbon dioxide (CO_2) are also produced. The anaerobic decomposition of livestock waste produces high methane content (70%) gas, which burns cleanly and at high temperatures, providing a sustainable and cleaner burning alternative to wood as a fuel source(11).

Total exposure to indoor air pollutants, including wood smoke and products derived from biogas combustion, is related to the amount of time spent in an area and the pollutant concentration in the area. Indoor air quality monitoring enables the assessment of individual exposure to such agents, and is enhanced by collection of 24-hour time-activity diaries(28). Passive air sampling offers a cheap, practical method for assessing air quality in both outdoor and indoor areas, and facilitates personal exposure monitoring for environmental epidemiological studies(29). Passive samplers require no power source and minimal training in order to operate, and can be transported long distances. There are many different types of passive samplers, such as, badges and radial or axial tubes(57). All passive samplers work by adsorbing the gas molecules of interest at a known uptake rate over a set surface area, following Fick's First Law of diffusion(29). Gas molecules bind to the surface of a substrate located inside a passive sampler by weak and strong intermolecular forces of attraction. One such adsorbent substrate commonly used in passive sampling for mid-boiling point VOCs (e.g. benzene, toluene, ethylbenzene, xylene) is Tenax TA. Tenax TA is an organic polymer that is often packed into stainless steel thermal desorption sampling tubes. The adsorbed molecules are then released from the Tenax TA using high temperature thermal desorption in a flow of ultra-pure helium. The VOCs in the helium stream are then driven into a gas chromatograph (GC) for VOC species separation. The VOC species leaving the GC are then identified and quantified with a suitable detector, e.g. flame ionization detector, electron capture detector, or mass spectrometer(58).

The objectives of this study were: 1) to compare the concentrations of VOCs present in the cookhouses of women on Kenyan dairy farms using biogas digesters and those relying primarily on wood as fuel; 2) to compare the seasonal differences in VOC exposure levels in cookhouses with biogas digesters between February and June/July; 3) to compare cookhouse VOC exposure levels to outdoor, ambient concentrations; and 4) to compare the amount of time women, on farms with and without biogas digesters, are exposed to wood smoke in the cookhouses.

3.3 Methods

3.3.1 Study Population

All participants included in the study lived on member dairy farms of Wakulima Dairy Limited (WDL), located in the Mukurwe-ini area of central Kenya. There were 31 farms identified with biogas digesters installed recently (with assistance from a non-governmental organization called Farmers Helping Farmers (FHF) – “biogas” farms) and

31 referent farms without biogas digesters. The referent farms were matched to the biogas farms according to age of the participant, family size, number of cows, and location. The referent farms were selected using a chain referral sampling method(46). In this method, the study sample is created through referrals made among people who know others who possess the 'characteristics of research interest'(47). A list of non-biogas digester farms was created by referral from farms with digesters. A non-biogas digester farm was randomly selected from the created list for participation in the survey; in the event a non-biogas digester farm chose not to participate in the survey, the next family on the list was approached.

3.3.2 Data Collection

Data collection took place in February 2010 and again in June and July 2010. At each phase of data collection, measures of cookhouse size (m^3), cookhouse ventilation, wood consumption (lbs/day), and time spent cooking with methane or wood (per day) were collected for each farm. The repeat measures (February and June/July) for the biogas farms were taken to investigate seasonal variation in wood consumption and VOC exposure potentially due to changes in biogas production. Similar information was collected from referent farms in the second phase of data collection (June/July) only, for logistical and personnel reasons. At each phase of data collection, indoor (cookhouse) VOC exposure levels were sampled for each participant farm, as described below.

Two women from the biogas group withdrew their participation in the study after the February data collection and were replaced for the June/July collection with two other WDL member dairy farms that recently had biogas digesters installed.

3.3.3 VOC Sampling

Perkin-Elmer (Perkin-Elmer, 940 Winter Street, Waltham, Massachusetts, 02451, USA) stainless steel, 1/4” OD x 3.5” L, thermal desorption tubes (TDT) were deployed as personal exposure monitors for seven-day periods according to the protocols found in the following standard methods: BS EN 13528-2:2002, ISO 16107:2007 and ANSI/ISEA104(59-61). For the passive diffusion monitoring, Tenax TA (35/60) mesh for C7-C26 compounds was used.

Women wore the TDTs every day, while cooking, for one week. The amount of time spent cooking with either methane or wood was recorded on a time record sheet each day (see Appendix A). During times that women were not cooking, and consequently not wearing the TDTs, the TDTs were stored sealed in two Ziploc© bags to prevent continuous sampling. Ten percent of the VOC TDTs used were sampling blanks that traveled to Kenya and to the participant farms to ensure that the tubes were not compromised during the travel or sampling processes. TDTs were also used to sample outdoor concentrations of VOCs over 24- and 72-hour periods. These samplers were located in an area far from anthropogenic sources of VOCs (up in trees, away from buildings) in order to determine ambient concentrations present in the environment.

Upon return to Canada, all of the VOC TDT samples were analyzed using a Perkin-Elmer TurboMatrix Automatic Thermal Desorption (ATD) system coupled to a Perkin-Elmer Clarus 500 GC, equipped with a Restek Rtx-1 60 m, 0.53 mm ID, 3 μm df capillary column with electron capture and flame ionization detectors. The capillary column flow rate was 3.67 mL/min, while the ATD pre-trap split was zero, the exit trap split was also zero. Prior to the primary desorption procedure, moisture was removed from the TDTs by purging with helium carrier gas (50 mL/min) at room temperature for 1 minute. During primary desorption (helium carrier at 50 mL/min; split-less), the TDTs were heated to 300°C for 10 minutes and VOCs were collected and focused on a cold trap (Perkin Elmer, M041-3628). The cold trap was set to 15°C; after the primary desorption period, the trap was heated to 330°C for 5 minutes to initiate the transfer of the VOCs to the GC column for measurement.

3.3.4 Data Analysis

Basic descriptive analyses were used to compare population characteristics and exposure times to fuels between groups, and between time points within the biogas group. Graphic evaluation and the Shapiro-Wilk test(48) were conducted to check for normal distribution and square-root transformations for normality were applied as necessary. The following tests were used to compare measured variables or transformed variables with a normal distribution: standard paired (between time points among biogas farms) and unpaired (between biogas and referent farms) t-tests, testing for equal variance according to Levene's test (continuous data), and chi-square tests (categorical data). For non-normally distributed variables, Mann-Whitney rank sum tests were used to compare exposure levels of individual VOCs between the biogas and referent groups, as well as to compare VOC concentrations in both groups with outdoor ambient VOC concentrations. The Wilcoxon sign rank test was used for comparisons between February and June, for the biogas group. In cases with multiple comparisons (e.g. for VOCs), the Bonferroni correction was used(48).

Significant differences in the VOC species profiles in the cookhouses of the biogas group and the referent group (June data) were assessed using a MANOVA on ranked VOC data –VOC concentrations were ranked for each cookhouse(62). Also, the overall difference in exposure levels of all VOCs, between the two groups, was assessed using a multivariate two-sample non-parametric comparison test(63).

All participant and VOC data were analyzed using Stata/IC 11.1 for Mac (StataCorp 4905 Lakeway Drive, College Station, Texas, 77845, USA).

3.4 RESULTS

3.4.1 Population Characteristics

Table 3.1 indicates the summary characteristics for each participant group. The women participating in the study ranged in age from 22 to 72 years and there were no differences in age, family size, or number of cows between the biogas and referent groups, confirming that the matching procedure used in the selection of the referent group was successful. The group of participants with biogas digesters was more likely to have an employed husband than the referent group but the difference was not statistically significant. The referent group relied completely on wood as the primary fuel source, while the primary fuel source for the biogas group was methane. There were no differences in education level, employment, smoking status, cookhouse size, or the ventilation systems (chimney, window) in place in the cookhouses.

Table 3.1. Population characteristics for women participants living on farms with and without biogas digesters, June data.

Variable	Biogas farms n=31			Referent farms n=31		
	Mean (95% CI)	Median	Range	Mean (95% CI)	Median	Range
Age[1]	45 (42, 49)	45	22, 63	44 (40, 48)	44	24, 72
Number of cows [2]	3.7 (3.0, 4.4)	3	2, 12	3.3 (2.7, 4.1)	3	1, 10
Family size[1]	3.5 (2.9, 4.2)	3	1, 7	3.9 (3.3, 4.5)	3	1, 8
Cookhouse size[1] (m^3)	20 (18, 23)	21	6.5, 32	19 (16, 22)	18	8.4, 37
	Percent (number) n=31			**Percent (number) n=31**		
Education[3]						
None	6 (2)			10 (3)		
Standard 4	13 (4)			6 (2)		
Standard 8	48 (15)			61 (19)		
Form 4	19 (6)			19 (6)		
Technical college	13 (4)			3 (1)		
Employed[3]	39 (12)			35 (11)		
Married[3]	74 (23)			84 (26)		
Husband employed[3]	74 (17)[§]			50 (13)[±]		
Smoker[3]	3 (1)			0 (0)		
Primary fuel source*[3]	77 (24) methane			100 (31) wood		
Ventilation[3]						
Chimney	31 (9)[†]			19 (6)		
Windows	86 (25)[†]			94 (29)		

1 parametric test performed on raw (normally distributed) data
2 parametric test performed on square root transformed data; means, 95% CIs, medians & ranges presented were back-transformed
3 categorical test performed on raw data
*$p<0.01$
[†] n=29; [§] n=23; [±] n=26
CI: confidence interval

3.4.2 Exposure Times

Comparisons of exposure time (Figure 3.1, Table 3.2) between the biogas and referent groups show that there was no significant difference in the amount of time that the women were spending in the cookhouses. However, the women without biogas digesters were spending, on average, 120% more time exposed to wood smoke than the biogas group ($p<0.01$).

Table 3.2. Comparison of exposure time (min/week) between biogas and referent groups (June), and between seasons (February and June) for the biogas group.

Exposure time (min/week)	Biogas farms (June) n=31			Referent farms (June) n=31			p value
	Mean (95 % CI)	**Median**	**Range**	**Mean (95% CI)**	**Median**	**Range**	
BG exposure	404 (256, 585)	518	0, 1502	-	-	-	-
WS exposure	509 (385, 652)	500	95, 1703	1122 (952, 1306)	1050	455, 2925	<0.01
Total exposure	1022 (826, 1238)	1009	310, 2807	1122 (952, 1306)	1050	455, 2925	0.46
	Biogas farms (June) n=29			**Biogas farms (Feb) n=29**			**p value**
	Mean (95% CI)	**Median**	**Range**	**Mean (95% CI)**	**Median**	**Range**	
BG exposure	400 (256, 585)	518	0, 1502	162 (84, 264)	165	0, 1024	<0.01
WS exposure	526 (396, 675)	500	95, 1703	568 (425, 731)	452	170, 2345	0.66
Total exposure	1037 (827, 1270)	1047	310, 2807	810 (634, 1007)	806	170, 2607	0.08

Parametric tests were performed on square root transformed data for all variables; means, medians & 95% CIs presented were back-transformed
BG: biogas; WS: wood smoke; CI: confidence interval

A comparison of exposure time between February and June data (Figure 3.2, Table 3.2), for the biogas group, shows that the women were spending, on average, more time in the cookhouse in June compared to in February, although the difference was not significant ($p=0.08$). The time spent exposed to methane combustion products, while cooking, increased, on average, by 147% in June compared to in February ($p<0.01$), while the amount of time exposed to wood smoke remained the same between the two seasons.

Figure 3.1. Median biogas (BG), wood smoke (WS), and total exposure time with 5th, 25th, 75th, and 95th percentiles and outliers, for study participants on referent and biogas farms, using June data.

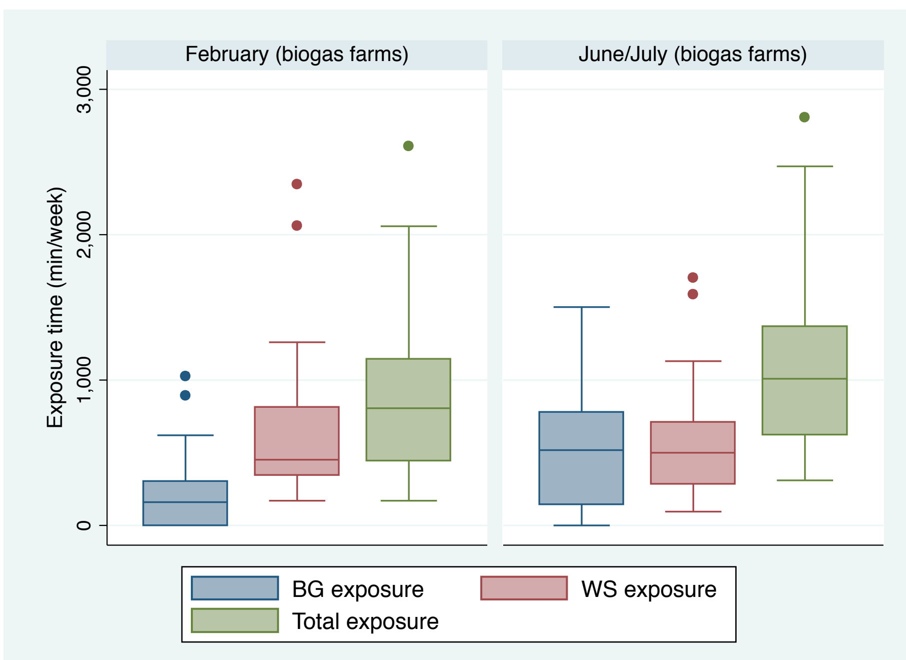

Figure 3.2. Median biogas (BG), wood smoke (WS), and total exposure time with 5th, 25th, 75th, and 95th percentiles and outliers, for study participants on biogas farms, using February and June data.

3.4.3 Cookhouse VOC Concentrations

Using the Mann-Whitney rank sum test, 10 of the 41 individual VOCs (Table 3.3) were significantly different ($p<0.05$) between biogas and referent groups. However, using the Bonferroni correction for multiple comparisons (α/n, where $\alpha=0.05$ and $n=41$; consequently $p=0.001$), trans-1,3-dichloropropene, bromoform, and 1,4-dichlorobenzene were the only VOCs that remained significantly different between the two groups (as shown in bold in Table 3.3), with all of them being lower in the biogas group versus the referent group.

Table 3.3. Individual comparisons of VOC concentrations (μg/m³) between the biogas and referent groups (June) as well as between the February and June data for the biogas group.

VOC	February biogas farms Median (range)	June biogas farms Median (range)	June referent farms Median (range)	p[1] value	p[2] value
benzene	36 (7.7, 4984)	28 (0, 467)	34 (0, 232)	0.18	<0.01
toluene	107 (23, 20842)	46 (2.3, 2286)	26 (3.6, 2477)	0.01	**<0.01**
ethylbenzene	38 (2.6, 7198)	15 (1.6, 997)	18 (1.0, 1198)	0.83	**<0.01**
p-xylene	64 (15, 12445)	28 (0.30, 1372)	33 (6.4, 2240)	0.32	<0.01
styrene	36 (4.0, 620)	22 (3.6, 516)	30 (6.7, 118)	0.40	0.06
o-xylene	33 (4.8, 6655)	27 (1.3, 1960)	40.9 (9.4, 1472)	0.10	0.28
isopropylbenzene	0 (0, 843)	7.6 (0, 375)	11 (1.5, 108)	0.36	0.24
n-propylbenzene	9.8 (0.67, 1000)	8.8 (0.11, 247)	12 (0.23, 216)	0.99	0.05
4-chlorotoluene	72 (6.2, 12167)	55 (0, 2923)	46 (0, 1909)	0.98	0.06
1,3,5-trimethylbenzene	46 (1.1, 3208)	17 (0.31, 813)	21 (2.5, 611)	0.50	<0.01
tert-butylbenzene	103 (19, 6936)	52 (4.0, 2221)	63 (9.8, 1037)	0.50	<0.01
sec-butylbenzene	70 (6.7, 911)	23 (0, 446)	20 (0.45, 100)	0.69	**<0.01**
p-isopropyltoluene	108 (28, 2361)	45 (5.4, 587)	39 (5.8, 436)	0.34	**<0.01**
n-butylbenzene	60 (0, 829)	25 (0.57, 459)	22 (0.12, 201)	0.30	**<0.01**
naphthalene	66 (0,1379)	5.1 (0, 723)	18 (0, 201)	0.12	**<0.01**
trichloroflurомethane	-	2.3 (0.69, 8.7)	2.0 (0, 11)	0.57	-
chloroform+ bromochloromethane	0.85 (0.25, 44)	0.07 (0, 53)	0 (0, 11)	0.12	**<0.01**
1,2-dichloroethane	69 (11, 635)	82 (8.4, 443)	96 (0, 692)	0.62	0.72
1,1,1-trichloroethane	0.52 (0.20, 3.0)	0.28 (0, 0.96)	0.23 (0.08, 5.8)	0.44	**<0.01**
1,1-dichloropropene	21 (6.6, 86)	30 (0, 169)	30 (0, 1185)	0.58	0.04
carbontetrachloride	1.6 (0.56, 7.4)	2.8 (0.68, 31)	2.3 (0.77, 13)	0.46	0.02
dibromomethane+ 1,2-dichloropropane	0.12 (0.03. 1.0)	0.04 (0, 0.34)	0.03 (0, 3.9)	0.81	**<0.01**
bromodichloromethane+ trichloroethene	0.26 (0.07, 1.3)	0.04 (0, 0.33)	0.08 (0, 1.4)	0.04	**<0.01**
cis-1,3-dichloropropene	6.7 (1.1, 70)	2.6 (0.30, 21)	5.1 (0, 20)	0.02	**<0.01**
trans-1,3-dichloropropene	0.78 (0, 19)	0.20 (0, 6.8)	2.0 (0, 18)	**<0.01**	0.10
1,1,2-trichloroethane	0.98 (0, 3.3)	0 (0, 3.1)	0 (0, 5.7)	0.11	<0.01
dibromochloromethane	0.05 (0, 0.34)	0 (0, 0.17)	0 (0, 0.30)	0.53	<0.01

Table 3.3. Individual comparisons of VOC concentrations (μg/m³) between the biogas and referent groups (June) as well as between the February and June data for the biogas group (continued).

VOC	February biogas farms Median (range)	June biogas farms Median (range)	June referent farms Median (range)	p[1] value	p[2] value
1,2-dibromoethane+ 1,3-dichloropropane	0.49 (0.05, 3.0)	0.17 (0, 1.5)	0.18 (0.03, 1.5)	0.34	<0.01
tetrachloroethene	0.45 (0.11, 2.5)	0.21 (0.04, 16)	0.19 (0.03, 0.37)	0.34	**<0.01**
chlorobenzene+ 1,1,2,2-tetrachloroethane	0.06 (0.01, 2.7)	0.05 (0, 1.1)	0.04 (0, 0.38)	0.71	0.14
bromoform	0.85 (0.15, 6.1)	0.05 (0, 0.72)	0.15 (0.01, 0.77)	**<0.01**	**<0.01**
1,1,2,2-tetrachloroethane	-	0.47 (0, 1.4)	0.80 (0.003, 3.5)	0.08	-
1,2,3-trichloropropane	8.9 (2.2, 90)	2.0 (0, 15)	4.1 (0.34, 37)	<0.01	**<0.01**
bromobenzene	132 (38, 3045)	27 (0, 837)	95 (3.2, 1180)	<0.01	<0.01
1,3-dichlorobenzene	3.7 (0, 18)	6.4 (0.41, 76)	17 (0, 83)	<0.01	**<0.01**
1,4-dichlorobenzene	-	2.9 (0, 15)	8.1 (0.93, 43)	**<0.01**	-
1,2-dichlorobenzene	6.9 (0, 119)	1.7 (0, 26)	6.7 (0, 21)	<0.01	0.01
1,2-dibromo-3-chloropropane	0.21 (0.03, 8.0)	0.10 (0.002, 0.93)	0.13 (0.02, 21)	0.25	0.01
1,2,4-trichlorobenzene	2.8 (0, 14)	0 (0, 15)	0 (0, 0)	0.32	**<0.01**
1,2,3-trichlorobenzene	1.7 (0, 22)	0 (0, 3.6)	0 (0, 2.5)	0.13	**<0.01**
hexachlorobutadiene	0.11 (0, 0.87)	0 (0, 0.69)	0 (0, 3.0)	0.10	0.33

[1] comparison between biogas and referent groups (June data)
[2] comparison between February and June data (biogas group)
Non-parametric tests were performed on raw (non-normally distributed) data for all variables

The majority of the individual VOCs tested (29/38) for the biogas group (Table 3.3) were significantly different (using the Wilcoxon sign rank test) between the two seasons ($p<0.05$). However, again using the Bonferroni correction for multiple comparisons (α/n, where $\alpha=0.05$ and $n=38$; consequently $p=0.001$) approximately 45% of the individual VOC exposure levels (17/38) remained significantly different between the two seasons, as shown in bold in Table 3.3. Sixteen of the 17 VOCs were higher in February than June, with the exception being 1,3-dichlorobenzene.

To assess the overall difference in mixture of the individual VOCs present in each of the cookhouses of the two groups, we used a ranked MANOVA. Ranks (for each cookhouse) of the individual VOC concentration levels were compared between the June biogas and referent groups (Table 3.4). The comparison showed that there was a significant difference in the mixture of the VOCs found in the cookhouses of each group (p=0.01).

Table 3.4. MANOVA results of ranked individual VOC data (June), with biogas status as the predictor.

	Statistic	Degrees of freedom	F(df1, df2)	F	Probability>F
Biogas/referent status	W 0.175	1	40.0, 21.0	2.47	0.0145
Residual		60			
Total		61			

W = Wilks' lambda; df: degrees of freedom

We also used a multivariate two-sample non-parametric comparison test to assess the overall differences in individual VOCs concentration levels between the biogas and referent groups. According to this test, there was not a significant difference in the overall concentrations between the two groups (U statistic=49.5; p=0.14).

3.4.4 Outdoor VOC Concentrations

Figures 3.3a through 3.3g represent the exposure levels of individual VOCs in biogas and referent farm cookhouses, compared to the outdoor ambient concentrations, for those VOCs with median concentrations greater than 0.1 $\mu g/m^3$. Since the number of outdoor comparisons (n=2) is much lower than the indoor sampling (n=62), statistical tests between the indoor and outdoor VOC concentrations were not possible. However, these figures do show that, with the exception of benzene, 1,2-dibromoethane+1,3-dichloropropane, 1,1,2-trichloroethane, and dibromochloromethane, indoor cookhouse concentrations were generally much higher than the ambient concentrations present in the outdoor surroundings of farms.

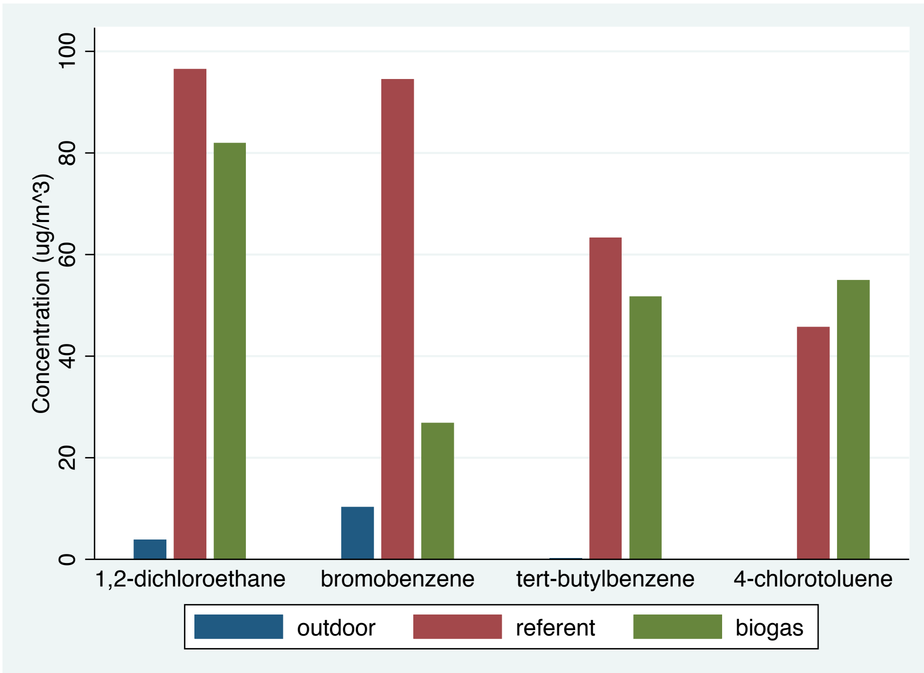

Figure 3.3a. Median VOC concentrations (μg/m^3) from biogas and referent farms compared to outdoor ambient concentrations, June data.

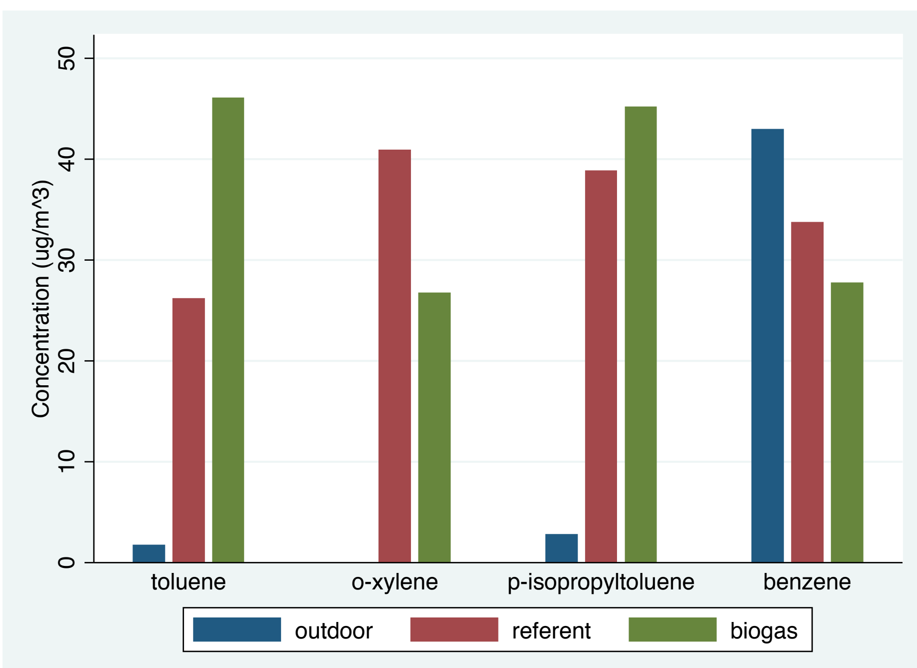

Figure 3.3b. Median VOC concentrations (μg/m^3) from biogas and referent farms compared to outdoor ambient concentrations, June data.

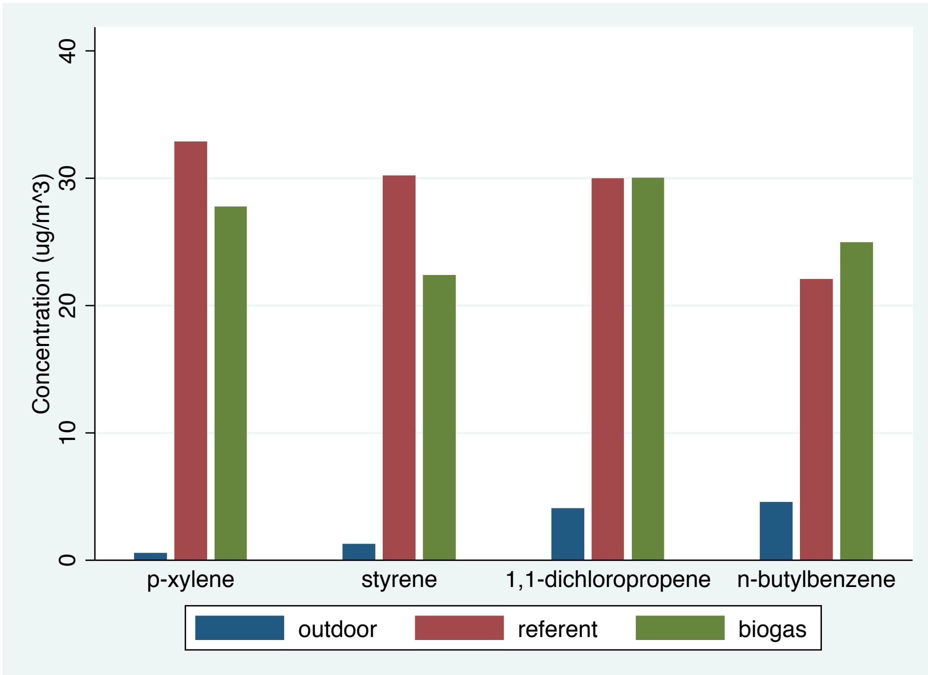

Figure 3.3c. Median VOC concentrations (μg/m^3) from biogas and referent farms compared to outdoor ambient concentrations, June data.

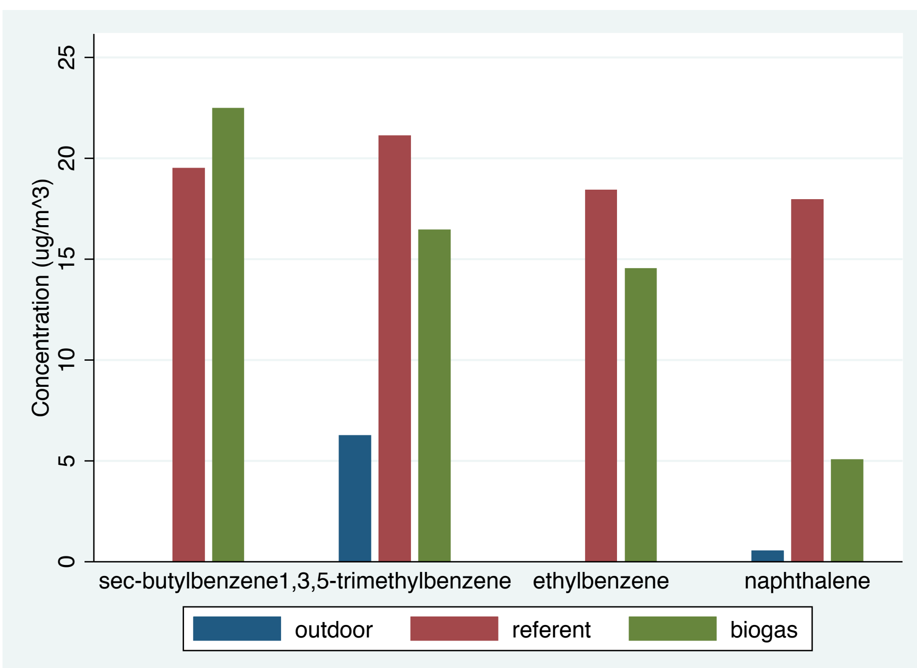

Figure 3.3d. Median VOC concentrations (μg/m^3) from biogas and referent farms compared to outdoor ambient concentrations, June data.

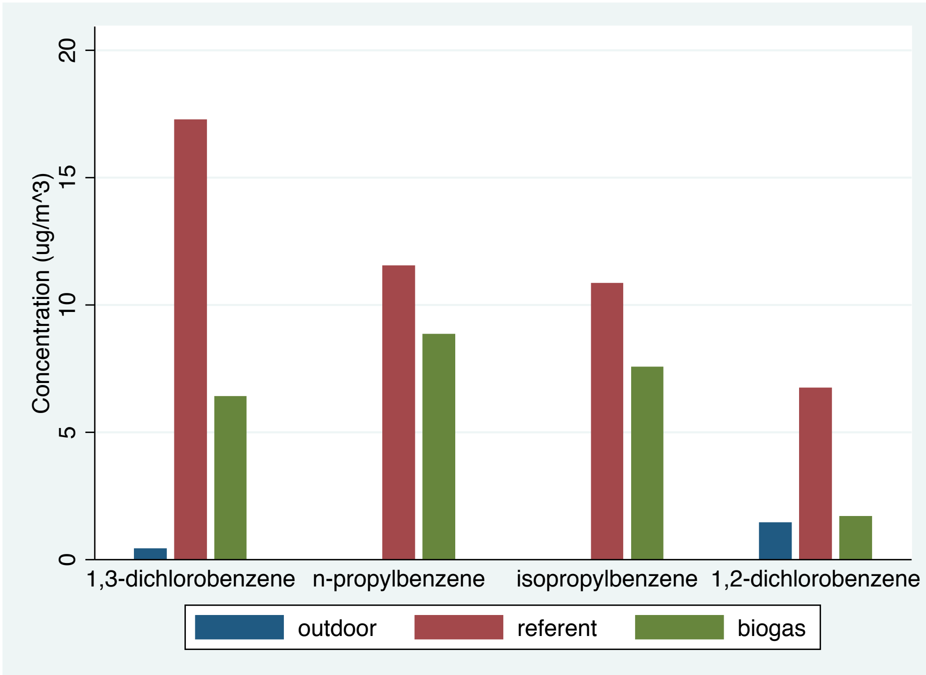

Figure 3.3e. Median VOC concentrations (µg/m^3) from biogas and referent farms compared to outdoor ambient concentrations, June data.

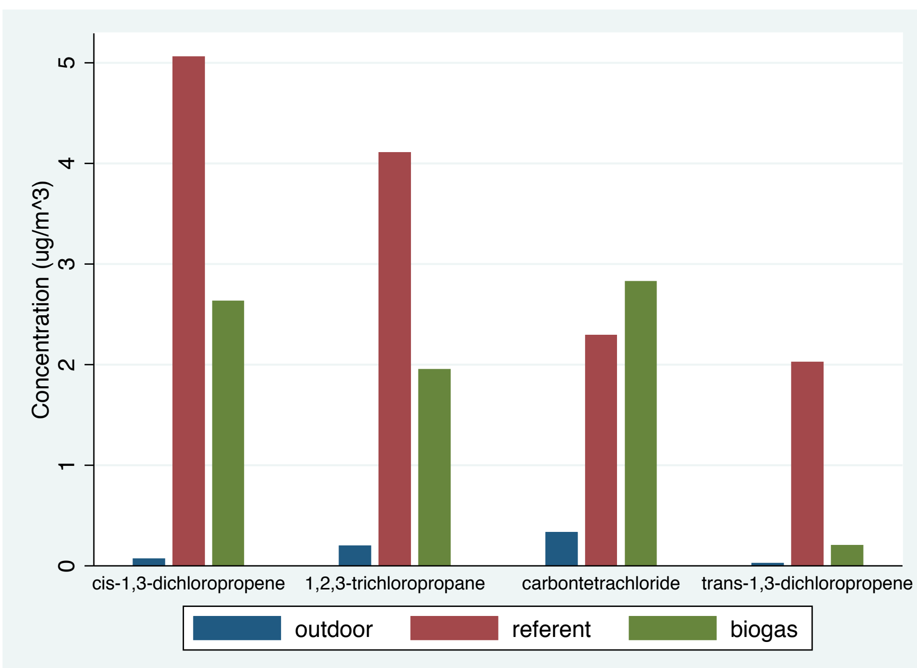

Figure 3.3f. Median VOC concentrations (µg/m^3) from biogas and referent farms compared to outdoor ambient concentrations, June data.

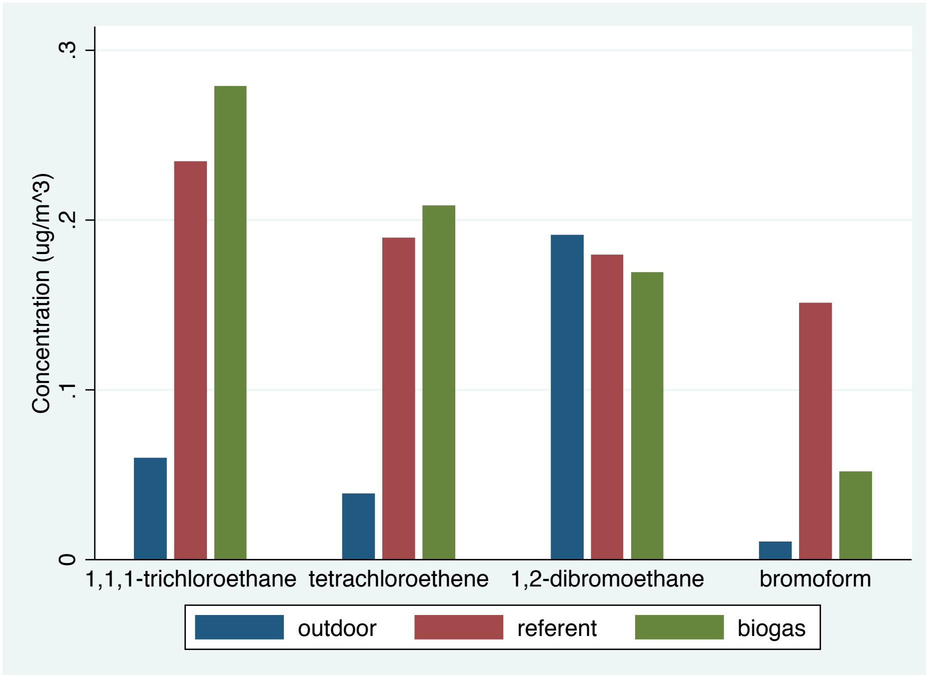

Figure 3.3g. Median VOC concentrations (µg/m^3) from biogas and referent farms compared to outdoor ambient concentrations, June data.

3.5 Discussion

The women participating in the study spent similar amounts of time cooking in their cookhouses, per week (Figure 3.1, Table 3.2). However, the women on farms with biogas digesters reduced the amount of time spent cooking with wood by more than 50%, and consequently reduced the amount of time they were being exposed to wood smoke. These women spent, on average, more than 6.5 hours cooking with methane per week, thus reducing the reliance on cooking with wood fuel. This was expected because a previous study showed that two cows fuelling a digester reduced wood consumption for a family of four by 40%(53). According to the average family size and number of cows (Table 3.1) for this study, the reduction in time spent cooking with wood, per week, of greater than 50% and the reduction in wood consumption (lbs/day) of approximately 40%(53) are similar to the existing literature.

When comparing the seasonal variation in time spent cooking with wood (Figure 3.2, Table 3.2), the women spent similar amounts of total time cooking with wood, however, cooking with methane increased by about 147% in June. This change in methane use may be due to maintenance work and training sessions that were provided to the farms with biogas digesters between February and June. During the February data collection, it was found that many of the digesters were not functioning optimally, consequently, training sessions for farmers on biogas digester maintenance, as well as servicing for non-functioning digesters, were provided by FHF. During the June data collection, the farmers reported that nearly all the digesters were functioning optimally, causing women to increase the amount of time spent cooking with methane. It is possible that the slight increase in total time spent cooking (Figure 3.2) in June compared to February was due to the colder temperatures requiring longer cooking times for food (average maximum temperature in February, 26°C, and in June/July, 21°C)(52). Another possibility is that there was a decrease in anaerobic decomposition in the colder period of June/July that resulted in decreased methane production, and consequently, lower pressure in the biogas digester causing longer cooking times over reduced heat.

The ventilation mechanisms present in the cookhouses and the size of the cookhouses were also similar among the groups, and therefore these variables were unlikely to be confounders of any relationship between biogas farm status and wood smoke exposure or cookhouse VOC concentration.

When comparing the exposure levels of individual VOCs between the two seasons, 16 of the 38 VOCs tested decreased significantly in concentration in June compared to February, after adjustment for multiple comparisons (Table 3.3). Wood smoke exposure times were similar between the two seasons, so it is difficult to determine why there was a reduction in VOC concentrations for some VOCs in June/July but not for all, particularly when the time of exposure to biogas smoke was higher in June/July than in February. It could be possible that the cookhouse internal surfaces were off-gassing more during the hotter month of February, causing higher levels of VOC exposure, despite the fact that time spent cooking with wood remained the same, on average.

There were a number of individual VOCs that were present in significantly higher concentrations in referent cookhouses compared to cookhouses on farms with biogas digesters (Table 3.3). However, there were fewer significant differences in VOC concentrations between the two groups than there were between February and June sampling within the biogas group (Table 3.3). When comparing the overall difference in VOC exposure levels, the multivariate two sample non-parametric test showed no difference between the two groups ($p=0.14$). These results show that there is evidence of some increases in VOC concentrations for referent farms based on individual VOCs, however, it is likely that the sample size was insufficient to detect overall changes in concentration levels of all the 41 VOCs, especially because few had significant differences at the individual level. Another explanation for not seeing a significant overall difference could be that the cookhouses were also used as storage areas for other household items, usually items that were undesirable to keep stored in the house.

However, we did not collect information on what was stored in the cookhouses because this was only noticed partway through the data collection period in June. It is possible that these circumstances led to the sampling of VOCs that were not emitted solely from the combustion of wood or methane as fuel. It is also likely that a greater difference among the total VOC concentrations wasn't seen in the biogas group because methane was supplemented with wood fuel use, meaning that wood smoke exposure was not eliminated. Finally, many of the women had methane burners located in cookhouses that were charred from years of exposure to large amounts of smoke and it is possible that these structures continue to off-gas even if cooking with wood is significantly reduced or eliminated.

Although there was no significant difference in overall VOC concentrations between the two groups, there was a significant difference in the composition of VOC species present in the cookhouses of the two groups, as shown by the ranked MANOVA (Table 3.4). While this provides no evidence of increasing or decreasing in specific VOC concentrations, it demonstrates that the mixtures of VOCs that dominated in the groups were significantly different, with methane combustion VOCs among biogas farms likely being the reason for this finding.

Sample size restrictions of outdoor ambient VOC concentrations prevented the statistical comparison of the outdoor VOCs to the indoor cookhouse concentrations. However, Figures 3.3a through 3.3g indicate large differences in individual VOC concentrations, with the exception of benzene, 1,2-dibromoethane+1,3-dichloropropane, 1,1,2-

trichloroethane, and dibromochloromethane. The indoor VOC concentrations were as much as 9 and 25 times (bromobenzene and 1,2-dichloroethane, respectively) higher compared to outdoor concentrations. Low ambient concentrations of VOCs were expected for this rural area of Kenya because air quality is generally good and the area is located far from large anthropogenic sources of air pollutants. However, automobile exhaust is a primary source of atmospheric benzene emissions, so it is possible that the higher concentrations of ambient benzene seen in the outdoor samples could be due to automobile traffic in the area(64). The concentration of 1,2-dibromoethane+1,3-dichloropropane was similar in both indoor and outdoor samples and the concentrations of 1,1,2-trichloroethane and dibromochloromethane were negligible (<0.04 $\mu g/m^3$ and <0.02 $\mu g/m^3$, respectively).

3.5.1 Limitations

One limitation to this study was the remote access to farms and the language barriers experienced working in the field. We relied on the women participants to prevent the TDTs from continually sampling, using Ziploc© bags, rather than sealing the TDTs between sampling periods. The rural location of the cookhouses also meant that we were limited in the equipment we could bring with us, and consequently, we were not able to collect data on carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), or PM concentrations.

A second limitation of the study was the small number of farms that had biogas digesters installed on them. The study was limited to the 31 biogas farms that had biogas digesters and their referent farms. Due to the lack of research that exists on cookhouse VOC exposure levels and women's exposure to VOCs in rural Kenya, this study, despite it's small sample size, provides information on protocols for evaluating VOC exposure in this field situation and on VOC concentrations differences between biogas and referent farms as well as between cookhouse and ambient outdoor concentrations.

Finally, the referent farms may not be truly representative of the study population due to the sampling method not being truly random. The basis of the chain referral method to select referent participants relies on the referral of potential participants by existing study participants. Consequently, a potential bias from the referral of study participants may exist, as they are likely to refer others of similar situation. Requesting referrals of multiple potential participants from each study participant, so a list could be generated from which the referent participant could be randomly chosen, aimed to reduce this potential bias. Matching the referent participants based on age, family size, number of cows, and location can also introduce potential bias, as this group of people within the WDL membership may be different from the entire WDL membership population. However, these potential limitations are also mitigated by the studies strengths. The study was conducted under real world circumstances, and the association between biogas digesters and VOC concentration is likely to be the same no matter what group of WDL farmers was used. Finally, the matching made it possible to compare the two groups (biogas and referent) even though the biogas group had already been defined by the installation of the biogas digesters.

3.5.2 Conclusions

There were higher levels of VOC exposure in cookhouses on farms without biogas digesters compared to farms with biogas digesters – particularly for trans-1,3-dichloropropene, bromoform, and 1,4-dichlorobenzene. Also, the women without biogas digesters spent more time in their cookhouses being exposed to wood smoke than the biogas group.

Within the biogas group, 17 VOCs were significantly different between samplings, with exposures being higher in February than June for 16 of the 17 VOCs, showing seasonal differences in exposure to VOCs in this group. Interestingly, the women with biogas digesters actually spent substantially more time ($p=0.08$) in their cookhouse in June than in February. It is not known if similar seasonal effects would be found in the referent group. The amount of time exposed to wood smoke remained the same between the two seasons, within the biogas group.

The overall concentrations of many VOCs present in the cookhouses well exceeded the outdoor ambient concentrations and the recommended guidelines for safe human exposure(14). Further investigation, with greater numbers of participants, would be beneficial to confirm the effects of biogas digesters on the personal exposure to VOCs for Kenyan farmwomen.

CHAPTER 4: RESPIRATORY DATA

4.1 Abstract

Exposure to wood smoke from cooking in a cookhouse is a risk factor for chronic obstructive pulmonary disease and other respiratory problems among women in developing countries. This paper presents a study evaluating the respiratory health effects, for women, of reducing indoor air pollution from open cooking fires by installing biogas digesters on rural smallholder Kenyan dairy farms. A total of 31 biogas digesters were installed on dairy farms in 2008 and 2009. Survey and spirometry data were collected in June 2010 to assess self-reported respiratory health and lung function among women living on farms with biogas digesters (n=31) and women living on farms relying primarily on wood as fuel (referent group, n=31). Compared to the biogas group, 23% and 19% more women reported experiencing shortness of breath (p=0.09) or chest pain while breathing (p=0.10), respectively. No significant differences in respiratory outcomes or lung function were found between the two groups of participants. Reducing indoor air pollution from wood burning may relieve dyspnea symptoms experienced by women but the effects of biogas digesters on lung function are unclear.

4.2 Introduction

Women living in developing countries rely on wood as their primary fuel source for cooking. In Kenya, women often cook in poorly ventilated cookhouses, which are separate structures from the houses. Consequently, women and young children in their care are often exposed to high levels of indoor air pollution, especially wood smoke(10,19).

The exposure to indoor air pollution has many documented negative effects on the health of people, particularly on women and children who typically spend more time indoors. Health problems range from eye problems and headaches, to cardiovascular and respiratory problems that can lead to premature loss of life. The exposure to high levels of indoor air pollution has been attributed to respiratory health outcomes such as chronic obstructive pulmonary disease (COPD), respiratory infections, asthma, pneumonia, and tuberculosis(4,5,13,36).

Reviews of literature have shown that the strongest evidence for adverse respiratory health outcomes, resulting from wood smoke exposure exists for women over 15 years of age. For this group, the relative risk of developing COPD, as a result of relying on biomass (e.g. wood) for cooking, was 3.2 (95% CI 2.3, 4.8) compared to referent women who did not rely on solid, biomass fuel(38).

Spirometry measures are widely used in the diagnosis of COPD and other respiratory diseases in North America. The most important measures for obstruction in lung function commonly assessed by spirometry are forced expiratory volume at 1 second (FEV_1) and the ratio of FEV_1 to forced vital capacity (FEV_1/FVC). For healthy individuals, the fraction of FEV_1/FVC should not be <0.7 and the FEV_1 percent-predicted should be $\geq 80\%$(40). However, spirometry measures are not widely available or used in the majority of African countries, and the lack of access to equipment and training means that there is a deficiency of baseline data for most African populations(65). Due to this lack of spirometry data, there are currently no African standards for predicted spirometry measures. However, studies have shown that in these cases, where no predicted measures for African comparison populations exist, the corresponding African-American standards can be used(66).

Biogas digesters represent an important and accessible technology that has the potential to reduce wood smoke exposure in cookhouse operations common in low and middle-income countries(56). Biogas digesters anaerobically decompose organic material, such as livestock waste, to generate gas to be used for cooking. The principal gas produced is methane, the primary constituent of natural gas, though small amounts of ammonia, hydrogen sulfide, and carbon dioxide (CO_2) are also produced. The decomposition of livestock waste produces high methane content (70%) gas, which burns cleanly and at high temperatures, providing a sustainable and cleaner burning alternative to wood as a fuel source(11).

The objectives of this study were: 1) to compare lung function (spirometry outcomes: FVC, FEV_1, peak expiratory flow rate (PEFR), and forced expiratory flow (FEF)) and self-reported respiratory health in women living on Kenyan dairy farms with and without a biogas digester; 2) to assess the self-reported improvements in respiratory health after the installation of the biogas digester, for women living on dairy farms with a biogas digester; and 3) to assess the impact of biogas digesters, and other predictor variables, on spirometry outcomes and self-reported respiratory health outcomes for Kenyan women living on dairy farms.

4.3 Methods

4.3.1 Study Population

All participants included in the study lived on member dairy farms of Wakulima Dairy Limited (WDL), located in the Mukurwe-ini area of central Kenya. There were 31 farms identified with biogas digesters installed recently (with assistance from a non-governmental organization called Farmers Helping Farmers (FHF) – "biogas" farms) and 31 referent farms without biogas digesters, matched to the biogas farms based on age of the participant, family size, and number of cows. The referent farms were selected using a chain referral sampling method(46). In this method, the study sample is created through referrals made among people who know others who possess the 'characteristics of research interest'(47). A list of non-biogas digester farms was created by referral from farms with digesters. A non-biogas digester farm was randomly selected from the created list for participation in the survey. In the event a non-biogas digester farm chose not to participate in the survey, the next family on the list was approached.

4.3.2 Data Collection

Data collection took place in February 2010 and again in June and July 2010. At each phase of data collection, participants in the biogas farms completed a survey on self-perceived health and quality of life, and underwent a basic respiratory exam, including auscultation, palpation, pulse oximetry, and spirometry. Similar assessments for the referent group were collected during the second (June/July) phase of data collection only. The respiratory exams were conducted by nursing students from the University of Prince

Edward Island (UPEI), under the supervision of the Dean of Nursing, according to adapted protocols for adult respiratory assessments(67). All spirometry assessments were conducted by the Dean of Nursing (UPEI) according to the American Thoracic Society protocol(68) and Knudson (1976) protocol for obtaining predicted values(69), using a Grace Medical Koko Legend Portable Spirometer (Grace Medical Marketing Inc., 5004 Barnwood Terrace, Kennesaw, Georgia, 30152, USA) . The basic respiratory exams and spirometry were conducted in a clinic format where participants would go to a central location. The nursing students and Dean of Nursing were all blind to which women lived on farms with biogas digesters.

Two biogas farms did not participate in the study after the February data collection, and were replaced for the June/July collection with two other WDL member dairy farms that recently had biogas digesters installed.

A 43-question survey (Appendix A) was administered in Kikuyu (local language), through a translator, to study participants with biogas digesters in February and to all study participants in June/July. The questionnaire was designed to collect information on wood collection, wood consumption, money spent on fuels, education and family characteristics, as well as self-reported historical and current health, including self-reported respiratory health, and quality of life indicators. There were 10 questions specifically related to biogas digesters that were omitted from the referent surveys. This paper focuses on the survey questions related to respiratory health.

4.3.3 Data Analysis

Basic descriptive analyses were conducted for each variable of the data collected. Normality of the variable distribution was evaluated graphically, as well as using the Shapiro-Wilk test(48), with square-root transformations for normality being applied as necessary. Standard unpaired t-tests (continuous data), testing for equal variance according to Levene's test, and chi-square tests (categorical data) were used to compare survey and measured variables.

Multivariable linear regression was used to determine the important predictors of spirometry outcomes for the participants, which were graphically evaluated for normality of the distribution. Univariable analyses were first conducted, and variables were retained for model building if $p \leq 0.2$. The variables "education" and "monthly milk income" were reformatted to contain fewer levels before proceeding. "Education" was transformed from a 5-level variable to a 3-level variable (0=no education or completed up to Standard 4; 1=completed up to Standard 8; 2=completed up to Form 4 or technical college). "Monthly milk income" was dichotomized to give 2 categories: 0=<5000 KSH and 1=≥5000 KSH. Following univariable analysis, potential explanatory variables were tested for collinearity using Pearson and Spearman's Rank correlation coefficients for continuous variables, chi-square tests for categorical variables, and two sample ANOVAs for continuous variables with categorical variables. A possible causal diagram was also created for the potential explanatory variables to avoid the inclusion of intervening variables during the model building process(49). Forward selection was used to determine the main predictors of the outcome in the model. Variables were initially included in the model building process at a significance level of $p \leq 0.1$. Intervening variables were then removed and only main effects were retained in the final model at a significance level of $p \leq 0.05$. Potential interactions of main effects were also assessed through forward selection with a $p \leq 0.05$.

Linearity between predictor variables and spirometry outcomes was assessed using a scatter plot of the variable and outcome, with a Lowess smoother line fitted to the plot. Quadratic terms of the predictor variables were added to the model to test for significance, if necessary. Scatter plots of the standardized residuals and predictor variables were also generated to test goodness-of-fit. Constant variance was assessed using the Cook-Weisberg test for heteroscedasticity. Influential observations were assessed using Cooke's distance.

All participant data were analyzed using Stata/IC 11.1 for Mac (StataCorp 4905 Lakeway Drive, College Station, Texas, 77845, USA).

4.4 RESULTS

4.4.1 Population Characteristics

Basic comparison between the biogas and referent groups shows that there were no significant differences in the average population and physical characteristics between the participants in either group (Table 4.1). Women in the biogas group were more likely to have a husband who was employed, compared to the referent group, although not significantly at $p \leq 0.05$. None of the participants in either group were smokers, although a few women in each group had other family members that smoked outside of the house or cookhouse buildings, but this difference was not significant. The women in both groups had similar family sizes, numbers of cows, and cookhouse sizes, as well as similar ventilation mechanisms in their cookhouses(70). Mean physical measures of the women were not significantly different between groups, however, women with biogas digesters were slightly heavier and had faster resting pulses compared to women in the referent group.

Table 4.1. Population and physical characteristics for biogas and referent groups of Kenyan farmwomen, June data.

Variable	Biogas farms (June data) n=31			Referent farms (June data) n=31		
Population characteristics	**Percent (number)**			**Percent (number)**		
Pregnant[3]	0 (0)			6 (2)		
Employed[3]	39 (12)			35 (11)		
Married[3]	74 (23)			84 (26)		
Husband employed[3]	74 (17) [§]			50 (13) [±]		
Smoker[3]	0 (0)			0 (0)		
Education level[3]						
none	6 (2)			10 (3)		
Standard 4	13 (4)			6 (2)		
Standard 8	48 (15)			61 (19)		
Form 4	19 (6)			19 (6)		
Technical college	13 (4)			3 (1)		
	Mean (95% CI)	**Median**	**Range**	**Mean (95% CI)**	**Median**	**Range**
Family size[1]	3.5 (2.9, 4.2)	3	1, 7	3.9 (3.3, 4.5)	3	1, 8
Number of cows[2]	3.7 (3.0, 4.4)	3	2, 12	3.3 (2.7, 4.1)	3	1, 10
Cookhouse size[1] (m^3)	20 (18, 23)	21	6.5, 32	19 (16, 22)	18	8.4, 37
Physical characteristics						
Age[1]	45 (42, 49)	45	22, 63	44 (40, 48)	44	24, 72
Height (inches) [1†]	63 (62, 64)	63	59, 71	62 (61, 63)	63	57, 66
Weight (lbs) [1†]	156 (144, 168)	152	119, 255	145 (135, 154)	144	98, 214
Blood pressure[1†]						
systolic	128 (123, 134)	128	108, 180	126 (121, 130)	122	108, 160
diastolic	84 (80, 88)	82	62, 118	83 (80, 86)	84	68, 100
Respiratory rate per minute (resting) [1†]	18 (17, 19)	18	15, 24	19 (18, 19)	18	16, 22
Pulse per minute (resting) [1 †]	83 (78, 88)	83	57, 110	77 (72, 81)	73	49, 104
Blood O_2 saturation[1†]	97 (96, 97)	97	94, 100	96 (95, 97)	96	88, 100

No differences exist between the groups at significance of $p \leq 0.05$
1 parametric test performed on raw (normally distributed) data
2 parametric test performed on square root transformed data; means, 95% CIs, medians & ranges presented were back-transformed
3 categorical test performed on raw data
[§] n=23; [±] n=26; [†] n=30 - one participant was not able to attend the respiratory clinic
CI: confidence interval

4.4.2 Self-reported Respiratory Health

During the participant interviews, women were asked to report on their respiratory status, for the last six months. Responses were initially recorded as 5-level categorical variables, but had been condensed to binary (never/ever) variables for the analyses. The results are presented below in Table 4.2. Women without biogas digesters were slightly more likely ($p<0.15$) to have experienced difficulty breathing, shortness of breath, and chest pain while breathing, during the last 6 months, compared to women living on farms with a biogas digester.

Table 4.2. Comparison of participant responses related to self-reported health for the biogas and referent groups of Kenyan farmwomen, June data.

Variable	Biogas farms (June data) n=31	Referent farms (June data) n=31	P value
	Percent (number)	**Percent (number)**	
Current cough	26 (8)	39 (12)	0.36
If yes, productive cough	88 (n=7/8)	50 (n=6/12)	0.70
Frequent coughing (during last 6 mo)	19 (6)	26 (8)	0.59
Shortness of breathe (during last 6 mo)	29 (9)	52 (16)	0.09
Breathing difficulty (during last 6 (mo)	23 (7)	42 (13)	0.12
Chest pain with breathing (during last 6 mo)	16 (5)	35 (11)	0.10
Uses medication to help breathe (during last 6 mo)	3 (1)	3 (1)	0.98

mo: month

The biogas group participants were also asked questions to assess their changes in health and quality of life after the installation of biogas digesters (Table 4.3). The majority of women reported improvements in general health, as well as the health of their children, reductions in wood smoke inhalation for themselves and their children, and reductions in respiratory problems for themselves and their children.

Table 4.3. Responses to questions about changes in respiratory and quality of life measures due to the installation of biogas digesters (n=31), June data.

Variable	Disagree	No change or not applicable	Agree
		Percent (number) n=31	
Health is better	0	13 (4)	87 (27)
Breathe in less smoke	0	3 (1)	97 (30)
Fewer breathing problems	0	48 (15)	52 (16)
		Percent (number) n=18	
Children's health is better	0	28 (5)	72 (13)
Children breathe in less smoke	0	22 (4)	78 (14)
Children have fewer breathing problems	0	50 (9)	50 (9)

4.4.3 Respiratory Assessments

After the interviews, each participant underwent a respiratory assessment that involved spirometry and a basic respiratory exam, including auscultation and palpation. There were no clinical differences in the basic respiratory exam, between the two groups of women, for measures such as inspiratory and expiratory wheezes, tracheal deviation, accessory muscle use, equal respiratory expansion, and pain or tenderness while breathing. The measured values for all spirometry outcomes were lower than the predicted values, for women of that age, ethnicity, weight, and height, for both groups, with the exception of the ratio of FEV_1/FVC (Table 4.4). The percent predicted values ranged from 83% (PEFR, referent group) to 93% (FEV_1 & FEF, referent group). The women in the referent group had percent-predicted FVC values 5% higher than the biogas group, on average. The percent-predicted values for FEV_1 were also 3% higher in the referent group, and the values for PEFR were 4% higher, on average, in the biogas group compared to the referent group. However, none of the spirometry results presented any significant or clinical difference in lung function between the biogas and referent groups.

Table 4.4. Spirometry measures for the biogas and referent groups of Kenyan farmwomen (n=60), June data.

Variable	Biogas farms (June data)			Referent farms (June data)			P value
	Mean	Median	Range	Mean	Median	Range	
FVC							
measured	2.6	2.7	1.4, 4.3	2.7	2.6	1.6, 4.1	0.65
predicted	3.1	3.2	2.1, 5.5	3.0	3.1	2.2, 3.6	0.39
percent predicted (%)	84	85	49, 114	89	85	51, 131	0.16
FEV_1							
measured	2.3	2.3	1.3, 3.9	2.3	2.3	1.6, 3.1	0.92
predicted	2.6	2.6	1.8, 4.4	2.5	2.6	1.8, 2.9	0.51
percent predicted (%)	90	89	61, 120	93	93	60, 117	0.34
PEFR							
measured	5.2	5.0	2.8, 7.4	4.9	4.7	2.9, 8.3	0.28
predicted	6.1	6.0	4.9, 10	5.9	6.0	5.0, 7.3	0.36
percent predicted (%)	87	87	47, 120	83	84	47, 133	0.48
FEF_{25-75}							
measured[1]	3.2	3.2	1.5, 5.3	3.1	2.9	2.1, 5.8	0.94
predicted[1]	3.5	3.5	2.6, 5.4	3.4	3.4	2.6, 4.0	0.47
percent predicted (%)	91	95	47, 120	93	88	59, 161	0.78
FEV_1/FVC ratio							
measured	0.90	0.89	0.76, 1.0	0.89	0.90	0.76, 1.0	0.72
predicted	0.85	0.85	0.83, 0.99	0.86	0.85	0.82, 0.99	0.86
percent predicted (%)	105	107	90, 117	104	104	88, 120	0.70

1 parametric test performed on square root transformed data
FVC: forced vital capacity; FEV_1: forced expiratory volume at 1 second
PEFR: peak expiratory flow rate; FEF: forced expiratory flow

Univariable associations between biogas digester status and several spirometry and self-reported respiratory outcomes are presented in Table 4.5. The effects of having a biogas digester were slightly associated with a decrease in reporting difficulty breathing, shortness of breath, or chest pain while breathing (during the last 6 months), without controlling for other factors, although these associations were not significant at $p \leq 0.05$. None of the spirometry outcomes were crudely associated with whether or not the participant lived on a farm with a biogas digester.

Table 4.5. Univariable association between biogas digester status and both spirometry (n=60) and self-reported (n=61) respiratory outcomes, June data.

Respiratory outcome	Coefficient	95% CI	P value	Crude OR
Breathing difficulty (during last 6 mo)	-0.86	-2.0, 0.24	0.13	0.42
Shortness of breath (during last 6 mo)	-0.91	-2.0, 0.14	0.09	0.40
Chest pain with breathing (during last 6 mo)	-1.0	-2.2, 0.20	0.10	0.36
FVC	-0.05	-0.13, 0.02	0.16	-
FEV_1	-0.03	-0.10, 0.03	0.34	-
FEV_1/FVC	0.01	-0.03, 0.05	0.70	-
PEFR	0.04	-0.06, 0.14	0.48	-
FEF_{25-75}	-0.02	-0.14, 0.11	0.77	-

CI: confidence interval; OR: odds ratio; mo: month
FVC: forced vital capacity; FEV_1: forced expiratory volume at 1 second
PEFR: peak expiratory flow rate; FEF: forced expiratory flow

Based on the data collected, the variation in respiratory outcomes could not be predicted, with the exception of FEV_1. A multivariable linear regression model (Table 4.6) shows that both family size and milk income explained approximately 16% of the variation in FEV_1 (R^2=0.16). For every increase in family size (by one member), there was an average reduction in the percent-predicted FEV_1 in the women of 0.02, after adjusting for milk income. Table 4.6 also shows that women with a monthly milk income of ≥5000 KSH experienced, on average, a reduction of percent-predicted FEV_1 of 0.07, compared to women living on farms with an average monthly milk income of <5000 KSH, after controlling for family size.

Table 4.6. Multivariable linear regression model of FEV_1 (n=60), June data.

Variable	Coefficient	Standard error	P value	95% CI
Family size	-0.02	0.01	0.02	-0.04, -<0.01
Milk income				
<5000 KSH	referent	-	-	-
≥5000 KSH	-0.07	0.03	0.03	-0.14, -0.01
constant	1.02	0.04	<0.01	0.95, 1.10

CI: confidence interval

The final model was tested for linear regression model assumptions. A histogram of the standardized residuals and a quantile-quantile plot demonstrated normality. The Cook-Weisberg test showed no violation of heteroscedasticity and all potentially influential observations or outliers were assessed using Cooke's distance, with no important observations being identified (modified Cook's distance=10.8).

4.5 DISCUSSION

Women in the referent group were more likely to report experiencing respiratory symptoms such as shortness of breath (dyspnea), coughing or chest pain while breathing, during the last 6 months, compared to women in the biogas group (Table 4.2). The 19% difference in chest pain reported between the biogas (16%) and referent (35%) groups means that the prevalence of chest pain in the referent group was more than double (120%) the chest pain in the biogas group. Similarly, the 23% difference in shortness of breath reported between the biogas (29%) and referent (52%) groups means that the prevalence of shortness of breath in the referent group was nearly double the prevalence in the biogas group (Table 4.2). While these results were not statistically significant, the large differences were likely attributable to the women in the referent group spending, on average, 2.9 times more time collecting firewood per week and 120% more time exposed to wood smoke while cooking per week, compared to women in the biogas group(53,70). Studies investigating fuel use and stove interventions in rural Mexican and Guatemalan cookhouses have shown that reducing biomass fuel use and wood smoke exposure also resulted in women reporting fewer respiratory symptoms such as wheeze, cough, difficulty breathing, and phlegm production(8,43), supporting the findings from this study. Prevalence estimates for respiratory symptoms in general populations are suspected of being underestimated in many cases(71). However, estimates from Australian populations have shown that dyspnea rates can range from 8 to 27% in the general population, when reporting on the past 6 months(72,73). These rates are much lower than what the participants from this study were reporting, for the referent group, and more comparable to rates reported in the biogas group, indicating that rates of dyspnea among the referent women can be much higher than other populations.

One study from a randomized stove intervention trial in Guatemala investigated the self-rated health improvements for women after installation of the improved stove, for the intervention group(6). The authors of that study found that approximately 53% of the women reported improvements in their health after the installation of the intervention stove(6). In this study, 87% of women reported that their health improved after the installation of the biogas digester. Ninety-seven percent of the participants reported inhaling less smoke while cooking and 52% reported having fewer respiratory problems (Table 4.3). The aforementioned study was able to collect data pre- and post- intervention while the current study relied on collecting information solely after the installation of the biogas digester. However, an 18-month follow-up period in the Guatemalan study meant that both groups of women were asked to report on health improvements at similar times, post-intervention.

No important differences with respect to age, family size, and number of cows were found between the two groups of women that participated in the study (Table 4.1), demonstrating that the matching process was effective. Further, there were no significant differences between the groups in education, income, or employment of the participant or her husband, and consequently these variables were unlikely to be confounders of any relationship between biogas farm status and respiratory outcomes. There were also no differences in the physical measures (e.g. weight, height, respiratory rate), which would affect spirometry outcomes, between the two groups of women, although women in the biogas group were slightly heavier, on average, compared to the referent group.

Results from the spirometry testing showed that all measures taken for Kenyan farmwomen were lower than the predicted values for a similar population of African-Americans, with the exception of the ratio between FEV_1/FVC. However, none of the percent-predicted values was below 80%. The Global Initiative for Chronic Obstructive Lung Diseases (GOLD) reports that a percent-predicted FEV_1 value ≥80% and a FEV_1/FVC ratio >0.7 provides no indication of COPD presence(40). According to these standards, average spirometric measures for the participants indicate normal lung function, and there were no clinical or statistical differences between the biogas and referent groups.

Spirometry references for populations such as in Kenya are difficult to find and none exist that evaluate the effects of a biogas digester on respiratory function. However, our spirometry results are in concordance with results presented from the Guatemala randomized stove intervention trial(8). That study also showed that none of the participants had spirometry results indicative of COPD, and there were no differences in lung function between intervention and control groups(8). It is possible that no effects of respiratory function were detected between the biogas and referent groups because there was not enough time, since installation, for the effects to manifest clinically. Women living on farms with biogas digesters had less than 2 years from installation, compared to a lifetime of wood smoke exposure, and in some situations the biogas digesters were not functioning optimally until March of 2010. The participants also continued to supplement methane fuel use with wood fuel in situations where insufficient amounts of methane were produced or when cultural traditions impeded methane use (e.g. cooking the traditional dish, Githeri, with wood). This continued exposure to lower amounts of wood smoke may have also contributed to no changes in respiratory function.

Results from the multivariable linear regression model for FEV_1 showed that both family size and milk income predicted approximately 16% of the variation in the spirometry outcome (Table 4.6). Intuitively, a larger family size increases general workload, consequently resulting in decreased FEV_1 measures for the women. The participants with milk incomes ≥5000 KSH were significantly older ($p=0.05$) than the participants in the lower milk income bracket, by 5 years, on average. Age was not included in the multivariable model because it was previously controlled for twice - biogas and referent participants were matched, within 5 years, for the age of the woman, and age was among the factors used when generating the percent-predicted values for the spirometry outcomes. While age was adjusted for in the percent-predicted values for FEV_1, it is possible that age partly explains the relationship between increasing milk income and decreased FEV_1.

4.5.1 Limitations

There was a moderate association between having a biogas digester and reporting fewer negative respiratory symptoms (although not statistically significant), however, no association was present for the spirometry outcomes (Table 4.5). It is possible that the small number of participants began to experience improvements in respiratory health that were not yet clinically evident. However, relying on self-reported measures lends to the possibility for reporter bias among participants. Thus, two limitations of this study were the sample size and the time frame in which the study was conducted. Only 31 farms had biogas digesters installed, to serve as the biogas group, so the numbers of participants may have been too small to detect any clinical differences in respiratory health. Also, the digesters were installed before the initiation of the study, so a pre- and post-comparison was not possible. The amount of time that elapsed since the installation (between 3 and 24 months) of the biogas digester until the data collection period (June/July 2010) may also have been too short for any improvements in respiratory function to develop.

Certain language and cultural factors may also have affected the data collection during this study. All the women participating in this study communicated primarily in a local language called Kikuyu. Consequently, the nurse conducting all spirometry testing had to work through a translator who was not familiar with the spirometry equipment or language. As a result of the language barrier, some difficulties arose in explaining the instructions of how to properly complete the spirometry tests to the participants. For example, terms such as inspiration and expiration did not translate into Kikuyu; this language has a limited number of ways of saying ‘breathe’. In future study, a translator with medical knowledge would likely be beneficial.

4.5.2 Conclusions

This study provides evidence that having a biogas digester is associated with improved respiratory systems among women living on rural Kenyan dairy farms. The majority of women living on biogas farms reported improvements in general health, inhalation of wood smoke, and respiratory problems, attributable to the installation of the biogas digester.

None of the spirometry results, for either group of women, indicated any presence of obstructive pulmonary disease, and there was no significant difference in spirometry results between groups. Further investigation, with greater numbers of participants having biogas digesters for a longer period of time, would be beneficial to determine if there are any clinically important measureable effects of biogas digesters on respiratory health for Kenyan farmwomen.

CHAPTER 5: CONCLUSION

5.1 CONCLUSIONS

A report by the US Department of Energy on biomass cook stoves highlights a 50% reduction in fuel use and 90% reduction in emissions, relative to baseline technology, as important targets in global improvements to cook stoves. The current study showed that biogas digesters are an alternative and sustainable fuel source, for cooking, which can reduce wood fuel consumption by approximately 40% (25 lbs/day to 14 lbs/day), for the average family of three people with three dairy cows. The reduction in wood fuel use not only lowers exposure to wood smoke but can also reduce negative impacts on the environment by minimizing wood harvesting for fuel and by minimizing harmful greenhouse gas emissions.

This study also found that women with biogas digesters spent less money buying wood and other fuels, and saved time during the week by reducing the collection and transportation times for procuring firewood. Consequently, women had more disposable income and had more time for other productive activities. Equally importantly, this study showed no seasonal variation in the effects of the biogas digester. For a country such as Kenya, that has seasonal changes in temperature and rainfall, it is important that technologies used to mitigate wood smoke exposure and reliance on biomass fuel function well during the entire year. It is also important to note that this solution cannot work in all situations. The methane production and wood fuel reduction depend on how many cows the family has to feed the digester, and the biogas digester also requires water to operate. This type of small-scale biogas digester may be most ideally suited to family farms, with enough livestock to support the digester, in areas where chronic water shortages are not a concern(18).

Literature exists quantifying the effects of particulate matter (PM) exposure to human health, and the reductions in PM concentrations in kitchens and cookhouses where improved stoves are installed(36). There is however, a deficiency of information on quantifying the species and concentrations of VOCs in kitchens and cookhouses in rural developing countries. Although this study was small, and perhaps underpowered to detect significant changes in VOC concentrations, it provided valuable information to contribute to the establishment of VOC profiles in rural Kenyan cookhouses, where women are relying primarily on wood fuel. The results from this study also demonstrated that there were differences in the concentrations of individual VOCs between biogas and referent farms, and that on average, the concentrations were lower in cookhouses on farms using biogas digesters than farms without biogas digesters. Although the results from this study did not conclusively demonstrate reductions in VOC exposure for the farmwomen, the results showed that women with biogas digesters spent substantially less time cooking over a wood fire compared to women in the referent group. By reducing time spent cooking over a wood fire, women are being exposed to smaller amounts of wood smoke and are almost certainly experiencing reductions in VOC and PM exposure.

Lastly, results from this study contribute to the existing literature that women report fewer negative health outcomes and improvements in health and quality of life from the reduction of wood smoke exposure and wood consumption. In this study, women reported having fewer respiratory symptoms, such as shortness of breath and chest pain while breathing, due to the installation of the biogas digester. The women also reported improvements in their general health and the health of their children, attributable to the installation of the biogas digester. Relying on self-report measures for health and quality of life lend to the possibility of reporter bias. However, when at all possible, combining self-reported results with clinical measures increases validity. In this case, the spirometry results did not show significant differences in lung function between the two groups of women, and the percent-predicted values were normal for all spirometry measures. It is possible that the sample size and time to effect from the installation of the biogas digester were insufficient for detecting changes in lung function. It is also possible that no changes in lung function were observed because wood smoke exposure was not completely eliminated. Many women with biogas digesters continued to supplement methane use with wood if the methane produced did not satisfy fuel needs or if they were cooking traditional dishes, such as githeri, that require high heat for an extended period of time.

5.2 Strengths and Limitations

The primary strength of this study was that the researchers were afforded the opportunity to work closely with this community in order to evaluate many possible effects of installing biogas digesters on rural, smallholder dairy farms – a topic on which little literature exists. The close ties existing between the Kenyan community and Farmers Helping Farmers (FHF) meant that there was no resistance to the project implementation in the area, and that participants were not hesitant to divulge some of the more intimate details of their lives. Given the rural nature of the community, attempting such a study, without connections to local translators and project coordinators, would consume considerable resources and time.

While the access to the farms and the participants' willingness to facilitate data collection was a huge advantage for this particular study, the sample size provided the greatest limitation. From the onset, the number of biogas farms able to participate in the study was limited to the 31 farms with biogas digesters installed in 2008 and 2009. Also, collecting detailed data in such a rural setting requires substantial resources, putting more constraints on the feasibility of larger-scale studies, which are needed to generate more conclusive evidence(18). Having such a small sample size in field studies reduces the ability to detect effects, and minimizes the amount of detailed quantitative analyses that can be conducted.

Secondly, unavoidable design features could have led to some biases in the results. Because the biogas digesters were not installed primarily for scientific research, they were not randomly distributed throughout the Wakulima Dairy Limited (WDL) membership. It is possible that the groups of participants, compounded by the small sample size, were not truly representative of the entire WDL population. However, matching made the referent group comparable to the biogas group, making comparisons between the groups reasonably valid. Also, the method by which referent farms were selected introduces the potential for selection bias. The basis of the chain referral method relies on the referral of potential participants by existing study participants. These participants are likely to refer others of similar situation. Requesting multiple potential referrals from each study participant, to generate a list from which the referent participant could be randomly chosen, aimed to reduce this potential bias.

5.3 Implications

In some cases, the evaluation of development programs is lacking; efforts are put towards implementation of projects, without putting an emphasis on the evaluation of the benefits. Results for this research project provide valuable information for the benefits of installing biogas digesters, one type of alternative cook stove, and contribute to field protocols used in evaluating similar technology. The data from this study elucidate the reduction in wood fuel use that may be possible with biogas digesters, and create profiles of VOC emissions generated in cookhouses of both biogas and referent farms. These are two important targets, fuel and emission reduction, identified by the US Department of Energy, for cook stove improvement initiatives(18). By assessing respiratory health outcomes, exposure to VOCs, wood consumption, and time spent collecting wood for fuel, there are now data to fill in gaps in knowledge surrounding biogas digester use, for fuel reduction, environmental impacts, and women’s health. These data also provide insight into potential benefits of installing biogas digesters for other smallholder dairy farms located in rural areas outside of the Mukurwe-ini district and areas outside of Kenya.

5.4 Future Research

This study identifies huge potential for future research. Pre- and post- implementation evaluations of alternate cook stove technologies, in the field, is needed to elucidate their effects and their functionality in other specific geographic and lifestyle situations, especially since biogas digesters may not function ideally in all circumstances. Further to this point, the evaluation of the effects of biogas digesters on reducing reliance on wood as fuel and wood smoke exposure in areas outside of central Kenyan or on other types of farms (other than smallholder dairy farms) would provide more evidence to support the use of this technology as an alternate fuel source.

A more comprehensive assessment of indoor air quality (such as PM, CO, NO_2 etc.) for the cookhouses of families using biogas digesters would provide more detailed evidence of the effects of biogas digesters on indoor air pollution in cookhouses. Research is also needed to investigate the specific sources (wood combustion, structure off-gassing, methane combustions etc.) of the different VOCs present in the cookhouses.

5.5 Dissemination

The information generated by this study will be disseminated at three levels. Results from the study will be provided to all individual study participants and all members of the WDL as soon as the study is completed. Information will also be incorporated, as a lay summary, into documents for FHF, to be used as information for the general public about projects associated with the organization. Finally, scientific results will be published in peer-reviewed journals, and will be presented at the International Conference for

Environmental Epidemiology (September, 2011) and at the University of Prince Edward Island. Some of the results were already presented at The Canadian Conference for Global Health (November, 2010) and the Canadian Society for Epidemiology and Biostatistics student conference (May, 2010), as well as at Dalhousie University.

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APPENDIX A

BIOGAS DIGESTER EVALUATION SURVEY JUNE 2010

PARTICIPANT NUMBER: _____
SURVEY DATE: ________________________
INTERVIEWER: _________________________
Age of participant: _____ years
Number of cows: _____ calves: _____
Number of people cooking for: _____
Number of people living in house: _____

Section 1: Wood Collection during the last month

1.1 How much time per week, on average, do you spend collecting wood for cooking? _____ min

1.2 If you have a biogas digester how much time per week did you spend collecting wood, on average, for cooking prior to getting your biogas digester? _____ min

1.3 How much money per week, on average, do you spend on wood for cooking? _____ KSH

1.4 If you have a biogas digester how much money per week did you spend on wood, on average, for cooking prior to getting your biogas digester? _____ KSH

1.5 How much money per week, on average, do you spend on other fuels for cooking? ____ KSH

1.6 If you have a biogas digester how much money per week did you spend on other fuels, on average, for cooking prior to getting your biogas digester? _____ KSH

1.7 Do you get wood that has been dried for 6 months or more? Yes No

1.8 When you get wood for cooking, how often do you cut down a whole tree?

a) everyday
b) every week
c) every month
d) a few times during the year
e) once during the year
f) never

1.9 When you get wood for cooking, how often do you cut limbs off of a tree?

a) everyday
b) every week
c) every month
d) a few times during the year
e) once during the year
f) never

1.10 Actual measure of amount of wood burned for cooking on a normal day? _____ lbs

1.11 Observations of the wood as green or dry.   Mostly green   Mostly dry

Section 2: Wood Burning and Cooking

2.1 What is the main source of fuel for cooking in your house?
charcoal
firewood
biogas
other ___________

2.2 For ventilation, does your cooking area have a:
chimney
hood
windows
other _________

2.3 How often do you burn the following things as fuel in your cookhouse?

	Every day	Every week	Every month	Not every month	Never
a) Plastic					
b) Crop waste					
c) Paper					
d) Cow dung					
Other _________					
Other _________					

2.4 How often do you use the following things to start fires for cooking?

	Every day	Every week	Every month	Not every month	Never
a) Plastic					
b) Crop waste					
c) Paper					
d) Cow dung					
Other _________					
Other _________					

Section 3: Historical Health Reporting

3.1 In the last 6 months, how often did you have difficulty breathing?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the last 6 months
- e) never

3.2 In the last 6 months, how often did you stop walking to rest, due to shortness of breath?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the last 6 months
- e) never

3.3 In the last 6 months, how often did you have problems with frequent coughing?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the last 6 months
- e) never

3.4 In the last 6 months, how often did you have chest pain with breathing?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the last 6 months
- e) never

3.5 In the last 6 months, how often did you use medicine to help you breathe?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the last 6 months
- e) never

3.6 In the last 6 months, how often did you have irritated eyes?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the last 6 months
- e) never

3.7 In the last 6 months, how often did you use medicine for your eyes?
a) every day
b) a few times each week
c) a few times each month
d) a few times during the last 6 months
e) never

3.8 In the last 6 months, how often did you have back pain?
a) every day
b) a few times each week
c) a few times each month
d) a few times during the last 6 months
e) never

3.9a Do you currently have a lung disease diagnosed by a doctor? Yes No
3.9b If yes, describe ___________________________
3.9c If no, have you ever been diagnosed with a lung disease by a doctor? Yes No
3.9d If yes, describe ___________________________

3.10a Do you currently have an eye problem diagnosed by a doctor? Yes No
3.10b If yes, describe ___________________________
3.10c If no, have you ever been diagnosed with eye problems by a doctor? Yes No
3.10d If yes, describe ___________________________

3.11a Do you currently have a back problem diagnosed by a doctor? Yes No
3.11b If yes, describe ___________________________
3.11c If no, have you ever been diagnosed with back problem by a doctor? Yes No
3.9d If yes, describe ___________________________

3.12 Generally speaking, how is your health? Good Fair Poor

Section 4: Biogas Digester Maintenance and Perceptions (for those who have one)

4.1 If you have a biogas digester, how much time per week do you spend maintaining the digester with the following activities:
collecting water in the rainy season ________ *min*
collecting water in the dry season ________ *min*
filling the digester with manure ________ *min*
filling the digester with water ________ *min*
removing composted manure from the digester ________ *min*
other (specify ____________________________) ________ *min*
other (specify ____________________________) ________ *min*

4.2a Have you had any problems with your biogas digester? Yes No

4.2b If yes, what kind of problems?

4.2c. If yes, how much time did it take to resolve?

4.3 What do you do with the digested manure from the digester?

4.4 Is this different from what you do with manure that is not put in the digester?

4.5 How much money per year do you spend on your biogas digester? _____ KSH

4.6 How much time each day can you cook with your biogas digester? _____ min

4.7 How would you rank the following effects of having a biogas digester?
(1 = strongly disagree; 2 = disagree; 3 = don't know; 4 = agree; 5 = strongly agree)

a. Your health is better	1	2	3	4	5
b. Your children's health is better	1	2	3	4	5
c. It saves you time so that you have more time for other things	1	2	3	4	5
d. It saves your children time so that they have more time for other things	1	2	3	4	5
e. You have fewer problems with sore muscles	1	2	3	4	5
f. Your children have fewer problems with sore muscles	1	2	3	4	5
g. It allows your children to go to school	1	2	3	4	5
h. It saves you money	1	2	3	4	5
i. It takes less time to cook	1	2	3	4	5
j. It is cooler in the cooking area	1	2	3	4	5
k. You breathe in less smoke	1	2	3	4	5
l. Your children breathe in less smoke	1	2	3	4	5
m. You have less eye irritation	1	2	3	4	5
n. Your children have less eye irritation	1	2	3	4	5
o. You have fewer headaches	1	2	3	4	5
p. Your children have fewer headaches	1	2	3	4	5
q. You have less breathing problems	1	2	3	4	5
r. Your children have less breathing problems	1	2	3	4	5
s. You have less back problems	1	2	3	4	5
t. Your children have less back problems	1	2	3	4	5
u. You have fewer other health problems (describe)	1	2	3	4	5
v. Your children have fewer other health problems (describe)	1	2	3	4	5

w. You worry less about children getting burned	1 2 3 4 5
x. Your skin is cleaner	1 2 3 4 5
y. Your pots are cleaner	1 2 3 4 5
z. Your clothes are cleaner	1 2 3 4 5
aa. Your hair is cleaner	1 2 3 4 5
ab. Other benefits (describe)	1 2 3 4 5

Section 5: Personal Questions

5.1 Number of children living at home with you: _____

5.2 Are you currently pregnant? Yes No

5.3 In the last year, how often did you smoke cigarettes?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the year
- e) never

5.4 In the last year, how often did someone else in your house smoke cigarettes?
- a) every day
- b) a few times each week
- c) a few times each month
- d) a few times during the year
- e) never

5.5 What is the highest level of education you have obtained?
- a) no formal schooling
- b) Standard 4
- c) Standard 8
- d) Form 4
- e) Technical College
- f) University

5.6a Do you have employment off of the farm? Yes No

5.6b If yes, describe ________________________________

5.6c If yes, average monthly income from this job?
- a) Less than 5000 KSH
- b) 5,000 to 10,000 KSH
- c) Over 10,000 KSH

5.7 Monthly income from selling milk?
- a) Less than 5000 KSH
- b) 5,000 to 10,000 KSH
- c) Over 10,000 KSH

5.8a Do you have a husband? Yes No
5.8b. If yes, does your husband have employment off of the farm? Yes No
5.8c If yes, describe ___________________________________

5.8d If yes, average monthly income from this job?
- a) Less than 5000 KSH
- b) 5,000 to 10,000 KSH
- c) Over 10,000 KSH

5.9a Does someone else do some of the cooking in your household? Yes No
5.9b If yes, what percentage of the cooking do you do? _____ %

Section 6: House & Picture Information

6.1 Size of cookhouse: length _____ width _____ height _____

6.2 Cookhouse picture identification #s: ____________________

6.3 Biogas digester picture identification #s: ____________________

6.4 Eye picture identification #s:
- Left inside: __________
- Left outside: __________
- Right inside: __________
- Right outside: __________

MONITORING FORM FOR WOOD BURNING AND BIOGAS BURNING

Study ID Number: _________ Date: ___________

Please record, to the nearest 10 minutes, the time when a wood fire was burning at your house, when a biogas fire was burning at your house (if you have a biogas digester), and the time you spent beside the wood fire or biogas flame. Use the first 2 columns as examples.

Time	Example: Time when a wood fire was burning at your house for cooking	Example: Time you spent beside the wood fire	Time when a wood fire was burning at your house for cooking	Time you spent beside the wood fire	Time when a biogas fire was burning at your house for cooking	Time you spent beside the biogas flame
4 am						
5 am						
6 am	Started at 6:00	30 minutes				
7 am		20 minutes				
8 am	Finished at 8:10	10 minutes				
9 am						
10 am						
11 am						
12 noon	Started at 12:20	20 minutes				
1 pm	Finished at 1:00					
2 pm						
3 pm						
4 pm						
5 pm	Started at 5:10	40 minutes				
6 pm		20 minutes				
7 pm						
8 pm	Finished at 8:20	10 minutes				
9 pm						
10 pm						
11 pm						
12 midnight						
1 am						
2 am						
3 am						

RESPIRATORY ASSESSMENT

Name: ID#:

DOB: Age:

Height: Weight:

Resting Respiratory Rate: Resting Pulse:

Time for Inspiration: Time for Expiration: Ratio:

Blood Pressure: O_2 Saturation:

Spirometry:

Efforts	**Predicted**	**1st**	**2nd**	**3rd**
FVC				
FEV_1				
FEV_1/FVC				
PEFR				
FEF_{25-75}				

Piko Meter:

Efforts	**1**	**2**	**3**	**4**	**5**
FEV_1					
PEF					

Observation: chest wall deformities

Yes __ No __ Barrel chest - chest wall increased anterior-posterior

Yes __ No __ Pectus excavatum - sternum sunken into the chest

Yes __ No __ Pectus carinatum - sternum protruding from the chest

Observation: signs of respiratory distress

Yes __ No __ Cyanosis - blueshade to mucous membranes

Yes __ No __ Pursed-lip breathing

Yes __ No __ Accessory muscle use (scalene muscles)

Yes __ No __ Intercostal indrawing

Yes __ No __ Cough
    Yes __ No __ Productive (cough)
    Colour of sputum _____________

Palpation

Yes __ No __ Tracheal deviation - check whether trachea is in centre line

Yes __ No __ Respiratory expansion - check whether expansion is equal

Yes __ No __ Check for any lumps that may interfere with breathing

Yes __ No __ Check for any tenderness that may interfere with breathing

Yes __ No __ Location of apex beat - check if there has been deviation of heart

Auscultation

Yes __ No __ Inspiratory crackles

Yes __ No __ Expiratory wheezes (asthma, emphysema)

Yes __ No __ Stridor and other upper airway sounds

Yes __ No __ Bronchial vs. vesicular breath sounds

APPENDIX B

GENERAL INFORMATION FOR RESEARCH PARTICIPANTS

Letter of Information

We invite you to participate in a research study titled: **Impact of biogas digesters on health and quality of life measures of Kenyan farmwomen.** Your participation in this study is voluntary and you may stop participating in the study whenever you want.

Who will be conducting the project?

We are a research team from the University of Prince Edward Island and Dalhousie University in Canada and the University of Nairobi in Kenya. Dr. John VanLeeuwen (adjunct faculty) and Dr. Judy Guernsey (faculty) from the Department of Community Health and Epidemiology at Dalhousie will supervise the research.

We will describe the study to you, to explain what the study involves and any potential risks, inconveniences, or discomfort you may experience. If you participate in the study, you may not benefit from it directly, but we might learn things that will benefit others. Ruth Wanjiru will be happy to talk about any questions you have about the study.

Purpose of the study and study design

We are conducting this study to find out if there are differences in exposure to smoke and toxins for women with and without a biogas digester. We also want to find out if there are differences in breathing and eye problems, the amount of wood women, such as yourself, use for fuel and the time you spend searching for wood for women with and without a biogas digester.

We will visit all the farms in the study in February and July 2010. When we visit your farm, we will interview the woman that does most of the cooking. The interview will aim to find out 1) how much time it takes to fetch wood per day; 2) the weight of the wood you burn per day; and 3) any breathing and eye problems that you have now or have had in the past. We will also ask you to wear a small tube for one week. The tube collects air from your cookhouse so that we can take it back to Canada to determine what kind of pollutants are in the air in your cookhouse. For this to work we will ask you to keep track of the amount of time you spend in your cookhouse and how much of that time is spent cooking with methane gas (if applicable).

While we are at your farm we will also have a nurse do a basic breathing exam to check the health of your lungs. The exam is very discrete and you will not be required to remove any of your clothes. The exam will not hurt in any way and does not involve risk of any harm to you. The nurse will observe and examine your chest wall for abnormalities and will listen to your breathing sounds using a stethoscope.

Who can participate in the project?

The study includes 30 women from farms that are members of the Wakulima Dairy and have biogas digesters. There are also 30 women from farms that are members of the Wakulima Dairy that do not have biogas digesters. You are the woman from your farm that has been chosen to participate for your farm because you are the one that does most of the cooking.

Inclusion and Exclusion Criteria

There are only 32 farms that have biogas digesters, so we will ask women on all those farms to participate, until we get 30 participants. There are many farms in the Wakulima Dairy that don't have biogas digesters so we will select other women, matched for age, income and family size, from other member farms until we have 30 willing participants. Women will be selected based on potential participants identified by the women with biogas digesters.

What you will be asked to do, time commitment, and where the research will be done

For women living on farms without biogas digesters:

If you agree to participate in our study, we will arrange a time when we will visit you at your farm. We will give you an interview that has questions about your fuel use and health. You will also be asked to wear a small, clip-on tube (the size of a pen) that samples the air in your cookhouse. We can use this air sample to find out what kind of pollutants are in the air you breathe. In order to use the information from the tube, we will also ask you to keep track of the time you spend in your cookhouse burning. There will also be a simple breathing exam, which we have already described. The entire visit to your farm will only take 1-2 hours. When we visit your farm we will ask you to sign a consent form that says the study has been thoroughly explained to you and you are willing to participate.

Anonymity and Confidentiality

The research team (listed below) will keep all the information we collect during the farm visits confidential. We will ensure that you will not be identified from any of your responses when we are analyzing the information. To protect your privacy, we will identify your responses and questionnaire information by a number and not your name. We will only enter your responses into computers belonging to the researchers at Dalhousie University, Canada, and they will be protected by a password. At the end of the project when we produce the final report, it will not include any information that could be used to identify you individually. There will be no limitations or changes to this confidentiality.

The information identifying you will be kept on a separate sheet from the questionnaire and will be kept under lock and key in the Department of Community Health and Epidemiology at Dalhousie University. This sheet will only be used if we need to contact you because a response is unclear, if we seek permission to use a quote from your questionnaire responses, or if we need to seek permission to take the information we got from you in this study and use it in other studies. Your information will be kept under lock and key for 5 years and then it will be destroyed.
While in Kenya, hard copies of survey information will be kept in a locked room in a locked house. Soft copies of data will be stored on a computer and memory stick (back-up) that will also be kept in the locked room of the locked house.
If you want to stop participating in the study at any time before it is completed, your personal information will be treated the same as those who participated in the complete study. It will be kept under lock and key and destroyed after 5 years. However, if you wish, we can destroy your information immediately.

Potential Risks, Harms, Injuries, Discomforts or Inconvenience

There is minimal risk of harm or discomfort from participating in this study. The only inconvenience to you will be the time required to participate in a farm visit, which will be kept to a minimum.

Benefits and Compensation

If you have a biogas digester on your farm, you will have a better understanding of the costs and benefits of your biogas digester. If you do not have a biogas digester, you will also receive a report of the findings and will have a better understanding of the costs and benefits of a biogas digester to help you decide on purchasing a biogas digester. This project may be an incentive to save for one for your farm. Whether you have a biogas digester or not, you will receive a final report of the study form the Wakulima Dairy.

After we finish getting your information while we are on your farm for the visit you will receive dewormer for two cows, which is valued at about $10 (731 KES), as compensation for your time and effort. You will also receive free animal health services (application of the dewormer) and information (factsheet). Then, if you agree to continue to participate in the second phase of the study, a second farm visit will be scheduled. During the second farm visit you will again receive dewormer and its application for two cows. Also, you will be given a watch ***upon the first farm visit (February for women with biogas digesters and July for women without biogas digesters)*** as a gift that you can keep after the second phase of the study. The watch will allow you to keep more accurate times of cookhouse smoke exposure, use of methane gas, and time spent fetching wood.

Conflict of Interest

The funds used to complete this study are from Dalhousie University, University of Prince Edward Island, The RURAL Centre and Farmers Helping Farmers, a non-profit organization. None of the researchers will receive any direct or indirect benefits from the research, other than those normally expected from research projects (intellectual benefits form learning more about a problem or situation, reputational benefits among other scientists from well-done research, and possibly occupational benefits in the form of promotions or awards from well-done research).

There could be a chance that the information we get from this study will be used for commercial purposes. However, none of the researchers have commercial involvement with the manufacturers of the biogas digesters, and we will not benefit personally from the manufacture and sale of biogas digesters.

Participation

Taking part in this study is completely voluntary. You can choose to withdraw your participation in the study at any time. If you would like to withdraw from the study, all you have to do is tell the Kenyan or Canadian project leaders (contact information below) or tell someone at the Wakulima Dairy office. You do not need to give any reason for choosing to withdraw and you will not experience any negative repercussions from withdrawing from the study.

The study will be done according to the ethical guidelines established by the Canadian Tri-Council Guidelines for Involvement of Human Subjects in Research published by the National Sciences and Engineering Research Council, the Social Sciences and Humanities Research Council and the Canadian Institute for Health Research.

We will give you a copy of the consent form, once you sign it or give oral consent.

The Office of Research Ethics of Dalhousie University in Canada has reviewed this research project. If you have any difficulties with, or wish to voice concern about, any aspect of your participation in this study, or the ethical conduct of this study, you may contact:

Patricia Lindley, Director of the Office of Research Ethics Administration
5248 Morris St. Dalhousie University
Halifax, Nova Scotia, Canada B3J 1B4
Phone: (902) 494-1462
Email: Patricia.Lindley@dal.ca

The project team includes:

Ruth Wanjiru
Kenyan Project Coordinator, Mukurwe-ini, Kenya
Dr. Judy Guernsey
Associate Professor of Epidemiology, Dalhousie University, Canada

Dr. Mark Gibson
Assistant Professor of Air Quality, Process Engineering and Applied Science, Dalhousie University, Canada
Dr. John VanLeeuwen
Professor of Epidemiology, University of Prince Edward Island, Canada
Dr. Kim Critchley
Associate Professor of Nursing, University of Prince Edward Island, Canada
Ms. Carolyn Dohoo
Graduate Student in Community Health and Epidemiology, Dalhousie University, Canada

* Note that none of the names above with the Dr. title is a physician, but rather a professor

Contact:
If you have any questions about this project, please contact:

Ruth Wanjiru
Kenyan Coordinator
0722-215235
Carolyn Dohoo or John VanLeeuwen
Canadian Project Leaders
carolyn.dohoo@dal.ca
jvanleeuwen@upei.ca

CONSENT FORM

Name: ______________________________ Study ID number: ___________

Project: Impact of biogas digesters on health and quality of life measures of Kenyan farmwomen.

By signing this form, I agree that:

• The project has been explained to me. □ Yes □ No

• All my questions were answered. □ Yes □ No

• The possible harms and benefits of this project have been explained to me. □ Yes □ No

• I understand that I have the right not to participate and the right to stop while the project is underway. □ Yes □ No

• I understand that I may withdraw without any negative effect to me. □ Yes □ No

• I have a choice of not answering any specific questions. □ Yes □ No

• I am free now, and in the future, to ask any questions about the project. □ Yes □ No

• I have been told that my name and address and information will be kept confidential. □ Yes □ No

• I understand my name and address will not be released or printed without asking me first. □ Yes □ No

• I understand that I will receive a signed and dated copy of this consent form. □ Yes □ No

• I agree that you may seek permission for future use of my data for other studies □ Yes □ No

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OVERALL PARTICIPANT CONSENT:

"I, (Participant First and Last Name) ___________________________*, consent to take part in this study."*

□ Yes □ No

PARTICIPANT AUTHORIZATION FOR FUTURE CONTACT:

"I also agree to continue participation in the second visit of this project in about a six month's time."

(relevant for women on farms with biogas digesters only) □ Yes □ No

PARTICIPANT AUTHORIZATION FOR QUOTATION USE:

"I also agree to substantial quotation use from the interviews, but only if I remain anonymous."

□ Yes □ No

Name of researcher who obtained consent: ___________________________

_____________________________ ___________________

Signature Date