DEGREE PROJECT IN TECHNOLOGY,
FIRST CYCLE, 15 CREDITS
STOCKHOLM, SWEDEN 2019

Use of Biochar Producing Cookstoves in Rural Kenya

Energy efficiency, air pollution concentrations, and biochar production potential

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This study has been carried out within the framework of the Minor Field Studies Scholarship Program, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida.

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Abstract

Household air pollution annually kills around 14 300 people in Kenya, due to the hazardous smoke of incomplete combustion coming from inefficient stoves. Exposure to this smoke leads to lethal health issues for the women and children staying in these kitchens, but the smoke also leads to a contribution to global warming. Which makes it important finding a replacement for the inefficient traditional cooking methods.

This report presents results from a field work situated in Kibugu, Embu in central Kenya. It includes testing of three stoves, the traditional Three stone open fire and two biochar producing stoves, the previously tested stove Gastov made by KIRDI and the MiG|BioCooker made by Make It Green Solutions AB. The data was collected using participatory cooking tests where five households got to cook the traditional meal Ugali with Sukuma wiki and Githeri (maize and beans). Firewood consumption, emissions of CO and PM, user experience and char production were measured during the test, to be able to compare the stoves.

The results indicate that the MiG|BioCooker can decrease the emissions of $PM_{2.5}$ and CO in the kitchens and produce biochar. But on the other hand, cooking with three stone open fire more effective in terms of cooking time. Even though the MiG|BioCooker could improve the conditions of the household's indoor air, the users seems to prioritize the practical characteristics of the three stone open fire that gives them more time and making it easier to cook. But with some modifications and by further use of the MiG|BioCooker, it might be a possible substitute to the three stone open fire in the future.

Keywords: Biochar, improved cooking stoves, three stone open fire

Acknowledgement

This Bachelor thesis was a part of the project *Bio-char and smallholder farmers in Kenya*, which is a collaboration between World Agroforestry (ICRAF), Swedish University of Agricultural Sciences (SLU), International Institute of Tropical Agriculture (IITA), Lund University and KTH Royal Institute of Technology. This thesis is the final step getting a bachelor's degree within Energy and Environmental Engineering and was funded by scholarships from Åforsk foundation and the Minor Field study program funded by SIDA, foundations that we would like to thank for giving us the funding needed to make this experience possible.

Supervisors for this thesis were Ph.D. Cecilia Sundberg, KTH and Ph.D. Mary Njenga, ICRAF and we would like to thank them for all the invaluable knowledge and help we have received. We thank staff at World Agroforestry for greeting us with such hospitality and thank KTH for this opportunity. We would also like to thank Lukong Pius Nyuykonge and Make It Green Solutions AB for producing the MiG|BioCooker and entrusting us with testing it out in the field.

We would also like to express our sincerest gratitude to James Kinyua for the patience and guidance during our field work. We would also like to thank our field coordinator Francis Njiru and his family. Franco, thank you for letting us become a part of your family and teaching us so many things that we will keep in our hearts forever. We would also like to thank all five households that agreed on helping us to make the tests possible Grace (mom), Julieta, Tabitha, Editor and Walter, asante sana for everything. Lastly, we would like to thank our fellow MFS students in Nairobi Agnes, Emil, Hilda, Jonas, Linda, Philip and Robin, thank you for all the support and rooftop talks.

Contents

Abbreviations and Acronyms

ARI – Acute lower respiratory infections

CAP – Country Action Plan

CCAK – Clean cookstoves association of Kenya

CCT – Controlled cooking test

CO – Carbon monoxide

CO_2 – Carbon dioxide

FGD – Focus group discussion

GHG – Greenhouse gas

HAP – Household air pollution

LPG – Liquefied petroleum gas

MPF – Migrating pyrolytic front

PM – Particulate matter

TLUD – Top-Lit updraft

WHO – World Health Organization

1. INTRODUCTION

Nearly 3 billion people depend on inefficient stoves and fuels to cook their food. Lack of clean cooking often means cooking with solid biofuels over open three stone open fire fires or inefficient stoves which contributes to climate change, forest degradation, air pollution, and poor health (The Global Alliance for Clean Cookstoves, 2018a). According to International Energy Agency (2017) over 846 million people lack access to clean cooking in Sub-Saharan Africa. Kenya which is a part of Sub-Saharan Africa is no exception with 86 percent of Kenya's population of 43 million people, relying on solid fuels (The Global Alliance for Clean Cookstoves, 2018a).

Cooking with inefficient stoves creates a lot of hazardous smoke which leads to a range of chronic illnesses and acute health impacts. Household air pollution alone contributes to about 4 million premature deaths per year, including 14 300 deaths in Kenya. The most affected is women and young children (The Global Alliance for Clean Cookstoves, 2018a). The smoke also contributes to high amounts of carbon dioxide emissions, which is one of the greenhouse gases that contributes most to climate change (The Global Alliance for Clean Cookstoves, 2018b).

Inefficient combustion of the solid biofuels not only creates hazardous smoke but also result in a higher demand of firewood. This is highly problematic as Kenya only has a 7% forest cover of the land area which is below the constitutional requirement of 10% (Kenya Forest Service, 2018; Sundberg, et al., 2018). It also forces women and children to spend many hours per week collecting firewood, around 1 hour per day (International Energy Agency, 2017).

Since traditional stoves have a low energy efficiency and produce high amounts of air pollution, Kenya has a high demand on more efficient and clean ways to cook. One opportunity for clean cooking is to use a stove that uses pyrolysis and produces heat for cooking and biochar that could be used for improvement of soil conditions consequently sequestering carbon. By heating biomass under oxygen-limited conditions it forms stable carbon structures, biochar, that helps soils retain nutrients and water (Sundberg, et al., 2018, p. 7).

A stove that produces biochar has a higher fuel efficiency than traditional stoves. This means that the families decrease their demand for biomass for cooking. With a closed combustion system, the air pollution decreases, which could improve the environment for the women and children while cooking. Another benefit with this kind of stove is that it produces less CO_2-emissions than traditional stoves. A biochar-producing cookstove comes with a range of applications that can help improve living conditions in Kenya as well as other African countries (Sundberg, et al., 2018, p. 9-10).

In previous studies of this kind of stove, the challenges were related to labor for fuel preparation, lightning and refilling of the stove (Gitau et al., 2019). The next step of this study is therefore to test a new kind of biochar-stove that could make the process for users easier since it is more continuous in refilling.

1.1. Aim

The aim of this study is to evaluate what possible effects local farm-level usage of the cookstove MiG|BioCooker have on fine particulate matter ($PM_{2.5}$) and carbon monoxide concentrations, energy efficiency, and biochar production potential. For collection of data a participatory cooking test will be done in Kibugu, Kenya. The MiG|BioCooker will be compared to the traditional cooking stove, the three stone open fire, and a previously tested gasifier stove called Gastov.

The objective was to evaluate how emission concentrations vary as well as to calculate energy efficiency of said biochar producing stoves. Derived results serve as a basis for evaluating possibilities on how to improve said stove as well as improving practical use.

Moreover, another objective was to investigate how users of the cookstove in rural households perceive its suitability for cooking, in comparison to the three stone open fire and the Gastov. This gives an indication of the potential for adoption of the cookstove in rural Kenya or required design modifications.

1.2. Research questions

- What are the concentrations of carbon monoxide and fine particulate matter in the kitchens when cooking the local meal Ugali and Sukuma Wiki with the MiG|BioCooker, compared to the three stone open fire and the Gastov?
- What is the energy efficiency of the three stone open fire, the MiG|BioCooker and the Gastov cooking the local meal Ugali and Sukuma Wiki?
- What is the produced char/fuel used ratio for each stove?
- How does the users perceive the MiG|BioCooker and its suitability for cooking, compared to the three stone open fire and the Gastov?

1.3. Delimitations

This report includes some measurements from a gasifier stove called Two-chamber, this stove is not discussed or compared in this report due to not being a subject of comparison in this study. The properties of the produced char, such as soil improvement etc., is not evaluated in this report nor is the properties of used fuel. The health and environmental impacts from the emissions is briefly discussed but the focus in this report is on the comparisons between stoves.

2. BACKGROUND

2.1. Current challenges in Kenya

The Clean Cooking Alliance set goals for working towards that people should not be depending on polluting inefficient stoves like open fires to cook their food. The Kenya Country Action Plan (CAP) made by Clean Cooking Alliance (2013) illuminate the problems by using ineffective cooking methods, like environmental impact, deforestation and health problems. In the Kenyan CAP, the Clean Cookstoves Association of Kenya (CCAK) set targets for 2020. These targets were that 7 million Kenyan households, and all institutions, will be using clean cookstoves and fuels for cooking and heating.

But it is not only the goals set by the CCAK that could be helped by finding improved ways for cleaner cooking. Many problems coming from inefficient cooking methods are closely linked to a variety of the sustainable development goals. For example, Goal 7: Affordable and Clean Energy where clean cooking is mentioned as one of the main aims within the goal (UN, n.d.).

2.2. Health

Exposure to smoke from incomplete combustion due to ineffective stoves has a big impact on the health of the people living in the developing world. World Health Organization (WHO) estimates the number of deaths annually in Kenya caused by household air pollution (HAP) to be 14 300 and that 14,9 million of the Kenyan population's health have been directly impacted by HAP (The Global Alliance for Clean Cookstoves, 2013). 67 % of this exposure is due to the use of traditional cookstoves and is mostly affecting women and children who spends the most time in the kitchen. These health problems are directly linked to SDG:s like Goal 3: Good health and well-being and Goal 5: Gender Equality (UN, n.d.).

Traditional cooking with solid fuels produces high emissions of particulate matter (PM), hydrocarbons and carbon monoxide out of which particulate matter and carbon monoxide has the most impact on health.

These emissions cause diseases like acute lower respiratory infections (ARI), chronic obstructive pulmonary disease and cancer. (International Energy Agency, 2006, p. 425-427; Desai, Mehta and Smith. 2004, p. 2). In Kenyan hospitals ARI are responsible for 26 percent of all deaths reported which makes it the second leading cause of death in Kenya (The Global Alliance for Clean Cookstoves, 2013). Young children exposed to household air pollution have two to three times bigger risk to catch ARI or childhood pneumonia (International Energy Agency, 2006, p. 425-427).

2.3. Environmental impact

The use of solid fuels for cooking and heating has several impacts on the environment, resulting in both higher emissions of greenhouse gases and higher demand of firewood leading to forest degradation.

The constitutional requirement of forest covered land in Kenya is 10%, but due to forest degradation there is only a 7 % coverage and it is declining (Kenya Forest Service, 2018). This makes the sustainable development goal 15 important for Kenya since it aims to support a more sustainable manage of terrestrial ecosystems (UN, n.d.). Buyinza et al. (2010) observed in their study that the underlying drivers for forest degradation is often complex and that the key drivers were policy conflicts - agricultural, settlement etc., low capacity to monitor the policies in place, agricultural expansion and harvesting of firewood and poles. 86 % of the Kenyan population rely on biomass for cooking (REN21, 2016).

The emissions from incomplete combustion of solid fuels like $PM_{2.5}$ and CO causing many different health problems, but they also have a lot of impact on the environment. PM consists of black carbon which is a potent component contributing to global warming. Black carbon is a short-lived pollutant with a lifetime of a few days to a few weeks, however the pollutant is very effective on absorbing light and warming surroundings and have 460-1 500 times stronger warming impact on climate than CO_2 per unit of mass.

Household cooking and warming stands for 58 percent of the global emissions of black carbon and is one of the components of the soot produced in the incomplete combustion. When this soot is being deposited on vegetation and ice it reduces the surface albedo and increases the temperature of the earth and contributes to the global warming (The Climate and Clean Air Coalition, n.d.)

Carbon monoxide has no direct impact on the environment like other GHG:s, instead it decreases the atmosphere's ability to reduce the lifetime of other strong greenhouse gases like carbon dioxide and methane. It reacts with OH radicals, and forms CO_2, which otherwise would have reacted with carbon dioxide and methane. Carbon monoxide also takes part in formation of lower-atmospheric ozone which affects both our health and the environment (Earth Observatory NASA, n.d.).

All these emissions contribute to the global warming and makes this problem closely connected to Goal 13: Climate action which aims to decrease the emissions of greenhouse gases to the atmosphere.

2.4. Cooking methods

The simplified way of describing the different stages of solid biomass combustion is by four stages: 1) drying, 2) pyrolysis, 3) wood gas combustion and 4) char gasification by gasifier cook stove (Roth et al., 2014). Both drying and pyrolysis requires heat which first removes all the excess moisture contained in the biomass. When the temperature reaches beyond 300°C the biomass starts to pyrolyze (break apart), as the temperatures start rising the biomass is completely converted into wood gas and the solid residue char. The creation of char is often termed carbonization. When converted the wood gas and char can be combusted with oxygen, wood gas combustion and char gasification.

When the fuel is in a gaseous state wood gas combustion takes place (Roth et al., 2014). These gases are ready to react with oxygen provided via secondary air. The process, called combustion, starts when the wood gases and oxygen is thoroughly mixed and ignited with a spark or heat from an existing flame. Ideally all the wooden gas should be oxidized to carbon dioxide and water vapor before leaving the combustion zone. The fourth stage, Char gasification, happens when primary air reaches the hot char. The primary air reacts with the char creating carbon monoxide which adds to the combustible wood-gases, and non-burnable solid minerals in the form of ash. By controlling the primary air, the char can be preserved and used as a soil amendment as biochar, thus sequestering carbon from the atmosphere.

2.4.1. Three stone open fire

The most common cooking technique in Kenya is cooking with solid fuels often burned on open fires called Three stone open fire (The Global Alliance for Clean Cookstoves, 2018a). A Three stone open fire consists of three stones of the same height arranged as a tripod. The unmodified Three stone open fire has spaces between each stone for putting in firewood, three sides in total. For the modified three stone open fire see Figure 2.1 the stones are put together with only one space for putting in firewood.

Figure 2.1 Modified three stone open fire

When cooking with the Three stone open fire the combustion process is uncontrolled, and all four stages of the burning process happens simultaneously. This uncontrolled combustion is causing the process to be incomplete, releasing undesirable emissions such as unburnt wooden gas, carbon monoxide etc. The unburnt wooden gas causes less energy efficiency and a higher demand for more solid fuel (Roth et al., 2014). The hazardous smoke, which partly consists of particulate matter, also contributes to chronic illnesses and acute health impacts (The Global Alliance for Clean Cookstoves, 2018a).

2.4.2. Gasifiers

The main idea behind the gasifier is separating the gas-generation and gas-combustion, controlling the inputs of heat and air making it a controlled environment (Roth et al., 2014). The fuel is converted into gases and vapors in a reactor designed to optimize heat-dependent drying and pyrolysis. These gases are then steered to a combustion zone where it is mixed with secondary air and burned, making the gasifier a gas-burning stove.

If the primary air is controlled and a limited amount or no amount of oxygen reaches the fuel, char-gasification can be prevented. This preserves the char which can be used as soil amendment.

There are two different ways to maintain the gas generation in a gasifier, allothermal and autothermal (Roth et al., 2014). Allothermal gasifiers has two separate fuels, one fuel outside the reactor, made for generating heat which will be used to pyrolyze fuel inside the reactor. Only the outside fuel has an air dependent combustion process. In an autothermal process the gasifiers produce its own heat inside the reactor, here a restricted amount of primary air is needed for partial combustion within the reactor. The restricted amount of primary air is just enough to burn a small amount of gases, generating enough heat to maintain the gas generation. Above the fuel bed there is a designated combustion zone where secondary air is added.

There are many parameter options and design features for gasifiers, one of the most common examples is the Top-Lit Up-Draft (TLUD) (Roth et al., 2014), which works like a lit match when holding it vertical with the head pointing upwards. A draft is created from the heat making the primary air move upward towards the unburnt wood and secondary air is mixed with the flame, which would be the combustion zone in a gasifier. In a TLUD gasifier the process is the same, the difference is that the fuel is any type of biomass filled in a container. The stacked fuel is lit from the top and moves downward in a migrating pyrolytic front (MPF). The MPF is a zone where a small amount of the wood-gas is combusted creating enough heat for the pyrolysis process. This front is moving downward leaving char behind and the wood-gases created is moving upwards towards the designated combustion zone.

Gastov stove

The Gastov is a TLUD gasifier made by The Kenya Industrial Research Development Institute (KIRDI). The Gastov consists of six parts, see figure 2.2, an insulated body (A), Snuffer (B), a pot skirt (C), a burner (D), a fuel canister handle (E) and a fuel canister (F) (Saraswati, 2018, p. 6). The insulated body has vent at the bottom for controlling primary air reaching the fuel canister inside the body. The gas combustion chamber called the burner is fitted on top of the insulated body. To protect the flame from wind and hold the pot in place a pot skirt can be fitted on top of the burner. When cooling the char, it is put inside the snuffer which cuts off oxygen stopping the char gasification. The canister handle is for moving the canister since it is lit outside before it is put in the insulated body and must be removed after cooking for cooling of the char.

Figure 2.2: The Gastov with all accessories by KIRDI

If the prepared fuel in the canister is charred before the meal is completed the char must be removed and the canister must be reloaded and relit before continuing the cooking process.

MiG|BioCooker

The MiG|BioCooker is a char producing cookstove made by Make It Green Solutions AB, see figure 2.3. It can use many different feedstocks such as sawdust, rice husk, all forms of wood, dry fallen leaves etc. (MiG, n.d.). The stove has two half circle shaped openings with hatches on both sides of the combustion chamber. The lower opening is for collecting char and the higher one on the opposite side of the stove is used for adding fuel and controlling the flame. Through the lower hatch there are openings supplying the combustion chamber with secondary air through openings on both sides of the combustion chamber. The stove is designed for continuous feeding of fuel enabling it to cook meals for a long period of time. If the chamber becomes full of char the lower hatch can be opened to remove it while in use.


Figure 2.3: MiG|BioCooker by Make It Green Solutions AB

2.5. PM and CO

When burning any fuel unwanted emissions gets released into the surrounding air. These emissions apart from CO_2 increase when incomplete combustion occur. These emissions have many side effects that affect both the human health and the environment. Listed below are some of these affects regarding PM and CO.

2.5.1. PM

Particulate matter (PM) is found in the air and is a mixture of solid particles and liquid droplets. These particles are emitted by many different sources such as unpaved roads, power plants, industries, automobiles, fires etc. Some particles are visible, this includes smoke, dust, dirt and soot. Some can only be detected using an electron microscope. PM is measured in $PM_{2.5}$ or PM_{10}. $PM_{2.5}$ is particles with a diameter of 2. 5 µm or less and PM_{10} is particles with a diameter of 10 µm or less (US EPA, 2018). These fine particles are inhalable and can get into the smallest passages in the lungs. These small passages lead directly to the bloodstream, spreading the $PM_{2.5}$ to organs causing respiratory and cardiovascular diseases (WHO, n.d.). According to WHO Air Quality Guideline values exposure on $PM_{2.5}$ should not exceed 10 µg/m^3 annual mean or 25 µg/m^3 24-hour mean (WHO, 2013).

2.5.2. CO

Carbon monoxide (CO) is formed when incomplete combustion of fuels occurs. It is a color- and odorless gas which mixes easily with the air. When inhaling CO, the gas diffuses to the bloodstream and reacts with hemoglobin to form carboxyhemoglobin (COHb) leaving less hemoglobin to bond with oxygen. This bond is about 245 times stronger than for oxygen and therefore longer lasting, which makes the COHb increase during longer time of exposure and affect the oxygen uptake capacity of the body leading to tissue hypoxia.

According to WHO Guidelines for indoor air quality (2010) long-term exposure of lower CO concentrations have a greater impact on human health than acute CO exposure. However, extreme acute exposure of CO (over several hundred mg/m^3) can lead to unconsciousness and death. Since acute exposure of CO and long-term exposure of CO appears different, the guidelines set up by WHO has different levels depending on the period of exposure (WHO, 2010, 55-88).

Table 2.1: Indoor carbon monoxide guidelines (WHO, 2010, p.87) converted to ppm using the converion factor of 1 mg/m^3 = 0.873 ppm (WHO, 2010, p.55)

Time of exposure	Concentrations [ppm]
15 minutes	90
1 hour	30
8 hours	10
24 hours	6

3. METHODOLOGY

The methodology used in this report were collecting data by a series of tests followed by different methods for analyzing the results of the tests. The method consists of selection of households and stoves, performance of cooking tests and collection of the household perceptions of the stove. Followed by analyzing the data results which is described in Processing of data.

3.1. Study site

The study was carried out in Kibugu (Embu County). Embu has a population of 516,212 where 51% are female and 49% are male (KNBS, 2010). The county is located 120 kilometers north east of Nairobi and on the south eastern side of Mount Kenya with an elevation of 1350m above sea level. The most grown commercial crops are tea, coffee, and macadamia nuts. Many farmers have planted *Grevillea robusta* on their farms due to its high suitability for shading coffee and tea. The *Grevillea robusta* also supplies farmers with firewood and timber (Lengkeek and Carsan, 2004). The main cooking fuel in Embu county is firewood (81,1%) followed by charcoal (11,2%) (Ngugi, 2013) and the most common type of cookstove used is the three stone open fire.

3.2. Selection of households

Earlier research has been conducted in the Kibugu area within the biochar and smallholder farmers in Kenya project where 50 households have been involved and has been equipped with the Gastov. In recent studies the households had been given a second canister and after two months of usage a follow up had been conducted. From the 50 households 5 were selected for the participatory cooking tests using criteria based on the follow up, within walking distance to each other and willingness to participate. The criteria based on the follow ups were those households that had been using the Gastov the most during the period between getting the second canister and the follow up. The schedule for the cooking tests were made so that each household had 6 tests for 4 consecutive days to ensure as similar conditions as possible.

The order of meals was decided in advance of the testing and order of stoves were randomized in MATLAB, the order was the same in each household. Based on these criteria a schedule was made, see table 3.1. The schedule was distributed to the farmers and depending on which dates the farmers were available they were given a letter between A-E. Due to religious reasons the MiG with Githeri test in Household D were moved up one day and due to technical errors the Three stone open fire with Ugali and Sukuma wiki test in Household E had to be redone May 3rd.

Table 3.1: Schedule of tests dates

Type of meal and stove	Household A	Household B	Household C	Household D	Household E
Ugali and Sukuma wiki					
Two-chamber	13 April	17 April	21 April	25 April	29 April
Three stone open fire	14 April	18 April	22 April	26 April	3 May
GASTOV	15 April	19 April	23 April	27 April	1 May
MiG|BioCooker	16 April	20 April	24 April	28 April	2 May
Githeri					
Treestone	16 April	19 April	23 April	27 April	2 May
MiG|BioCooker	15 April	18 April	22 April	26 April	1 May

3.2.1. Descriptions of kitchen

To be able to evaluate differences regarding how different layouts of kitchens might affect the levels of emissions a documentation of each kitchen was made. For three households' earlier studies had already documented the measurements and will be used in this report. All five kitchens were in a separate house from the main house. Objects of interest that has been documented is doors, windows, ventilation. The measurements are presented in length x width x height [m]

In household A the kitchen was 3.24 x 2.64 x 2.41 with an open door measuring 2 x 0.76. The window was closed during cooking and measured 0.60 x 0.51. No other ventilations were present although some of the wooden planks had some gaps in between them letting out smoke.

In household B the kitchen was 3.56 x 2.48 x 2.61. The door measured 1.85 x 0.84 and was open during cooking. It had one window measuring 0.65 x 0.65 and was closed during cooking. The ventilations in this kitchen were a hole colored with mesh measuring 0.72 x 0.67, a triangle in the side wall closest to the ceiling measuring 0.43 cm in height and 2.64 cm in length.

In household C the kitchen was 3.14 x 3.08 x with a door 1.75 x 0.59 and a window 0.45 x 0.35, both open during cooking. They also had a chimney directly above the stove and no other ventilations.

In household D the kitchen was 2.8 x 2.18 x 2.84. The door was 1.7 x 0.68 and was open during cooking. There were two windows the first one measuring 0.45 x 0.33 and the second one measuring 0.43 x 0.30 both closed during cooking. Other ventilations in the kitchen was a raised roof working as a chimney with all sides open, measuring 0.61 x 0.53.

In household E the kitchen measured 2.40 x 2.01 x 1.93. The door measured 1.76 x 0.61 and was open during cooking. The window measured 0.41 x 0.32 and was closed during cooking. No other ventilations were present.

3.3. Selection of Cookstoves

The MiG|BioCooker is produced by Make It Green Solutions AB as a solution for cleaner cooking in developing countries. The company wanted to do a participatory cooking test within households in rural Kenya to be able to see the user perception of the new stove. Due to its potential of continuous refill of firewood and heating the house it potentially solved the problems the Gastov had.

In the previous project, The Gastov had been compared to the Three stone open fire to examine if the stove could replace the Three stone open fire as the most commonly used stove. During this research it was noticed that for dishes taking longer time to cook, the cook would prefer to use the traditional Three stone open fire due to its ability to have a continuous refeeding of firewood. The cook must refill and relight the canister of firewood when cooking for a longer period with the Gastov. Refilling and relighting the cannister has been proven to be difficult and time consuming. A potential solution for this problem is the MiG|BioCooker, due to its possibility to have a continuous refill of firewood. This study will focus on the MiG|BioCooker compared to the Gastov testing which stove has the best potential as an improved stove to replace the Three stone open fire.

To be able to examine if the MiG|BioCooker is a better substitute than the traditional used cooking method, the Three stone open fire was used as a reference since it is the most commonly used stove in Kenya. The three stone open fire that was used during testing was a modified version of the traditional one. The modification of the stove is that the stones has been put together in a U shape, only leaving one side open for putting in firewood.

3.4. Cooking tests

In each household a participatory cooking test was conducted for collection of data. The test method used were based on the Controlled Cooking Test (CCT) prepared by Rob Bailis (2004), with modifications enabling the tests to be performed in the field. The tests were conducted in each household's kitchen prepared by the main cook of the household. The meal cooked with each stove contained two dishes Ugali (cornmeal porridge, *Zea mays*) and Sukuma wiki (Collard greens (*Brassica oleracea)* fried with onions and tomatoes). Additional tests were conducted making the meal Githeri (boiled dry maize (*Zea mays*) and beans *(Phaseolus vulgaris)*) with the two cooking methods MiG|BioCooker and three stone open fire. To ensure as similar conditions as possible, the Ugali and Sukuma Wiki tests were performed during the afternoons starting between 16:00-16:30 and the Githeri tests was performed in the morning starting between 09:00-09:30. Emissions were recorded one hour prior the start of cooking and one hour after the cooking was finished.

When lighting the stoves, the MiG|BioCooker and the Gastov where lit outside of the kitchen and brought inside when the wood gas combustion process was initiated. Due to the immovability of both the Two-chamber and the Three stone open fire, these two stoves where lit inside the kitchen. Lighting materials used were mostly paper, twigs and dried *Grevillea robusta* leaves where used, these materials could be found on the farm and were commonly used by the cook.

A set amount of ingredients was used for all three dishes, see Table 3.2, except for the water in Githeri. When making Githeri the maize and beans must boil for a long period of time and during some of the tests the pot boiled dry before the maize and beans were ready, hence the need of more water.

Table 3.2: Amount of ingredients for the dishes

Type of meal and stove	Amount [g]
Ugali	
Maize meal	1000
Water	1786
Sukuma wiki	
Onion	76
Tomatoes	269
Salt	8
Water	40
Oil	81
Sukuma + spinach	750
Githeri	
Dried maize and beans	841
Water	3335 + additional water if needed

When collecting data during the tests a protocol and an observation form, see Appendix H and I were used. Data such as cooking time, fuel consumption, amount of char produced and any other observations that might affect the result were collected. The equipment used for collecting data regarding the concentration were hanged 100 cm from the stove and 150 cm above ground. The logging interval chosen for all instruments were 10 sec. The CO data logger EasyLog USB from Lascar Electronics was used for collecting CO concentrations in ppm. When measuring particulate matter concentrations, $PM_{2.5}$, the Particle and Temperature Sensor (PATS+) from Berkeley Air monitoring group was used, concentrations where recorded in µm/m^3.

3.5. Processing of data

3.5.1. Concentrations of CO and $PM_{2.5}$

To calculate the concentrations of emissions from each test, the data of each emission was divided into one hour before cooking, during cooking process, and one hour after the end of cooking. The start time of the cooking process was calculated from the time the stove was lit and inside the kitchen. Due to the non-stationary stoves being lit outside the start time of cooking process for the MiG|BioCooker and Gastov was calculated from when the stoves where put inside the kitchen. For the three stone open fire, start of cooking process was when lighting the stove.

The data provided for the mean value for each test and emission was from “during cooking process”. These means were summarized in tables, one for each type of emission and any outliers were removed. For $PM_{2.5}$ all values above 100 000 that lasted less than 10 seconds were removed and no outliers for the CO tests were removed. The results from each household were compared to WHOs guidelines for indoor emissions and for ranking between stoves. When comparing the stoves with each other the means were only used within each household due to different characteristics of each kitchen. Each meal was also compared separately. The stoves were ranked from best to worst for each emission in each household providing a way to compare each stove regardless of household.

3.5.2. Cooking process

For comparisons between stoves the cooking process was divided into two parts.

Time to light was calculated from the moment the cook set fire to some of the lighting materials to the moment when the fire was considered well lit. The definition of well-lit was when the fire could sustain itself without any help from the cook. When the Gastov and MiG|BioCooker was well-lit they were moved to the kitchen.

Time to cook was the time between when the first pot was put on the stove and when the last pot was removed from the stove. When cooking Githeri the first and last pot was the same due to this meal only using one pot. The cook was asked to cook the meal the way they usually make it which will influence cooking time between households.

3.5.3. Fuel consumption and char production

When calculating fuel consumption and char production a series of different parameters was considered. Fuel consumption was divided into two options regarding what the char was used for after cooking. Option one was based on the use of char as soil amendment and was calculated as gross fuel. Option two, net fuel, were based on the use of char as fuel.

Gross fuel consumption [g] is amount of fuel used during the whole cooking process. This was calculated using a large pile of firewood that was measured before the start of cooking. At the end of cooking the remaining firewood in the pile and the withdrawn fuel from the stove was weighed and subtracted from the weight of the large pile.

Net fuel consumption [g] assumes that the char will be used as fuel and that the char has close to the same heating capacity as the firewood. When calculating net fuel, the difference between gross fuel and char produced was used, see Equation (1).

$$Net\ fuel\ consumtion = Gross\ fuel\ consumption - Char\ produced \qquad (1)$$

Char production [%] was calculated using amount of char produced per g gross fuel consumption in each test, see equation (2).

$$Char\ production = \frac{char\ produced}{Gross\ fuel\ consumtion} \qquad (2)$$

3.5.4. Paired sample sign test

To determine if there was a significant difference between the stoves a paired sample sign test was conducted in. The comparisons were MiG|BioCooker compared to the Three stone open fire cooking Ugali and Sukuma Wiki, MiG|BioCooker compared to the Gastov cooking Ugali and Sukuma Wiki, and MiG|BioCooker compared to the Three stone open fire cooking Githeri. In each of the comparisons the stoves from the same household, dependent samples, were paired and the comparison was made within each household. The hypothesis is that there is one stove that is better than the other. For each of our criteria having the lower number is better except for char production.

H0: The median difference is zero
H1: The median difference is ≠ 0

To be able to do the test the following calculations were done:

Table 3.3: Paired sample sign tests calculations

Household	Ugali and Sukuma wiki				Githeri	
	MiG|BioCooker – Three stone open fire	Sign	MiG|BioCooker – Gastov	Sign	MiG|BioCooker – Three stone open fire	Sign
A		+/-		+/-		+/-
B		+/-		+/-		+/-
C		+/-		+/-		+/-
D		+/-		+/-		+/-
E		+/-		+/-		+/-
No. of positive signs		X1		X2		X3
No. of negative signs		Y1		Y2		Y3
Sample size, n		XI+Y1		X2+Y2		X3+Y3
Success, x		=min(X1;Y1)		=min(X1;Y1)		=min(X1;Y1)

When all differences had been calculated a value of the sample size (n) and a value of success rate was obtained. The probability, P is set to 0.5 due to two outcomes +/-. To find the p-value the binomial probability b(x,n,P) was used. If the calculated p-value > 0.05 H0 cannot be rejected and no significant difference can be shown. The level of significance is set to $\alpha=0.05$ in all paired sample size test conducted in this report.

3.6. Evaluation of usability

Following every cooking test, a semi-structured interview was conducted. All the households were asked the same questions, see Appendix F. During the first day of testing in each household, general questions were asked about the most commonly used firewood, stove and type of meal cooked. After each test cooking Ugali and Sukuma Wiki questions were asked to evaluate the household's opinion of the used stove. Question number one was about which characteristics they liked about the stove, the second question was about suggestions on what kind of modifications the tested stove needed, and the third question was how much they would be willing to pay for the stove.

When all four stoves had been tested in one household, the cook were asked to rank them. For this ranking a table was used, see Appendix G. The stoves were evaluated on eight different categories: *saves fuel*, *saves cooking time*, *heating of the house*, *less smoke*, *easy to handle*, *easy to prepare fuel*, *durability/maintenance*, and *appearance*. For each category the cook had fifty beans to spread out between the four stoves.

After all tests in all households, a focus group discussion (FGD) was held. During this discussion, the cooks were asked to rank all the stoves again and settle on a mutual ranking from 1 to 4. The stove they thought was best got a 4 and the stove they thought was the worst got a 1. In some areas the cooks could not settle on the ranking between two of the stoves. When this happened, they gave the best ranking to the stove with the most votes. After the ranking the cooks were asked to discuss the MiG|BioCooker regarding what needed to be modified and what challenges they saw moving from the Three stone open fire to any type of improved stoves, focusing on the improve stoves they used during the tests.

4. RESULTS

This section presents the results of the study, the first chapters are based on measured data such as emissions, cooking process, fuel efficiency and charcoal production. Followed by a chapter about user experience, based on interviews with the households.

4.1. Emissions

4.1.1. Carbon monoxide (CO)

The mean value for Carbon monoxide concentrations for each household, stove and type of meal is presented in Table 4.1.

Table 4.1: Mean value of CO concentrations in kitchen during cooking period for all tests measured in ppm

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
	ppm				
A	69	33	28	91	52
B	10	3	6	7	7
C	10	2	4	36	2
D	43	4	27	34	6
E	52	54	35	133	70
Mean value	37±26	19±23	20±14	60±51	27±31

The MiG|BioCooker had the lowest concentrations of CO in three out of five tests with Ugali and Sukuma wiki as the prepared meal and the Gastov had the lowest concentrations in the remaining two tests. The Three stone open fire had the highest concentrations in four out of five tests with Ugali and Sukuma wiki as the prepared meal. When preparing Githeri the Three stone open fire had significantly higher concentrations according to a paired sample sign test. No statistical significance could be shown between the stoves with Ugali and Sukuma wiki as the prepared meal due to the small number of tests. See appendix A for a summary of the paired sample sign test.

When cooking Ugali and Sukuma wiki, the mean reduction of CO by MiG|BioCooker and Gastov was 48.6% and 45.9% respectively compared to three stone open fire. The percentage concentration reduction for the MiG|BioCooker compared to the Three stone open fire was above 50 % in all tests except the last one in Household E where it had an 4 % increase compared to the Three stone open fire. In Household A it was a reduction of 50%, in Household B it was a reduction of 70 %, in Household C it was a reduction of 80 % and a reduction of 90 % in Household D. When comparing the Gastov to the three stone open fire the reduction in Household A and C was 60 %, there was a reduction of 40 % in Household B and D, and a reduction of 30 % in Household E.

4.1.2. Particulate matter ($PM_{2.5}$)

The mean value for fine particulate matter concentrations for each household, stove and type of meal is presented in Table 4.2.

Table 4.2: Mean value of $PM_{2.5}$ concentrations in kitchen during cooking period for all tests measured in µg/m³.

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
	µg/m³				
A	58 090	1700	460	58 180	25 760
B	17 520	700	50	460	3860
C	1400	170	190	2990	340
D	9970	130	620	7200	1750
E	2020	9740	140	82 500	31 750
Mean value	17 780±23 470	2 490±4 100	290±240	30 260±37 650	12 690±14 870

The three stone open fire had the highest concentration of $PM_{2.5}$ in four out of five tests while cooking Ugali and Sukuma wiki. The MiG|BioCooker had the lowest concentration of $PM_{2.5}$ in two out of five tests and the Gastov had the lowest concentrations in the remaining three tests. In the tests preparing Githeri, the Three stone open fire had the highest concentration of $PM_{2.5}$ in four out of five tests. There was no significant difference in $PM_{2.5}$ values between stoves (irrespectively of meal) according to a paired sample sign test with significance level of 95%. See appendix B for a summary of the paired sample sign test.

When cooking ugali and Sukuma wiki the MiG|BioCooker and Gastov reduced $PM_{2.5}$ concentration by 86% and 98% respectively when compared with three stone open fire. The percentage concentration reduction for the MiG|BioCooker compared to the Three stone open fire was above 80 % in all tests except for Household E where it was an increase of 482 %. For Household A the reduction was 97 %, in Household B there was a reduction of 96 %, in household C the reduction was 88 % and the reduction in Household D where 99 %. For the comparisons between Gastov and three stone open fire all tests had more than 80 % reduction in $PM_{2.5}$ levels. In household A the reduction was 99 %, in Household B the reduction was more than 99 %, in household C the reduction was 86 %, in household D there was a reduction of 94 % and in Household E there was a reduction of 93 %.

4.2. Cooking process

Time taken to cook each meal is presented in Figure 4.1 and 4.2.

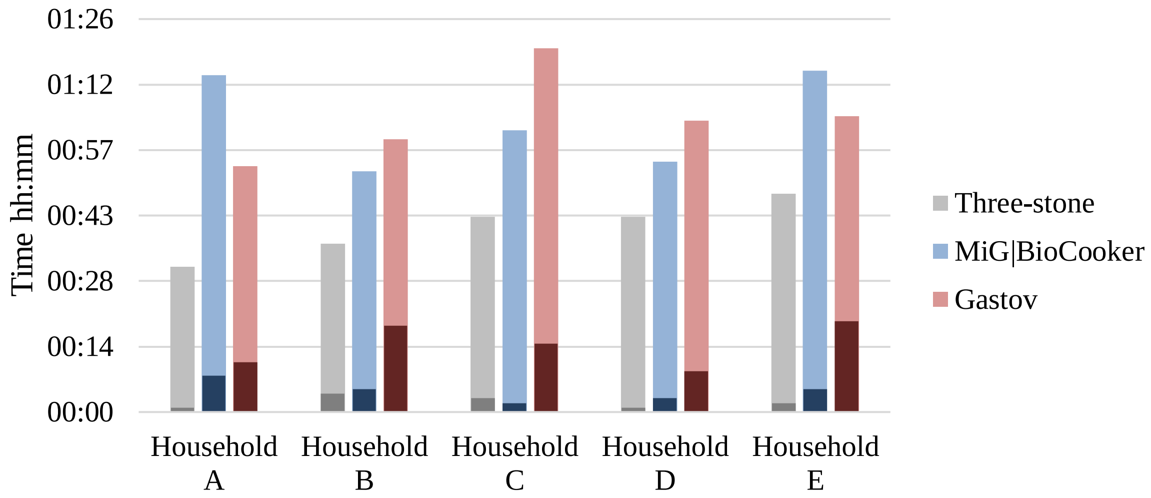

Figure 4.1: Cooking process for each household when cooking Ugali and Sukuma Wiki. Divided into lighting time, dark area of the column, and cooking time, the pale area of the column.

According to a paired sample sign test, cooking with the three stone open fire took significantly less time compared to the MiG|BioCooker when cooking Ugali and Sukuma Wiki. The mean time taken for the MiG|BioCooker, Gastov and the three stone open fire was 01:03±00:10, 01:04±00:09 and 40:36±00:06 respectively. On average it took 23 minutes less time to cook with the three stone open fire compared to MiG|BioCooker and Gastov respectively. For the same meal the MiG|BioCooker was faster than the Gastov in three out of five tests but no significant difference could be shown between the MiG|BioCooker and the Gastov, due to the small number of tests. See appendix C for a summary of the paired sample sign test. In one of the five tests with the Gastov the fuel burnt out and needed refilling and relighting of the second canister. But the time taken to light the second cannister was enough time to finish cooking the meal using the heat from the char produced in the first cannister.

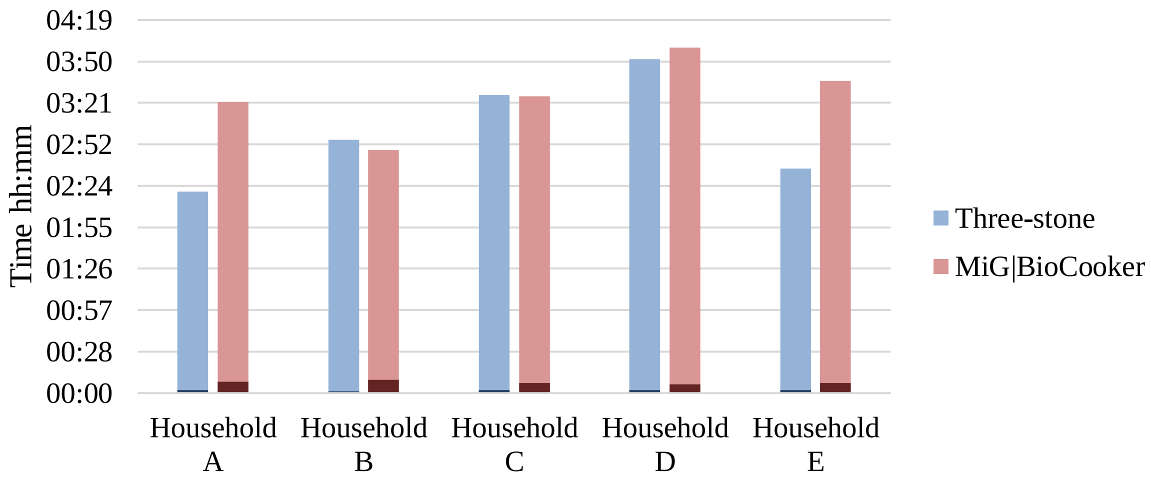

Figure 4.2: Cooking process for each household when cooking Githeri. Divided into lighting time, dark area of the column, and cooking time, the pale area of the column.

When cooking Githeri the three stone open fire cooked the meal faster in three out of five tests. In two out of those three tests the MiG|BioCooker took over one hour longer to cook the meal. But according to the paired sample sign test no significant difference between the MiG|BioCooker and the Three stone open fire could be shown. See appendix C for the paired sample sign test. The mean time was 03:02±00:37 for three stone open fire and 03:26±00:25 for the MiG|BioCooker.

4.3. Fuel efficiency and char production

In figure 4.3-4.4 fuel consumption of each household is presented. Gross fuel is amount of fuel used during cooking and is represented by the whole column, lighting materials such as twigs or leaves is not taken into consideration. Net fuel is the amount of fuel used, gross fuel, with amount of char produced subtracted, given that the amount of char produced is used as fuel. Net fuel is presented as the pale section in the column and amount of char is presented as the dark section of the column.

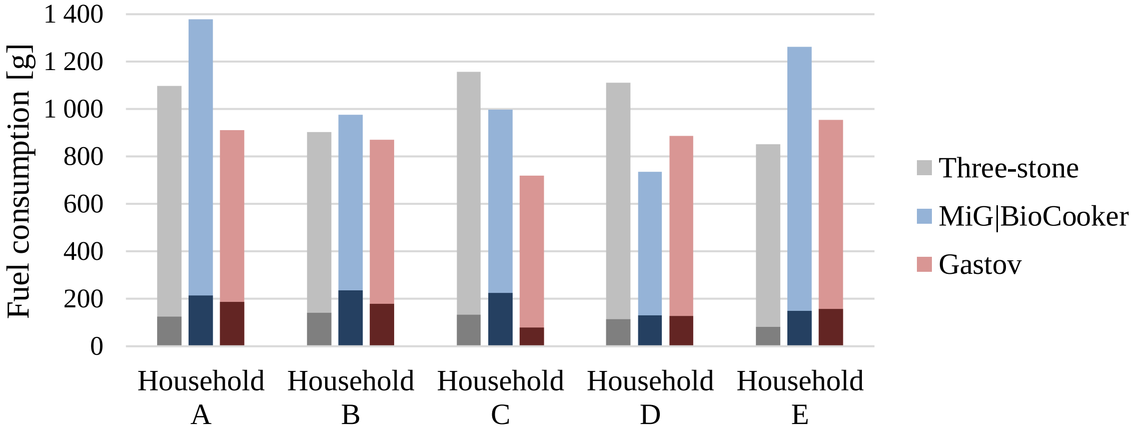

Figure 4.3: Fuel consumption and char produced in g when cooking Ugali and Sukuma Wiki. The dark section of the column in amount of char produced and the lighter section of the column is net fuel. Together they form gross fuel.

According to a paired sample sign test no significant difference could be shown between any stoves but when comparing the MiG|BioCooker with the Gastov, the Gastov used less amount of fuel in four out of five tests. The Three stone open fire used less amount of fuel when compared to the MiG|BioCooker. For the paired sample sign test and mean value calculations see appendix D.

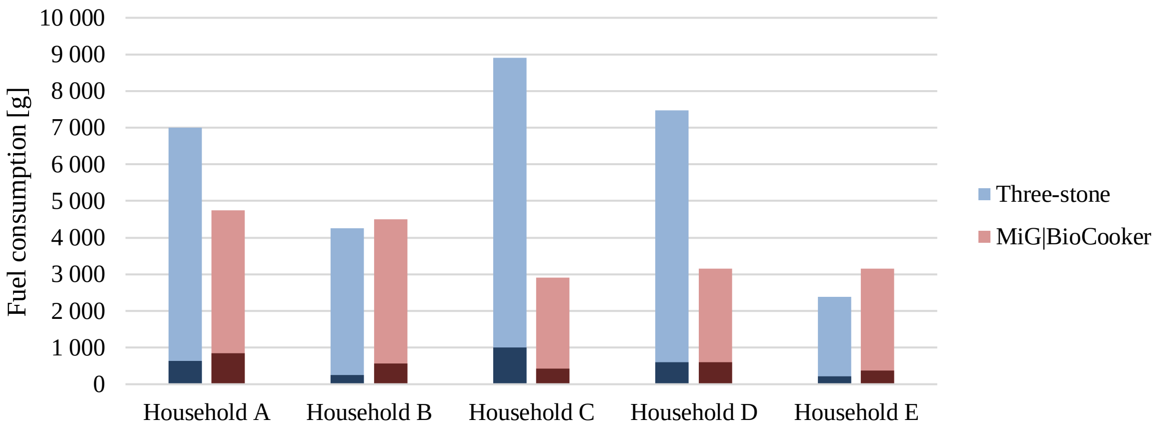

Figure 4.4: Amount of fuel used in g when cooking Githeri. The dark section of the column in amount of char produced and the lighter section of the column is net fuel. Together they form gross fuel

When cooking Githeri the MiG|BioCooker consumed less amount of fuel in three out of five tests and no significant difference could be shown between the stoves. For the paired sample sign test see Appendix D. In both Household C and D, the Three stone open fire used more than twice as much fuel compared to the MiG|BioCooker, which was the highest of all households. The MiG|BioCooker used 6004 g less fuel compared to the Three stone open fire in Household C and in Household D the MiG|BioCooker used 4320 g less fuel compared to the Three stone open fire.

Table 4.3: Percentage (by weight) of char produced from firewood for each test.

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
	%				
A	11.5	15.6	20.4	9.0	17.7
B	15.7	24.2	20.4	6.1	12.7
C	11.6	22.6	11.0	11.3	14.7
D	10.2	17.8	14.3	7.9	19.3
E	9.6	11.9	16.5	9.0	11.6
Mean value	12±2	18±5	17±4	9±2	15±3

Irrespectively of meal the MiG|BioCooker had a significantly higher char percentage than the three stone open fire according to the paired sample sign test but no significant difference could be shown between the MiG|BioCooker and the Gastov. During the cooking with the Gastov in Household C the firewood finished burning before the food was ready. Since lighting the second canister took some time the char in the first canister continued to burn releasing heat that finished the meal. When comparing the Gastov with the MiG|BioCooker, the MiG|BioCooker had a higher percentage of char produced in three out of five tests. See appendix E for a summary of the paired sample sign test.

4.4. User experience

This section presents the results of the perception of stove and rankings, collected in field by interviews, and by the focus group discussion where the farmers ranked the stoves together and got to discuss improvements of the MiG|BioCooker.

4.4.1. Interviews

General description of commonly used fuel and stove used by the household
Overall, *Grevillea robusta* was said to be the most used firewood, in Household B and D it was the only firewood used. In the other households' other fuel types were also commonly used, such as eucalyptus (Household A), liquefied petroleum gas (LPG) (Household C) or coffee pruning (Household E). LPG was mostly used for cooking tea and reheating cooked meals. All the households collected the firewood directly from their own farm, except for Household D who bought it.

All households used three stone open fire as their most commonly used stove, but every cook commented that they also used Gastov for some of the food that took shorter time to cook like rice, ugali and Sukuma. The three stone open fire was used for foods that took longer time, like Githeri.

Perceptions of stove

The cook's perceptions of the MiG|Biocooker was that it was easy to light , cooks fast and is beautiful and presentable. Household A, D and E liked that it is easy to regulate the flame and heat. Household C and D commented that it produces less smoke and in Household C the cook also noted that it produces a lot of char. The cook in Household A thought that the char was easy to remove. Two of the cooks, in Household C and D, thinks that the stove is stable. The cook in Household B also commented on that it saves fuel, according to her the three stone open fire demanded two times the fuel compared to the MiG|Biocooker.

The modifications that were suggested by the households was to make the MiG|Biocooker bigger, all farmers but one commented about the size of the stove, that they want a bigger cooking spot with a bigger hole for the flame and a bigger landing where you can put a bigger pot. The cook in Household A commented that if she would want to cook for a bigger gathering, she would have to go back to three stone open fire. They also wanted the space where you put the firewood to be bigger so they could put more fuel and bigger pieces of wood. This would help the cooks when they do not need to add fuel so many times and do not need to cut small pieces when preparing the fuel. Two of the cooks, in Household B and D, commented that the points where you put the pot is weak and too high making the distance from the pot and the flame (heat) too far. In Household C, the cook suggested that the stove should be covered on the sides where you remove the char so that it would not fall on the sides of the stove.

Every household commented on the handles of the stove. The handles on the hatches are made of wood and when using the stove, they easily get burnt. The cooks suggested that they would be longer so that the wood would get further away from the fire. They also wanted handles on the sides of the stove so that they could carry the stove when it is lighted outside. This was due to the stove being hot after lighting. Other suggestions from the farmers was to include something like the canister holder for the Gastov (see figure 2.2), since they moved the stove during the test with this one.

The characteristics that the households liked about the three stone open fire was that it is good when you cook for bigger families or gatherings since you can modify the stones to fit bigger pots, this was commented in all households except for Household B. In Household A, C and D they pointed out that it cooks fast, warms the house and produces charcoal. The cook in Household D often used this char to either warm water after cooking or to be able to light the stove again a few hours after she stopped cooking since the char kept burning and stayed hot for a very long time. Two of the households, A and D, commented that if you use dry fuel the three stone open fire does not produce much smoke.

Modifications to the three stone open fire suggested by the cooks was to make it more permanent, three cooks, B, C and E, wanted to cement it. The cook in Household D, which already had it cemented, see figure 4.5, suggested to use three stones on top of the cemented modified Three stone open fire. According to her it would make the flame more concentrated and she could make the hole where you put the firewood even smaller, a smaller place where you put firewood according to her meant that she would use less firewood.

Figure 4.5: Cemented modified Three stone open fire in Household D

All households except for Household B commented on the Gastov and that it does not smoke much. All cooks commented either that it cooks fast or has a good flame and that it saves fuel. In Household D the cook noted that Gastov does not waste any flame and heat because of the insulation and that the stove is easy to use. Easy to use referred to that you just put in all fuel at the same time and does not have to add fuel when cooking. The cook in Household E liked the landing where the pot is standing and that it has handles on the outside so he could carry the stove inside after lighting.

The modifications proposed for the Gastov was to make it bigger in general, they wanted to be able to put thicker and longer logs in the canister so that they would be able to cook for a longer time with one canister. Also, to make the landing bigger so that they could cook with bigger pots. In Household C the cook commented that it's hard to prepare the fuel because all wood pieces must be in the same size. The cook in Household B thought that the stove needed a compartment where you can put small sticks when lighting the stove since it often fell off.

4.4.2. Ranking

Individual

In four out of five households, MiG|BioCooker were the best ranked when adding up all points given from the different categories. Except for Household E where the three stone open fire got the best result. Overall, the MiG|BioCooker got the best ranking in the area *Appearance* in all five households. In other areas, *Saves cooking time, saves fuel, less smoke, easy to handle* it was a difference of opinion between the households even though the MiG|BioCooker got good results in these areas in some of the households. In *Durability/Maintenance* the MiG|BioCooker got the worst results in four out of five households

Table 4.4: Ranking of Stoves in Household A

Household A	MiG|BioCooker	Gastov	Two-chamber	Three stone open fire	Total
Saves fuel	25	15	6	4	50
Saves cooking time	19	8	11	12	50
Heating of the house	7	9	11	23	50
Less smoke	21	11	11	7	50
Easy to handle	11	8	12	19	50
Easy to prepare fuel	14	8	9	19	50
Durability/Maintenance	10	11	9	20	50
Appearance	24	10	7	9	50
Total	131	80	76	113	400

In Household A the MiG|BioCooker got the best ranking in the categories: *Saving fuel, Saving cooking time, Less smoke and Appearance*. But the worst ranking when it comes to *Heating of house* and *Durability/maintenance*. In the categories *Easy to handle and Easy to prepare fuel* the three stone open fire got a better ranking than MiG|BioCooker.

Table 4.5: Ranking of Stoves in Household B

Household B	MiG|BioCooker	Gastov	Two-chamber	Three stone open fire	Total
Saves fuel	30	10	10	0	50
Saves cooking time	30	20	0	0	50
Heating of the house	20	0	0	30	50
Less smoke	20	30	0	0	50
Easy to handle	30	20	0	0	50
Easy to prepare fuel	20	0	0	30	50
Durability/Maintenance	0	10	10	30	50
Appearance	30	10	10	0	50
Total	180	100	30	90	400

In Household B the MiG|BioCooker was highest ranked in *Saving fuel, saving cooking time, Appearance* and *Easy to handle*. While the cook ranked three stone open fie higher than MiG|BioCooker in *Easy to prepare fuel* and *Heating of house* and ranked Gastov higher in *Less smoke*. MiG|BioCooker was ranked worst of all three stoves in *Durability/Maintenance*.

Table 4.6: Ranking of Stoves in Household C

Household C	MiG|BioCooker	Gastov	Two-chamber	Three stone open fire	Total
Saves fuel	15	20	10	5	50
Saves cooking time	15	10	10	15	50
Heating of the house	10	5	20	15	50
Less smoke	25	10	10	5	50
Easy to handle	10	5	15	20	50
Easy to prepare fuel	10	5	15	20	50
Durability/Maintenance	15	10	5	20	50
Appearance	20	15	10	5	50
Total	120	80	95	105	400

In Household C the MiG|BioCooker was ranked highest in *Less smoke* and *Appearance* whilst Gastov got better ranked in *Saving fuel*. Three stone open fire was better ranked than MiG|BioCooker in the areas *Heating of house*, *Easy to handle*, *Easy to prepare fuel* and *Durability/maintenance*, but in *Saving cooking time* it was tie between Three stone open fire and MiG|BioCooker.

Table 4.7: Ranking of Stoves in Household D

Household D	MiG|BioCooker	Gastov	Two-chamber	Three stone open fire	Total
Saves fuel	15	15	12	8	50
Saves cooking time	14	9	11	16	50
Heating of the house	11	14	9	16	50
Less smoke	15	18	14	3	50
Easy to handle	20	18	2	10	50
Easy to prepare fuel	8	4	10	28	50
Durability/Maintenance	8	8	10	24	50
Appearance	24	13	7	6	50

Total	115	99	75	111	400

In Household D the MiG|BioCooker got best ranked in *Easy to handle*, *Appearance* and shared first place with Gastov in *Saving fuel*. Three stone open fire was ranked higher in *Saving cooking time* and *Easy to prepare fuel*, and Gastov was ranked higher in *Less smoke*. In *Heating of the house* MiG|BioCooker got the worst ranking and shared the worst rank on *Durability/Maintenance* with Gastov.

Table 4.8: Ranking of Stoves in Household E

Household E	MiG|BioCooker	Gastov	Two-chamber	Three stone open fire	Total
Saves fuel	12	14	17	7	50
Saves cooking time	12	7	14	17	50
Heating of the house	12	7	14	17	50
Less smoke	14	17	12	7	50
Easy to handle	14	12	7	17	50
Easy to prepare fuel	12	7	14	17	50
Durability/Maintenance	7	12	14	17	50
Appearance	17	14	12	7	50
Total	100	90	104	106	400

In Household E the MiG|BioCooker got highest ranked in *Appearance* while Gastov got higher ranked in *Saving fuel* and *Less smoke*. Three stone open fire got the higher ranking in the areas *Saving cooking time*, *Heating of house*, *Easy to handle* and *Easy to prepare fuel*. The category where MiG|BioCooker got the worst rank was in *Durability/maintenance.*

Final group ranking

Table 4.9: Ranking in FDG. For the ranking 4 is the highest rating and 1 is the lowest.

FGD	MiG|BioCooker	Gastov	Two-chamber	Three stone open fire
Saves fuel	4	3	2	1
Saves cooking time	3	1	2	4
Heating of the house	2	1	3	4
Less smoke	3	4	2	1
Easy to handle	2	1	3	4
Easy to prepare fuel	2	1	3	4
Durability/Maintenance	1	2	3	4
Appearance	4	3	2	1
Total	**21**	**16**	**20**	**23**

When ranking the stoves, the cooks had a hard time with agreeing in some categories. When they could not agree on a ranking, they voted between those two stoves, the stove with the most votes got the best ranking. For example, when talking about *Saving fuel*, the cook's opinions where divided between MiG|BioCooker and Gastov since they have a very different feeding of firewood, so it was hard for them to estimate the fuel used. When voted the MiG|BioCooker got three out of five votes, thereby it got the best ranking.

When discussing *Saving time*, the cooks ranked Gastov and Two-chamber tie, but when voted the Gastov got 2 votes compared to Two-chambers 3 votes.

When talking about *Easy to handle* the cook in Household A did not agree with the rest of the cooks. She wanted to change ranking on MiG|BioCooker and Two-chamber.

Easy to prepare fuel also made the cooks disagree about the 3rd and 4th position where MiG|BioCooker and Gastov where tie. In this area, MiG|BioCooker got the better ranking since it can use thicker firewood than Gastov and since you do not have to be as exact with measurements when cutting the firewood.

When discussing *Durability/Maintenance* the cooks commented that they have not used the stoves for so long time which makes it hard for them to rank the stoves.

Overall, when summarized the ranking on all areas. Three stone open fire got the best ranking with 23 points. The MiG|BioCooker were second with 21 points, Two-chamber got 20 points and Gastov got 16 points.

4.4.3. Focus group discussion

In the FGD, the cooks also got to discuss the new stove, the MiG|BioCooker and were asked about what they would like to modify with the stove. Many modifications were already mentioned during the interviews. Including that the handles of the hatches burns. That the stove over all should be bigger so they could use bigger firewood and put more fuel in at the same time. They also discussed that the stove should have handles on the sides so it would be easier to carry it inside after lighting. They commented that they would prefer handles on the sides of the stove, that would be away from the heat, since it is more safe than to carry it inside with something like the canister holder, but they think it would be good to have both so the user could choose themselves how they want to carry the stove.

Figure 4.6: comparing the heights of the MiG|BioCooker (left) and Gastov (right)

The cooks discussed the points were the pot rests and commented that they are too weak and too high. Instead of the landing of MiG|BioCooker they would prefer something like the landing on the Gastov. Where the pot rests on a bigger area and stays closer to the flame, see figure 4.6. The cooks also comment on the height of the MiG|BioCooker and compared it to the Gastov which is a bit lower than the MiG|BioCooker and said that they would prefer a lower stove so that they are able to sit when stirring. The households also commented on that the landing on the MiG|BioCooker is removable, which also makes it a bit unstable, they suggested that the landing would be stabilized but they would still want to be able to remove it from the stove.

Regarding insulation, the cooks pointed out that the MiG|BioCooker gets very hot when lighted. After some discussion they draw the conclusion that they prefer the stove to be able to heat the house even though it gets hot, as long as there is handles which are separated from the heat. They also comment on the outer insulation in the color of silver, since it easily gets burned on the sides where it's close to the fire.

Another thing the cooks discuss during the FGD is handling of firewood. As mentioned, they would want the stove to be bigger so they do not have to cut the firewood in such small pieces and that this would also make the fire last longer. The cook in Household D commented that she wanted to be able to put in un chopped wood, like they usually do in the Three stone open fire. The cooks also commented on that it is hard to arrange the firewood in the stove so that the fire do not die while putting in more fuel.

They also discussed the lighting process, since they often put in a lot of lighting material like small twigs, paper and leaves the MiG|BioCooker becomes full of ash before you put in the main firewood. To prevent the ash to affect the burning of the wood and to separate it from the char they suggested a mesh in the bottom of the stove where the ash could fall through.

When using the stove inside the house, for warming at night, they suggest having a tray underneath the hatch where you remove the char. This could protect the floor inside the house while removing the char.

When asked about the challenges moving from Three stone open fire to the improved stoves, the cooks answered that it is hard to arrange the fuel when lighting, with the Three stone open fire you just have to put the firewood there and it will light up. Also, the preparation of the wood is a challenge, with the Three stone open fire you do not have to chop it into smaller pieces. They also comment on the stability issues of the pot on the stove and the stove on the floor. Since their kitchen floor is made of dried mud it is not completely flat, which makes it harder to make the improved stoves stable.

5. DISCUSSION

5.1. Emissions

In all households except Household E the MiG|BioCooker had a lower amount of emissions compared to the three stone open fire see table 4.1-4.2. Due to the small number of tests done the last test data where enough to show that there was no significant level of less emissions from the MiG|BioCooker. But even if the levels in Household E were higher, all other tests done had a 50 % or higher decrease in CO levels and a 80 % or higher decrease in $PM_{2.5}$ levels which can make a huge impact on making the cooking environment better for the cooks.

Comparing the Gastov and the MiG|BioCooker the CO levels were lower in three out of five tests but the levels were very close to each other and further research and more tests needs to be done to verify the results. But both stoves did have mostly CO levels that was under WHO's limits for one-hour exposure stated in section *2.5.2. CO*. The levels that exceeded WHO's limits was in Household A and E for the MiG|BioCooker, the households with smallest kitchens and no ventilations except the door open. We recommend looking into the layout of the kitchens and how to modify them to remove as much smoke as possible, not all will have the means to get an improved stove but modifying the kitchens can improve the health situation a lot. As mentioned in the background of this report decreasing the CO emissions will also contribute to the atmosphere being able to take care of the CO_2 emissions instead of creating more CO_2 which it would with a higher amount of CO emissions.

When analyzing $PM_{2.5}$ levels, the MiG|BioCooker had a much lower level compared to the Three stone open fire except for the last test where it was much higher. Comparing the $PM_{2.5}$ levels to the recommended hazardous levels are hard due to that $PM_{2.5}$ levels are more hazardous when comparing long term exposure. The limits published is mostly over a 24-hour period or a yearly period but if you calculate the maximum amount of exposure during a 24-hour period by multiplying the 25µg/h limit by 24 hours you get a maximum of 600 µg per day. When considering that the cooks cook at least 3 meals per day a maximum of 200 µg per meal could be close to the recommended limit. And considering that one meal during our tests usually took about one hour the limits from the Gastov was below that in 3 out of five tests and for the MiG|BioCooker the levels were under that limit in two out of five tests, see table 4.2. Compared to the Three stone open fire both the MiG|BioCooker and the Gastov was much closer to the recommended limit which at least tells us that both improved stoves are better than the three stone open fire. As mentioned above, all but one test had a reduction of over 80 % and most tests had a reduction of over 90 %, which is a huge reduction and with a complementary modification to the kitchen all levels might reach below recommended limits. A reduction of over 80 % would also reduce the number of particles in the air which could contribute to a decrease in global warming.

As said before, when making the test in Household E the levels where very different compared to the other households. This could have been because of many different reasons but due to the significantly higher number in the last test, more research needs to be done to evaluate if this was just a outlier or if this could be a repeating event. Our own observations are that there were very high spikes in $PM_{2.5}$ levels when we added more fuel and then the fire went out when cooking with the MiG|BioCooker. This might be prevented if the cooks get familiar with the stove using logs that lasts longer and can prevent the fire from going out, but this theory needs to be confirmed with more tests when the cooks are more familiar with the stove. This could also be a reason for why the levels where significantly higher in Household E, because in that household the grevillea pruning where very thin which led to the need to add more fuel very often.

5.2. Time taken to cook and management of the process

The three stone open fire took significantly less time to cook both meals which mostly is because it produces more uncontrolled flames than both the MiG|BioCooker and the Gastov. On average it took 23 minutes less time to cook with the Three stone open fire cooking Ugali and Sukuma wiki, see figure 4.1. The Gastov and MiG|BioCooker took about the same amount of time to cook but one has to consider that the Gastov can only cook for a limited amount of time before a second canister has to be lit. All the Households in this experiment had gotten a second canister which could make it easier to cook meals that need longer time to cook but to confirm that further testing needs to be done. With the MiG|BioCooker you can cook meals that take up to three hours, maybe even more, making it a better option compared to the Gastov where you have to reload which will take time.

When considering the cooking process, the parameter of how much time the cook needs to spend keeping an eye on the fire needs to be considered. For both the Three stone open fire and the Gastov, the cook can easily walk away from the fire and work on the farm for a bit before going back to check on the meal. For the MiG|BioCooker it was harder to leave it for more than five minutes or so because the stove needed refilling and that the cook needed to move some of the wooden pieces so that the flame would not die. This might be prevented if the cooks get more used to the stove using the most suitable kind of firewood and learns how to use the stove in the best way possible.

When cooking Githeri the MiG|BioCooker took almost an hour more to cook the meal in some of the households. If the stove is easy to leave unattended with the flame still going the time consumption might become less of a problem. The cook usually leaves the kitchen during cooking if it consists of ingredients like maize and beans that only needs to boil for a longer period without having to stir continuously. But since the cooks weren't used to the MiG|BioCooker and this stove required adding fresh fuel after few minutes they had to stay in the kitchens so that the fire did not go out.

5.3. Fuel efficiency and char production

When considering fuel efficiency, the MiG|BioCooker did worse than both the Gastov and the Three stone open fire in over half of the tests. The MiG|BioCooker did have a better fuel efficiency in three out of five tests cooking Githeri and the difference between fuel consumption were much larger compared to the ones where the Three stone open fire was better. From observations made during the tests bigger logs, 5-10 cm in diameter, that where split in two or more pieces lasted a lot longer than the smaller prunings, about 2-3 cm in diameter, with the bark still attached. The smaller prunings were also harder to light which led to a lot of smoke when adding more fuel in the MiG|BioCooker.

Char production was the highest in the MiG|BioCooker in most of the tests done although the Gastov was very close to the same percentage, for a better overview see table 4.3. A percentage that means that those stoves produces about 50 % more char per used amount of firewood compared to the Three stone open fire. If one considers the char production, both the Gastov and the MiG|BioCooker has a good potential of making char that could be used as soil amendment.

The question that might need to be considered in further research is if the percentage for the MiG|BioCooker can be even higher when the cooks have gotten more familiar with the stove and its functions. In this study the cooks had no more than a few cooked meals with the stove before the actual tests were made which can influence the outcome of the tests.

5.4. User perceptions

According to the individual interviews and the FGD, the perception of the MiG|BioCooker was that it saves fuel, especially for the cook in Household B who commented that it saves two times the fuel comparing to the three stone open fire. But as said, the results in figure 4.3 show that from the tests with Ugali and Sukuma wiki, the MiG|BioCooker had the highest fuel consumption in three out of five households including Household B. When cooking Githeri the results were not corresponding to the other tests and showed that the MiG|BioCooker used less fuel than the Three stone open fire in three out of five households (A, C and D). In Household C and Household D the Three stone open fire spent more than twice as much fuel than the MiG|BioCooker.

These different results between the households could be explained by the human factor. Both since the MiG|BioCooker was the only stove that had not been used before but also since the MiG|BioCooker differs from both the three stone open fire and the Gastov when it comes to feeding fuel and lighting. It was slightly hard for the cook to learn how to use it without getting too much smoke and use too much fuel. When lighting the MiG|BioCooker the cook often wanted to put in a lot of firewood when lighting or when feeding new firewood, like they usually did with the three stone open fire. This made the MiG|BioCooker hard to light or made the fire go out and produced a lot of smoke occasionally. This was something the cooks commented on, that they could not leave the stove when they had put more firewood in. these difficulties using the MiG|BioCooker contributed to high peaks in the concentrations of emissions which made the mean higher overall. If the cooks would have more time to use the MiG|BioCooker they would probably learn how much fuel to put in for it to burn properly and how long time one piece of firewood would burn before they had to add more.

The comments made by the cooks in the FGD and the interviews made it clear that the MiG|BioCooker should be improved in some areas before it could work as a substitute to the Three stone open fire. For example, in the ranking, the Three stone open fire got the best results in the areas *heating of the house, durability/maintenance, easy to prepare fuel* in all five households. And in the group ranking it got the best ranking in *Easy to handle* and *Saves cooking time* too. Within these areas the cooks commented on modifications for the MiG|BioCooker both in the interviews and in the FGD. Such modifications like handles to be able to carry the stove in the house after being lit, which would both improve the stove to be easier to handle and to heat the house. Improved handles for the hatches would also improve the durability of the stove since they got burnt when the flame was big. Also, the outer insulation in the color of silver was something commented as a problem for durability. Since it easily got burnt or worn out fast it could need another outer shell to protect the insulation layer. This would probably also help in making the stove less hot on the outside when cooking, which was mentioned as a concern during the FDG.

The challenges the cooks commented on, moving from Three stone open fire to improved stoves like the MiG|BioCooker was also connected with the areas where Three stone open fire got good results in ranking. There were comments about the preparation of the fuel where three stone open fire does not need much firewood preparation. Also, the cooks thought that with the MiG|BioCooker the firewood was hard to arrange when lighting, as said before this could get easier as the cooks get more used to it. But even though they would have used it for a long time, it would still need more arrangement of the firewood than the three stone open fire. Something else that came up as a challenge with the MiG|BioCooker was that it was unstable which also makes it less easy to use. Since they often have dried mud floor in the kitchens it is hard to make the stove completely stable. But if you had the stove standing on four legs instead of a flat surface it would be easier to make it stable, like the Gastov.

When it comes to user experience, maybe the most important characteristics is to be easy to handle. Since if the user has an easier way to cook, they will use that instead. For now, it seems like the cooks really like the stove but mostly for its appearance, that it produces char and that it smokes less than Three stone open fire. For now, the stove is too impractical in comparison to the Three stone open fire in respect to their needs. To be able to replace the three stone open fire it would probably, except for the modifications mentioned earlier, need to be bigger overall, both in the combustion chamber and the landing where the pot stands. This would make it possible to cook for bigger gatherings and would also make it possible for the cook to put more firewood in.

Time is another important factor when talking about the users' need. In the test with the Ugali and Sukuma Wiki, it took less time with the Three stone open fire which gives them more time to do other chores on the farm. And when cooking Githeri they do not have the possibility to sit in the kitchen and cook during the three hours it takes to cook the maize and beans because they have a lot of other things to do on the farm. When cooking with the MiG|BioCooker they need to keep an eye on the fire to a greater extent than with the Three stone open fire which makes it more impractical for the cook. One cook did mention that they thought that it would be possible to do so after getting used to the new stove which would have to be confirmed in further studies.

As said, more training with the MiG|BioCooker would probably give the users better experience of the stove, increase the fuel efficiency and lower the emissions. But there still modifications that would need to be done to make it easier to move from the traditional Three stone open fire to improved stoves like the MiG|BioCooker.

Furthermore, if the users started to cook with the MiG|BioCooker or other biochar-producing stoves, they would decrease their exposure to emissions of $PM_{2.5}$ and CO and therefore improve the SDG number 3. Good health and well-being but also to Goal 7: Affordable and Clean Energy where one of the subgoals is about clean cooking. This would contribute to better health in the families but also less contribution to the global warming as described in *2.3. Environmental impact*. Since the MiG|BioCooker also produces more char than the three stone open fire there is a possibility to either decrease the families demand for fuelwood by using the char as a fuel, or to use the char as soil amendment. Therefore there are other SDG:s the MiG|BioCooker could contribute to like Goal 13: Climate Action and Goal 15: Life on land (UN, n.d.).

5.5. Limitations

If comparing the individual rankings with the final group ranking you could see some differences in the answers. This could also be explained by the time aspect. Since the FGD was made in the end of all tests, some households had been having their tests many days or almost two weeks before the final group ranking, these households may have forgotten what they thought about the stoves while testing them. Even one of the cooks, in Household D, commented on that it was hard for her to remember the first tests in the household, which also could affect the rankings in each household.

In this report the Two-chamber stove is not discussed, but when ranking the stoves, the Two-chamber stove had to be taken in consideration since it was one of the stoves tested by the households and the exercises provided useful information on the perception of the cooks on this stove.

Also, when making the individual ranking, the cooks did not change the number of beans in the piles after making the first distribution of beans. After the first distribution the cook often just moved the piles. This makes the number of beans a bit misleading since the cook mostly ranked the stoves relative to the other stoves.

When hanging the measuring equipment an assumption was made that the cook was standing when cooking, therefore, the equipment was hanging 1.5m from the ground. But since all cooks were sitting when cooking the assumption should have been changed to a shorter height. The question is whether these results could have been different if the equipment would hang closer to the ground since the smoke rises in the kitchen. Another assumption that was not completely right was that the cook always is in the kitchen when cooking. Especially when cooking Githeri but also with the Ugali and Sukuma Wiki, the cook was working on the farm almost all the time. Hence it is a bit misleading to assume that the cook gets exposed to all the emissions when cooking.

In two of the tests the equipment for measuring PM levels turned off because of some problem with the battery. When cooking Githeri with MiG|BioCooker in Household C the shutdown was detected before the cooking started so that we could restart the equipment and still get the measurements. But in test number 18 the equipment stopped logging in the middle of the test. Therefore, this test had to be redone on the last day of the stay. This incident should not affect the results too much since it was made shortly after the original test where the weather and other surrounding factors was quite similar.

According to the paired sample sign tests, most of the results are not showing any significant difference between the stoves. This depends primarily on the small number of tests. The results where the paired sample sign test showed significant difference and where we therefore can draw any conclusions is that the Three stone open fire took significant less time than both MiG|BioCooker and the Gastov. And when cooking Githeri, the Three stone open fire had significant higher CO-concentrations than the MiG|BioCooker. When comparing char percentage, the MiG|BioCooker had a significantly higher result than the Three stone open fire for both meals. If more tests could have been done, more conclusions could probably be drawn. But since we had limited time doing these tests this was not possible for this project.

The kitchens where the tests were done differed a lot in ventilation, size and how big the openings were between the timber. This could be an explanation to the differences in results between the households. Since only one test could be done per kitchen, these data should be treated with caution as it is only from five varied households. For future research this area could be interesting to study how different kitchen designs could affect the concentration of emissions.

Another factor that could have affected the result, that have been mentioned earlier, is that the MiG|BioCooker is a new stove for the cooks while the three stone open fire and the Gastov both have been used for a longer period. This could also contribute to the big differences in the results of the emissions since some households got a better understanding of the stove while using it.

This project could either way serve as a basis for other developing countries who wish to implement biochar producing stoves and could contribute to achieving cleaner cooking in said countries. This project is also closely linked to multiple collaborations and will contribute to maintaining and facilitating relations over borders.

6. CONCLUSIONS

Regarding the small number of tests done in this project, it is hard to draw any short conclusions. The results that showed statistical significance were that the traditional Three stone open fire takes shorter time to cook with than both Gastov and MiG|BioCooker. But on the other hand, it emits a higher concentration of CO than the MiG|BioCooker when cooking Githeri. For Githeri as well as Ugali and Sukuma, the result shows that the MiG|BioCooker have a higher production of char than the Three stone open fire.

Even though the number of tests was too small to give a statistically significant result, it still shows an indication that the MiG|BioCooker could decrease the CO and $PM_{2.5}$ levels in the kitchens making it a healthier environment for the cooks. For CO the result shows a 50% reduction of CO and an 80% reduction of $PM_{2.5}$. If more test would have been done, this would probably be statistically significant too. Especially if the users get more used to the MiG|BioCooker, which could affect both the smoke production leading to a decrease in $PM_{2.5}$ and CO levels, but also demanding less firewood when cooking. For future research on this subject, it would be interesting to see if and how different designs of the kitchens could affect the concentrations of emissions in the kitchens since this was something that could have been contributed to large differences between the households. Also, it would be interesting to see if the results would be different if the households were more used to the stove.

Despite that the MiG|BioCooker shows a decrease in emissions like $PM_{2.5}$ and CO this is not enough argument for the users to move from the traditional cooking methods. Because when it comes to the cook’s choice of stove, it is more often the most practical. For now, the Three stone open fire is still considered the best, by the cooks, when it comes to cooking for bigger families, that it is easy to use, both handling the stove and preparing the firewood and that it takes less time cooking. But with some modifications maybe the MiG|BioCooker soon can be a replacement for the Three stone open fire.

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Appendix A

Table of mean values of CO in each test

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
	ppm				
A	69	33	28	91	52
B	10	3	6	7	7
C	10	2	4	36	2
D	43	4	27	34	6
E	52	54	35	133	70
Mean value	37±26	19±23	20±14	60±51	27±31

Paired sample sign test of CO concentrations for each set of stoves

Using mean values of CO concentrations of each test and stove a paired sample sign test were conducted. Three different comparisons were made. MiG|BioCooker vs. Three stone open fire, MiG|BioCooker vs. Gastov cooking Ugali and Sukuma Wiki, and MiG|BioCooker vs. Three stone open fire cooking Githeri. Level of significance were 95 % (α=0.05)

H0: The median difference is zero

H1: The median difference is $\neq 0$

Household	Ugali and Sukuma wiki				Githeri	
	MiG|BioCooker – Three stone open fire	Sign	MiG|BioCooker – Gastov	Sign	MiG|BioCooker – Three stone open fire	Sign
A	-36	-1	5	1	-39	-1
B	-7	-1	-3	-1	-1	-1
C	-7	-1	-2	-1	-34	-1
D	-40	-1	-23	-1	-28	-1
E	2	1	19	1	-63	-1
No. of positive signs		1		2		0
No. of negative signs		4		3		5
Sample size, n		5		5		5
Success, x		1		2		0
p-value		0.1875		0.5		0.03125

Since the p-value in the comparisons when cooking Ugali and Sukuma wiki were >0.05 no significant difference could be accepted. In the comparison between MiG|BioCooker and Three stone open fire cooking Githeri the p-value < 0.05 and the hypothesis H1 can be accepted, there is a significant difference between the stoves.

Appendix B

Table of mean values of PM in each test

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
	μg/m³				
A	58 088	1701	457	58 178	25 761
B	17 516	700	46	462	3860
C	1400	171	194	2989	343
D	9966	128	620	7198	1750
E	2017	9736	142	82 493	31 754
Mean value	17 797±23 466	2 487±4 102	292±239	30 264±37 654	12 694±14 869

Paired sample sign test of PM concentrations for each set of stoves

Using mean values of PM concentrations of each test and stove a paired sample sign test were conducted. Three different comparisons were made. MiG|BioCooker vs. Three stone open fire, MiG|BioCooker vs. Gastov cooking Ugali and Sukuma Wiki, and MiG|BioCooker vs. Three stone open fire cooking Githeri. Level of significance were 95 % (α=0.05)

H0: The median difference is zero

H1: The median difference is ≠ 0

Household	Ugali and Sukuma wiki				Githeri	
	MiG|BioCooker – Three stone open fire	Sign	MiG|BioCooker – Gastov	Sign	MiG|BioCooker – Three stone open fire	Sign
A	-56387	-1	1244	1	-32417	-1
B	-16816	-1	654	1	3398	1
C	-1229	-1	-23	-1	-2646	-1
D	-9837	-1	-492	-1	-5448	-1
E	7720	1	9595	1	-50739	-1
No. of positive signs		1		3		1
No. of negative signs		4		2		4
Sample size, n		5		5		5
Success, x		1		2		1
p-value		0.1875		0.5		0.1875

Since the p-value in all the comparisons were >0.05 hypothesis H0 cannot be rejected and no significant difference could be accepted.

Appendix C

Table of Cooking process in each test

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
	hh:mm				
A	00:32	01:14	00:54	02:20	03:22
B	00:37	00:53	01:00	02:56	02:49
C	00:43	01:02	01:20	03:27	03:26
D	00:43	00:55	01:04	03:52	04:00
E	00:48	01:15	01:05	02:36	03:37
Mean value	00:41±00:06	01:04±00:10	01:05±00:09	03:02±00:37	03:27±00:25

Paired sample sign test of Cooking process for each set of stoves

Using mean times of Cooking process of each test and stove a paired sample sign test were conducted. Three different comparisons were made. MiG|BioCooker vs. Three stone open fire, MiG|BioCooker vs. Gastov cooking Ugali and Sukuma Wiki, and MiG|BioCooker vs. Three stone open fire cooking Githeri. Level of significance were 95 % (α=0.05)

H0: The median difference is zero

H1: The median difference is ≠ 0

Household	Ugali and Sukuma wiki				Githeri	
	MiG|BioCooker – Three stone open fire	Sign	MiG|BioCooker – Gastov	Sign	MiG|BioCooker – Three stone open fire	Sign
A	00:42	1	00:20	1	01:02	1
B	00:16	1	-00:07	-1	-00:07	-1
C	00:19	1	-00:18	-1	-00:01	-1
D	00:12	1	-00:09	-1	00:08	1
E	00:27	1	00:10	1	01:00	1
No. of positive signs		5		2		3
No. of negative signs		0		3		2
Sample size, n		5		5		5
Success, x		0		2		2
p-value		0.03125		0.5		0.5

In the comparison between MiG|BioCooker and Three stone open fire cooking Ugali and Sukuma Wiki the p-value < 0.05 and the hypothesis H1 can be accepted, there is a significant difference between the stoves. Between the MiG|BioCooker and the Gastov, and between the MiG|BioCooker and Three stone open fire cooking Githeri p-values were >0.05, hypothesis H0 cannot be rejected and no significant difference can be accepted.

Appendix D

Table of firewood consumption in each test

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
	g				
A	1097	1379	911	6997	4740
B	903	975	872	4252	4507
C	1156	997	719	8915	2911
D	1112	736	887	7478	3158
E	852	1262	955	2379	3153
Mean value	1024±137	1070±254	869±89	6004±2638	3694±859

Paired sample sign test of firewood consumption for each set of stoves

Using mean values of firewood consumption of each test and stove a paired sample sign test were conducted. Three different comparisons were made. MiG|BioCooker vs. Three stone open fire, MiG|BioCooker vs. Gastov cooking Ugali and Sukuma Wiki, and MiG|BioCooker vs. Three stone open fire cooking Githeri. Level of significance were 95 % (α=0.05)

H0: The median difference is zero

H1: The median difference is $\neq 0$

Household	Ugali and Sukuma wiki				Githeri	
	MiG|BioCooker – Three stone open fire	Sign	MiG|BioCooker – Gastov	Sign	MiG|BioCooker – Three stone open fire	Sign
A	282	1	468	1	-2257	-1
B	72	1	103	1	255	1
C	-159	-1	278	1	-6004	-1
D	-376	-1	-151	-1	-4320	-1
E	410	1	307	1	774	1
No. of positive signs		3		4		2
No. of negative signs		2		1		3
Sample size, n		5		5		5
Success, x		2		1		2
p-value		0.5		0.1875		0.5

Since the p-value in all the comparisons were >0.05 hypothesis H0 cannot be rejected and no significant difference could be accepted.

Appendix E

Table of percentage of char produced in each test

Household	Ugali and Sukuma wiki			Githeri	
	Three stone open fire	MiG|BioCooker	Gastov	Three stone open fire	MiG|BioCooker
			%		
A	11	16	20	9	18
B	16	24	20	6	13
C	12	23	11	11	15
D	10	18	14	8	19
E	10	12	17	9	12
Mean value	12±2	18±5	17±4	9±2	15±3

Paired sample sign test of Cooking process for each set of stoves

Using mean times of Cooking process of each test and stove a paired sample sign test were conducted. Three different comparisons were made. MiG|BioCooker vs. Three stone open fire, MiG|BioCooker vs. Gastov cooking Ugali and Sukuma Wiki, and MiG|BioCooker vs. Three stone open fire cooking Githeri. Level of significance were 95 % (α=0.05)

H0: The median difference is zero

H1: The median difference is ≠ 0

Household	Ugali and Sukuma wiki				Githeri	
	MiG|BioCooker – Three stone open fire	Sign	MiG|BioCooker – Gastov	Sign	MiG|BioCooker – Three stone open fire	Sign
A	4.11	1	-4.83	-1	8.71	1
B	8.48	1	3.79	1	6.58	1
C	10.98	1	11.58	1	3.38	1
D	7.64	1	3.48	1	11.34	1
E	2.26	1	-4.66	-1	2.60	1
No. of positive signs		5		3		5
No. of negative signs		0		2		0
Sample size, n		5		5		5
Success, x		0		2		0
p-value		0.03125		0.5		0.03125

In the comparison between MiG|BioCooker and Gastov the p-value > 0.05, hypothesis H0 cannot be rejected and no significant difference can be accepted. Between both comparisons regarding the MiG|BioCooker and the three stone open fire, p-values < 0.05 and the hypothesis H1 can be accepted, there is a significant difference between the stoves.

Appendix F

Questionnaire for interviews

Background information:

Number of people in the household? Number of people under 18? Number of people under 5 years old?

Fuel:

1. Which fuel did you use for cooking last week and how many times did you use it?
2. Is this the commonly used fuel? If no which type of fuel is the commonly used fuel?
3. How do you get the fuel mentioned above?
4. How much time do you spend collecting the fuels you have mentioned above?
5. How much money do you spend on fuel a month/week?
6. How do you usually dry your fuel?

Stove:

7. Which stove do you commonly use for cooking?
8. Do you use different stoves for different kinds of meal? If yes which ones?

General:

9. Who takes the decision of buying a new stove in your household? – What is the role of husband and wife in the decision making?
10. What type of meal do you commonly cook?
11. Is there any type of meal that you usually cook but can’t cook with the Gastov? (If the answer is yes, ask them if they can try to cook this meal with MIG)
12. What would you prioritize, using the char for fuel or using it as a soil amendment? (ask with the beans?) (this question needs to be revised)

Evaluation of stoves:

13. What characteristics of the stove do you like?
14. How do you find the handling of the stove?
15. Based on your experience on the stove use, would you propose any modification to it to better suit your cooking needs? If yes, what modification would you propose?
16. How much would you be willing to spend on it?

Appendix G

Table for ranking

Stove Area	MiG|BioCooker	Gasifier	Two-Chamber	Three stone open fire	Number of points to distribute
Saves Fuel					50
Saves cooking time					50
Heating of the house					50
Less smoke					50
Easy to use					50
Easy preparation of fuel					50
Durability/ maintenance					50
Appearance					50

Appendix H

Cooking test protocol

Template for field-based cooking test						Test number:	
Date:	Name of household:						
Fuel used:	Type of stove:		Circle: Gasifier stove, two chamber, MIG and 3stone				
Data of field-based performance			Data of food cooked				
PARAMETERS	Units		Dish 1:				
			Ingredient				Amount (g)
Start weight of prepared fuel in the canister W1	g		1				
Start time to light T1	time		2				
Time when fuel catches fire well T2	time		3				
Start time to cook dish 1 (T3)	time		4	Water used (liters)			
Time when water boils (T4)	time		5				
Time when dish 1 is ready (T5)	time		6				
Start time to cook dish 2 (T6)	time		7				
Time when dish 2 is ready (T7)	time						
Time fuel charred (T8)	time		Weight of the pot (g)				
Time when char cools (T9)	time		Weight of pot plus dish 1 (g)				
Weight of charcoal produced (C1)	g		Weight of the dish 1 (g)				
Weight of ash produced (WAs1) …	g						
Gasifier round 1 calculations							Time (min)
Time taken to light the stove (T2-T1)	min		Time to cook dish 1with gasifier (T4-T3)				
Time taken to char T8-T2	min		Time to cook dish 1with 3stone fire MIG, two chamber (T19-T18)				
			Dish 2:				
Change Over 1			Ingredient				Amount (g)
Start weight of prepared fuel in the canister W2	g		1				
Start time to light the stove T10	time		2				
Time when fuel catches fire well T11	time		3				
Start time to cook (T12)	time		4	Water used (liters)			
Finish time charring (T13)	time		5				
Time when char cools (T14)	time		6				

Weight of charcoal produced (C2)	g		7				
Weight of ash produced (WAs2)	g						
Gasifier round 2 calculations							
Time taken to change over (T10-T8)	min		Weight of the pot (g)				
Time taken to light the stove (T11-T10)	min		Weight of pot plus dish 2 (g)				
Time Taken to char (T13-T11)	min		Weight of dish 2 (g)				
Summary							
Total time of cooking process (T7…...-T1)	min						Time (min)
Total time to cook the meal (T7…...-T3)	min		Time to cook dish 2 with gasifier (T7-T6)				
Net fuel used to cook the dishes (subject to cooking time)	g		Time to cook dish 2 with 3stone fire, MIG, two chamber (T21-T20)				
Gross fuel used to char (W1+W2+…. n)	g						
Total char produced (C1+C2+…. n)	g						
Total ash produced (WAs1+WAs2…n)	g						
% char produced from fuel in charring 1 (C1/W1*100)	%						
% Char produced from fuel in charring 2 (C2/W2*100)	%						
Avg % char (C1/W1*100)+(C2/W2*100) …..n/n	%						
Total fuel used-char produced	g						
Three stone open fire/MIG Bio cooker/two chamber stove							
Start weight of firewood pile W3	g						
weight of pulp loaded into gasification chamber Wp1	g						
Start time to light the stove T15	time						
Time when fuel is well lit T16	time		Moisture content (%)		1	2	3
Start time to cook dish 1 T17	time						
Time when water boils T18	time						
Time when dish 1 is ready T19	time						
Start time to cook dish 2 T20	time						
Time when dish 2 is ready T21	time						
Weight of fuel remaining in the pile W4	g		Temperature of flames (time)				
Weight of fuel withdrawn from fire (if any) W5	g			Temperature C°:			
Weight of char produced C3	g			Flames	Time (Min)	hatch position	
Weight of uncharred fuel UCF1	g		TF1		5		

Weight of half-charred fuel HCF1	g		TF2		15		
weight of ash produced WAs3	g		TF3		25		
Summary			TF4		35		
Time taken to light the stove (T14-T15)	min		TF5		45		
Total time of cooking process (T20….-T14)	min		TF6		55		
Total time to cook the meal (T20….-T16)	min						
Net fuel used to cook the dishes (subject to cooking time)	g						
Gross fuel used to char (W3+W5) =W6	g						
% Char produced (C2/W2*100)	%						
Total fuel used-char produced	g						

Appendix I

Cooking test observation form

Household Name: __ Date of the cooking test: __ Stove used:___

No.	Observations	Findings
	Kitchen condition during the test	
1	Is the kitchen a separate building or within the main building?	
2	Which side does the kitchen door open?	
3	Which side of the kitchen does the window(s) open?	
4	How many windows does the kitchen have?	
5	Is the kitchen fully enclosed or with some sides left open?	1. Fully enclosed 2. Some sides left open (name the of sides that are left open)
6	Dimensions of the kitchen	1. Length ______________________ 2. Width_______________________ 3. Height_____________________ 4. Ventilation openings__________
7	Materials used to build the kitchen walls	
8	Materials used to roof the kitchen	
9	Household members in the kitchen and what they were doing	
10	What cook stoves are in the kitchen	
11	How are the three stone in the open fire set	
12	Other observations on the kitchen	
	Fuels used during the test	
13	Fuel type(s) used by the household for cooking	1. Firewood (give name(s))____________ 2. Residues (give name(s)) ____________
14	Where the households keep the firewood it uses	
15	Who prepares the fuel that is used to cook?	1. Age…… 2. Education…….. 3. Sex…………..
16	When is the fuel prepared?	a. at the cooking time b. In advance but within the same day c. In advance and on a different day
17	What is used to prepare the fuel?	

18	Other observations on fuel	
	Cooking during the test	
19	Where is the stove lit?	a. Outside in the open b. Outside in a verandah c. Inside
20	What is used to light the stove	
21	Who cooked the meal for the household?	1. Age____________________________ 2. Gender__________________________ 3. Education level ___________________
22	Where the household used the stove	
23	When does the smoke occur?	
24	How does the cook respond to it?	1. Open window 2. Open door 3. Open hatch 4. Blow fire 5.
25	Are there instances where the gasifier flame dies, and the cook puts the pot down and blows the fire?	
26	Other activities done by the cook alongside cooking	
27	Position of the stove in the kitchen	
28	Does the cook cover the pot when cooking?	
29	Does the cook use the stove skirting?	
30	Status of the door and the window(s)	1. Door _________________ 2. Window_______________
31	What the cook does after finishing cooking?	
32	How is the produced biochar handled	i. Where is the charcoal cooled a. Inside the kitchen b. Outside in the open c. Outside at the verandah ii. Where is the char stored?......... iii. Is the char stored immediately it cools or after some time? ___________________________ iv. Is it mixed with previously produced char or kept separately? ________________________
33	Others observation during cooking	

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