Addis Ababa University

Addis Ababa Institute of Technology

Center of Renewable Energy Technology

Testing of Improved Biomass Cook stove (*Tikikil* and *Mirt*) in Rural Households of Southern Ethiopia Using the New Field Testing Standard: The Case of Gamo Zone

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment for the Degree of Master of Science in Renewable Energy Technology

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "Testing of Improved Biomass Cook stove (*Tikikil* and *Mirt*) in Rural Households of Southern Ethiopia Using the New Field Testing Standard: The Case of Gamo Zone" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my Knowledge.

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ABBREVIATION AND ACRONYMS

ASTM	American society testing Materials
CCT	Controlled cooking Test
CO	Carbon monoxide
CO_2	Carbon dioxide
CRGE	Climate Resilient Green Economy
CSA	Central Statistical Agency
ETB	Ethiopian Birr
EnDev	Energizing Development (GIZ)
EREDPC	Ethiopian Rural Energy Development & Promotion Center
GPS	Geographic Positioning System
GTP	Growth and Transformation Plan
HAP	Household Air Pollution
ICS	Improved Cookstoves (*Tikikil* and *Mirt*)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IWA	International Workshop Agreement
KPT	Kitchen Performance Test
MC	Moisture content
MoWE	Ministry of water and Energy
OECD	Organization for economic cooperation and development
PM	Particulate Matter
UNFCCC	United Nation Framework Convention on Climate Change
USD	United States Dollar
VM	Volatile Matter
WBT	Water Boiling Test
SFC	Specific Fuel Consumption
WHO	World Health Organization

ABSTRACT

This study has been carried out in the Gamo Zone of Ethiopia with the aim of evaluating the performance of household biomass cookstoves in actual field settings in kitchens. Both *Tikikil* and *Mirt* cookstoves were distributed to 38 households to evaluate the daily fuelwood consumption, $PM_{2.5}$ emissions, and the overall usability of these stoves by comparing them to the *Choche* cooking stoves which is practiced in the community by applying the newly developed ISO 19869:2019 field standard procedure. Data on daily fuelwood and energy consumption, as well as user preferences, were collected through before-and-after surveys of randomly selected households. Direct field examination of seven home-specific fuel use for baking *injera* for three replication and monitoring $PM_{2.5}$ emissions over 24 hour in 20 household kitchens using both *Choche* and the improved cookstoves (*Tikikil* and *Mirt*). The cooking tests and kitchen performance assessments were carried out using Excel-based data and calculation tools developed by the Shell Foundation. Descriptive statistics and paired t-tests for mean differences were performed using SPSS software. The concentration of PM over a 24-hour period in households was calculated using PICA software.

The study finds that, the mean daily fuel use for *Choche* cooking stove was 8.72 kg (SD = 2.26), and the mean daily fuel use for improved cook stoves was 5.80 kg (SD = 2.06). The paired differences between the two means were 2.91 kg (SD = 2.65), which was statistically significant ($p < .001$) ICS in this study reduced fuelwood use on average by 33.3%. A household in the locality would emit, 5,858.9 kg and 3,898.89 kg CO_2e per year from using the *Choche,* and ICS *(Tikikil* and *Mirt)* stoves, respectively. The difference between the two types of stoves in CO_2 emissions is 1.96 metric tons per year per household. The mean specific fuel consumption for *Choche* and *Mirt* stoves was 609.52 g/kg (SD= 65.83), and 444.95 g/kg (SD= 59.48), respectively. The mean total cooking time for *Choche* and *Mirt* stoves was 99.90 minutes (SD=4.51) and 95.47 minutes (SD=7.51), respectively, the paired differences between the two cooking methods was 4.42 minutes (SD= 5.88). The average $PM_{2.5}$ concentration with the *Chocho* stove is 1102±408.6 $\mu g/m^3$, while for *Tikikil* and *Mirt* stoves was 749.6±225.1 $\mu g/m^3$, This figure is about 45 times and 30 times above the WHO 24-hour guideline of 25 μg/m^3 of household air pollution. The relative difference in mean between the two stove types is 32.6 % emission reduction by *Tikikil* and *Mirt* stoves.

The performance of the *Tikikil* and *Mirt* improved cookstoves demonstrates their enhanced efficiency compared to the *Choche* stove. As a result, these improved cookstoves have a positive impact on better fuel utilization, reducing cooking time household health by reducing exposure to indoor air pollution. The finding majorly suggests that further studies need to be conducted in depth on the traditional cooking practice of the rural community and try to engage them in designing the alternative technologies, awareness creation should be in place for the adoption of improved cookstoves and enhance collaborative efforts among the government, non-government, and private sectors for the success of large-scale dissemination. In view of this, important lessons could be drawn from this case study and local household cooking practice for future interventions.

Key words: *Choche, Mirt, Tikikil*, Improved cookstove, Particulate Matter, Fuelwood

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CHAPTER ONE
INTRODUCTION

1.1 Background

Cooking is a fundamental and unique human activity that binds us as families, cultures, and even religious communities. It is regarded as the pinnacle of art. However, it has become to be extremely difficult to ensure that everyone has access to clean cooking energy in the twenty-first century (WB, 2022). Sustainable Development Goal 7 calls for "ensuring affordable, reliable, sustainable, and modern energy for all" by 2030. Cooking practices can also help contribute to achieving for good health and well-being (SDG 3), gender equality (SDG 5), sustainable cities and communities (SDG 11), and climate action (SDG 13) (UN, 2015). One-third of the world's population uses biomass energy as a primary energy source with traditional stoves that haven't progressed much since prehistoric times for their daily energy needs, and more than three-quarters of all those without electricity live in Africa (WB *et al.*, 2022).

People worldwide use various cookstoves and fuels for modern cooking, including biomass, liquefied petroleum gas (LPG), piped natural gas (PNG), kerosene, bioethanol, charcoal, and biogas (Afrane & Ntiamoah, 2011; Benka-Coker *et al.*, 2018). Furthermore, electric, solar, and induction cooking devices are used (Alem *et al.*, 2013; Mekonnen & Hassen, 2019). In low- and middle-income countries, open fires and inefficient stoves are regularly used; WHO expects that in 2030, almost 2.4 billion people will still cook using solid fuels and kerosene as their main fuel sources, without significant policy action, it is predicted that 2.1 billion people will still not have access to clean technology and fuels (IEA, 2022a).

The ongoing use of traditional biomass fuels and stoves has a number of negative effects on human health, the environment, and the quality of life (Beyene & Koch, 2013; Mekonnen & Hassen, 2019). Traditional cookstoves that use biomass fuels incompletely produce high amounts of household air pollution, including hazardous pollutants and tiny soot particles that can inhale deeply (Tamire *et al.*, 2021). Every year, 3.2 million people get illnesses that lead to an early death as a result of HAP brought on by the incomplete combustion of biomass fuels and kerosene used for cooking (WHO, 2022). Nearly 25 exajoules (EJ), or 830 Mtce, of biomass were used in 2021, largely in developing countries in Africa and Asia, for traditional cooking and heating, leaving nearly 2 billion people without access to clean cooking (IEA, 2022b).

Sub-Saharan Africans comprised the majority of the 568 million people or 77% of the total population, who didn't have access to electricity and the 923 million who cooked using harmful fuels in 2021(WB *et al.*, 2022). At the beginning of 2020, Africa was already behind track to meeting the Sustainable Development Goal (SDG) of having universal access to modern energy by 2030 (SDG7), and the Covid-19 outbreak has further slowed progress (IEA, 2022a).

In Ethiopia, households account for 92% of total energy average consumption per year (UNEP, 2019), Only 2.4% of households use a clean fuel stove solely, whereas 63.3% use a three-stone as their main cooking appliance (Padam *et al.*, 2018). Eight out of ten residents live in rural areas with limited access to modern energy, forcing them to rely on traditional biomass energy (fuelwood, charcoal, dung cakes and crop residue), as is characteristic in much of sub-Saharan Africa. Over 90% of Ethiopia's energy needs are met by solid biomass fuel (Fekadu *et al.*, 2021; Guta, 2012a; IEA, 2019; Mondal *et al.*, 2018; UNEP, 2019). Rural households use 0.79 tons of fuelwood annually on average per person, mostly from nearby forests and farms (MWE, 2012).

As Improved cookstoves (ICS) have drawn a lot of attention as crucial intermediate technologies (Jeuland & Pattanayak, 2012). Ethiopia has demonstrated a particularly significant commitment to ICS dissemination by incorporating them in official strategy documents because to the possible medium-term benefits (Kebede *et al.*, 2022). By 2030, the Climate Resilient Green Economy plan of Ethiopia (EPA, 2011), pledges to promote ICS that will be used by around 20 million households and reduce emissions of greenhouse gases by approximately 34.3 Mt CO_2e. As one of the few strategic targets in the Ethiopian energy sector, "reducing the demand for biomass by enhancing fuel efficiency" is currently held in high regard. According to a research conducted in rural Ethiopia by Dresen *et al.* (2014), households that switched to ICS were able to cut down on the amount of fuelwood they used for cooking by about 40%. This translates into an annual fuelwood savings of 1.28 tons per household.

Tikikil and *Mirt* cookstoves are the two most widely known and used cooking and baking stoves in the country (Asfaw, 2011; Fekadu *et al.*, 2021).

This study was carried out in the Gamo Zone of the SNNP-Region of Ethiopia to assess the performance of household biomass cookstoves in actual field settings in kitchens. *Tikikil* and *Mirt* cookstoves were disseminated to thirty eight households to evaluate the fuel wood consumption on a daily basis, $PM_{2.5}$ emissions in the household, and acceptability of the stove by comparing it with the traditional cooking practices of the community. Cooking experiments examined specific fuelwood usage, household air pollution of $PM_{2.5}$, and cooking time as performance indicators. Home cooks were polled to learn more about their preferred stoves' features and preferences, as well as their readiness to pay for ICSs.

1.2 Statement of the problem

Biomass fuels are currently Ethiopia's most widely used energy source, meeting 86 percent of the nation's total energy demands. To prepare food and make coffee and tea, it is primarily used in households as well as businesses. The energy demand from biomass has been gradually increasing, from around 1260 PJ in 2009/2010 to just under 1600 PJ in 2019/2020 (MoWE, 2022). This substantial reliance on solid biomass fuels has accelerated the degradation of land resources and deforestation, in addition to the rising domestic energy demand brought on by a rapidly population growing of the country (Beyene & Koch, 2013).
The thermal efficiency of the biomass cookstove had benefits in terms of fuel wood savings. The most common cooking and baking stove are in the country are the *Tikikil* and *Mirt* cooking and baking stoves respectively; however, little is known about how these ICSs has impact on the amount of fuelwood consumed by households (Wassie & Adaramola, 2021). And also their widespread use has been restricted, and traditional cooking solutions still take priority in most of the country’s households.

Additionally, few studies on nation's stove performance testing was carried out using the Water Boiling Test, Controlled Cooking Test, and Kitchen Performance Test (Beyene *et al.*, 2015; Fekadu *et al.*, 2021; Gebreegziabher *et al.*, 2018), each of which had its own drawbacks (Weinbaum, 2010). As a result, there is a significant knowledge gap regarding the real impact of ICSs when used in typical rural household settings, subject to numerous limiting circumstances, for instance, the cooking practices of the community, the type of food they cook, and baseline traditional cooking practices in the local area. As a result, ISO developed new test protocols for the stove tests (ISO, 2019). Additionally, the joint effects of the *Tikikil* and *Mirt* stoves on the actual in-field use of wood fuel (in kitchen) and the reduction of Particulate Matter emission ($PM_{2.5}$) were not assessed in comparison to the traditional cooking methods.

1.3 Objectives

1.3.1 General objective

The general objective of this research is to assess the performance and usability of household improved biomass cookstoves (*Tikikil* and *Mirt*) in the actual household's kitchen of Gamo zone by applying the ISO 19869:2019 standard: Clean cookstoves and clean cooking solutions: field testing methods for cookstove procedures.

1.3.2 Specific objectives

- To examine the fuelwood savings potential of the improved cookstoves compared to the traditional cookstove.
- To measure the household $PM_{2.5}$ reduction by improved cookstove.
- To evaluate the GHG reduction potential of improved cookstove utilization.
- To make an assessment of improved cookstove usability and user satisfaction.

1.4 Significance of the study

Tikikil and *Mirt* cookstoves have been developed and promoted over the past 30 years throughout the country and have been tested by different public institutions, NGOs, and researchers in the laboratory and actual household to understand how well they function comparing to the traditional or three stone fire. A few studies also investigated stove preferences and usability because an improved stove is useless if it is not adopted and used frequently. This was primarily done through surveys that inquired about cooks' willingness to pay for the stoves and their perceptions of whether they were suitable for typical cooking in the home. A user survey that focuses on a number of qualitative and quantitative issues relating to stove acceptance must be combined with a technical component that measures fuel consumption and cooking time in order to accomplish these aims. In this situation, there has been very little adoption of the stove, and the majority of rural households continue to cook over a traditional method or open fire.

This study will contribute by offering a thorough empirical assessment of the performance of favorable ICSs in Ethiopia with regard to fuelwood requirements, Household air pollution (HAP), cooking times, and the level of satisfaction expressed by users. Given that context-specific factors can affect household energy choices, the study were examine over how location, access to roads, and the market affect household energy choices (Puzzolo *et al.*, 2016). With a user survey that focuses on a range of qualitative and quantitative issues pertaining to stove acceptance decisions and their implications on policies for the Ethiopian rural household energy transition.

1.5 Limitation

The key limitation is that there was not enough funding to extend the sample size and analyse regional and seasonal variations in daily fuel wood consumption, specific fuel consumption, and HAP, as well as durability and safety stove tests. The results may not be representative of the performance of the stoves across the country because this study only used one case study area with a sample of 38 households to evaluate the performance of the stoves. Additionally, the researcher was unable to measure the CO emission in the actual household due to the lack of readily available and accurate measuring tools. Another drawback has also been the availability of secondary data on adoption and willingness to pay for the stoves.

1.6 Organization of the research

The structure of the thesis is organized as follows: Chapter one discusses the introduction of the research, which includes the background of the research, the problem statement, and the objective of the research. Chapter two discusses the different reviews of the research. Chapter three discusses the methodology of the research, which includes field study development, study design, data collection for fuel measurement, and data analysis. Then results and discussion were done, and the last chapter discussed conclusions and recommendations for future works.

CHAPTER TWO
LITERATURE REVIEW

Energy sources will play a significant role in how countries across the world develop in the future. Three groups of energy sources have been identified: fossil fuels, renewable and nuclear. Coal, oil, and gas are examples of fossil fuels. Coal, petroleum crude oil, and natural gas are the main sources of energy, fuels, and chemicals in the global energy markets. Fossil fuels are susceptible to depletion as they get used up since it takes millions of years for them to develop in the earth. Biomass is the only other known naturally occurring carbon resource with enough energy to be used as a replacement for fossil fuels (Karekezi *et al.*, 2004).

For centuries, people have utilized wood as a significant energy source for heating, lighting, cooking, and boiling water. The first fuel ever used by humans was biomass, which was also the foundation of the world's fuel economy up until the middle of the eighteenth century (Abbasi & Abbasi, 2009; Adkins *et al.*, 2010; Balat & Ayar, 2005). Approximately 2.8 billion people worldwide do not have access to clean cooking facilities today. 2.5 billion People, or one-third of the world's population, still cook their food in the traditional method using solid biomass (IEA, 2022b). Over 90% of the population in sub-Saharan Africa use wood-derived firewood and charcoal as their main source of household energy (IEA, 2022a). Ethiopia's energy supply is mostly dependent on biomass, which accounts for more than 91% of the country's energy consumption, like many other sub-Saharan African nations (UNEP, 2019).

There are different views on the utilization of biomass resources for basic human energy demands in the theoretical and empirical literature. The early proponents had a negative view on the use of biomass fuel. According to this group of researchers, using biomass resources for basic energy requirements deprives consumers of their health and other forms of well-being while also damaging the ecosystem. Optimistic people maintained that utilizing sustainable biomass with advance technologies will result in the generation of renewable energy(Guta, 2012b).

Energy comes from both traditional and modern sources. Modern energy supports sustainable development and is connected with public health, education, food security, poverty alleviation, and mitigating climate change (ESMAP, 2021; Mainali *et al.*, 2014). In this sense, energy is the lifeblood of modernization because it is essential to the advancement of human politics, economics, and social life as well as the preservation of the environment (Healy & Clinch, 2004).

The attention has shifted in recent years from fuelwood consumption in general to how biomass dependence affects indoor air quality and greenhouse gas emissions, particularly the release of carbon dioxide that has been stored and black carbon (Gebreegziabher *et al.*, 2018; Grieshop *et al.*, 2011; Jeuland *et al.*, 2015; Tamire *et al.*, 2021). An important side effect of the use of biomass fuels in the household is the large variance in levels of HAP exposure, especially for women and children. Below is a summary of current biomass energy utilization research.

2.1 Biomass energy source

All organic substances that are not fossil and have a chemical energy content are considered biomass (Balat & Ayar, 2005). They consist of all flora and trees that are found on land and in water, also known as virgin biomass, as well as all waste biomass, which includes sewage, solid waste, and municipal bio-solids (Balat & Ayar, 2005; Zheng *et al.*, 2010). Biomass is renewable, in contrast to fossil fuels, in the sense that it can be replaced as a source of energy in a very short amount of time. Wood, animal, and plant wastes all have the potential to become biomass. The only renewable alternative to organic petroleum is biomass. These resources could be used directly to meet basic energy needs (such as firewood, charcoal, dung cake, etc.) or they could be converted into priceless renewable energies (such as biogas, biofuel, bioelectricity, hydrogen energy, etc.) that can be used in the transportation, industrial, and household sectors (Balat & Ayar, 2005).

Biomass is one of the most valuable and useful resources on earth since it is the solar energy that is chemically stored in plant and animal materials. For all organic materials originating from plants, trees, crops, and algae, it is a fairly simple statement. A few of the components of biomass include water, starches, sugars, proteins, simple hydrocarbons, cellulose, hemicelluloses, lignin, lipids, extractives, ash, and other compounds. Cellulose and hemicelluloses (holocellulose), two bigger carbohydrate groups, are highly valuable. Non-sugar-type molecules make up the lignin portion (Demirbas, 2009).

Depending on how the fuelwood is harvested, conservation of fuelwood can result in less forest degradation and less carbon emissions. The percentage of utilized woody biomass "that can be established as non-renewable biomass" is thus a crucial factor (UNFCCC, 2012). The management system has a major impact on how unsustainable biomass harvests are. For example, relatively little management, such as replanting and harvest mitigation, is anticipated if fuelwood is taken under free access regimes. Nearly all of the biomass in these settings is expected to be nonrenewable. Since accurately estimating non-renewable biomass is challenging, a significant field of current study has offered default estimates of the percent non-renewable biomass for low-income countries, with default values above 90% in several sub-Saharan African nations (Bailis *et al.*, 2015; Lee *et al.*, 2013).

There are very few energy options for rural Ethiopian households with little financial means. In locations where fuelwood is limited, the great majority of households combine agricultural products like crop residues and animal dung with fuelwood as their primary energy source (Mondal *et al.*, 2018). Solid bio-based energy dependence is usually associated with shortages of modern energy options, poverty, and a variety of other problems. The "fuel stacking" theory is supported by the fact that modern fuels are often used conjunction with traditional biomass fuels but have not succeeded in displacing solid biomass energy in many developing nations (Guta, 2012b).

As noted by Wassie and Adaramola (2021) “In Ethiopia, household energy means rural energy and rural energy means biomass”. Biomass is still the main source of energy and cooking the largest consumer of energy in Ethiopia. The degradation of Ethiopia's remaining forests has been accelerated by this country's excessive reliance on woody biomass fuels and the ineffective energy production from a traditional or open-fire stove with low thermal efficiency (13–15%) (Guta, 2014; Wassie & Adaramola, 2021).

Ethiopia's forest resources have been significantly depleted as a result of this reliance on traditional biomass; the country uses 124 million m^3 of wood annually, of which 116 million

m^3 is used as fuel (fuelwood and charcoal) (MoEFCC, 2017). And the annual loss of forest cover is estimated to be 140,000 ha per year (Kilawe & Habimana, 2016). According to Bailis *et al.* (2015) Ethiopia is one of only four nations that simultaneously consumes the most nonrenewable biomass, has the largest household air pollution disease burden, and the highest fuelwood consumption per capita.

In Ethiopia the main uses of biomass energy are in domestic baking and cooking (Mondal *et al.*, 2018). The production and consumption of wood and charcoal are significantly greater in the household sector than they are in other sectors. The total amount of wood consumed each year is 55 million tons or around 0.79 tons of wood and charcoal per person (MWE, 2012). It will remain to be so particularly in the household sector for the anticipatable future. Prevailing methods of meeting cooking energy requirements in Ethiopia are primarily responsible for such large consumption of energy in the household sector.

2.2 Improved Cookstoves (ICS)

The increased push for improved cook stoves (ICS) nowadays is largely motivated by worries about how traditional stoves affect climate change on a global scale. Over the past three decades, many ways have been used to refer to stove models that have been upgraded for fuel efficiency or produced to limit household air pollution. ICS gives significant private and social benefits by lowering reliance on inefficient biomass- or solid-fuel burning stoves, giving them new life and a new constituency. Given that traditional stoves emit a lot of household air pollution, it was and is frequently assumed in the past and present that poor homes would certainly prefer to use ICS, as the majority of these stoves use fuelwood (Jeuland *et al.*, 2020).

The term "ICS" which has a vague definition, has been assigned numerous interpretations by various authors. A more efficient biomass cookstove offers fuel savings, ease of use, and cooking times that are shortened or maintained. Reducing the amount of fuel needed can lead to savings on household expenses or time that can be put to other uses, like leisure. (Jeuland & Pattanayak, 2012; Mobarak *et al.*, 2012).

ICS have significant advantages over traditional cooking methods because they frequently do not require expensive technology and may simply demand for small adjustments to standard cooking practices. If households can truly prepare meals with less wood and ICS are accepted and used frequently by households, these crucial aspects can make them very appealing. Additionally, it may result in reduced greenhouse gas (GHG) emissions, lessened forest degradation, and cleaner indoor air. Therefore, very straightforward ICS technologies that may satisfy actual user needs through ease and reduced biomass consumption and that only need for minimal changes to cooking practices in the home are potentially significant intermediate technologies, however, development towards widespread ICS adoption and usage has been disproportionately gradual (Mobarak *et al.*, 2012).

Throughout most of Ethiopia for more than three decades, *Mirt*, an Amharic word meaning best, has been utilized and disseminated. *Mirt* stove is particularly designed for *injera*, the main staple bread in the majority of Ethiopia. According to (Gebreegziabher *et al.*, 2012) *injera* baking accounts for around 60% of household fuelwood use and for about 50% of the primary energy used in the nation.

Injera stoves are usually considered to be inefficient, though their size and efficiency do vary slightly from place to place in Ethiopia. Despite requiring a lot of energy, it is still rarely researched for alternate energy sources (Tesfaya *et al.*, 2014). The typical *injera* has a diameter of 52 cm and weighs 310 grams (Adem & Ambie, 2017). The stove was developed based on a design from the German aid organization GTZ in Ethiopia, and was introduced for the first time in the Addis Ababa Market which has been pushing it since 1998.

Injera is baked on a clay platter called a *mitad* that is placed on top of a *Mirt* or traditional stove. From different tests, *Mirt* stove-specific fuel consumption compared to open-fire baking was found to be between 30 and 49% (Adem & Ambie, 2017; Dresen *et al.*, 2014; Megen_Power, 2008). All the fuels used on a three-stone fire (firewood, cow dung, branches, leaves, etc.) could also be used on this stove (Megen_Power, 2008).

Tikikil cooking stove is basically a rocket stove, but it was adopted to suit the conditions in most Ethiopian households and local production techniques. The rocket stove is an improved stove design developed by GTZ, Energy Coordination Office (ECO) (Wassie & Adaramola, 2021). The stove includes a pot "skirt" and an L-shaped combustion chamber to increase heat transfer and combustion efficiency during cooking. A horizontal fuel magazine and a vertical internal chimney make up the combustion chamber. Wood is put into the fuel magazine horizontally, ensuring equal burning from one end and a more controllable feed rate. The interior chimney produces a draught that speeds up the fire's gas combustion. The skirt that envelops the cook pot is then pressed to let these gases pass. (GTZ, 2010).

2.3 Cookstove performance testing procedures

The most popular testing techniques, such as the controlled cooking test, water boiling test, and randomized kitchen performance test, can be used to gauge how much fuel is consumed per unit of time. Each has pros and cons (Bailis *et al.*, 2007; Lee *et al.*, 2013).

The WBT examines the heat transfer and combustion efficiency of the stove by measuring how well it performs a regular task in a controlled environment on boiling and simmering of water. They are the simplest, quickest, and least expensive to carry out, but they only show how a stove performs technically when water is boiling, not necessarily when real cooking takes place in homes. They cannot give insight into how the stove performs when cooking actual items under genuine circumstances because they are conducted under controlled conditions by experienced technicians rather than local cooks (Shell_Foundation, 2007).

Some of the limitations of the WBT, according to the Eindhoven Wood Burning Stove Group, are that the recovery of the charcoal is operator dependent because it is not well defined. Since the weights of the charcoal are so small, there will always be significant measuring mistakes. At best, it is difficult to estimate the combustion value of charcoal created in a wood fire. Between the high-power phase and the low-power phase, a lot of tasks must be completed quickly, increasing the likelihood of errors or misreading’s. The WBT test also has different fuel consumption and is only ideal for introducing new, improved stoves; therefore it is not a reliable approach to determine actual fuel use in typical household kitchen situations. Additionally, the test entails a measurement of the heat transfer process, using the water as a real medium to measure the heat transfer from the fire to the pot, rather than a simulation of the food-cooking process with the meal replaced by water (Weinbaum, 2010).

The primary field test used to assess stove performance in actual environments is called the Kitchen Performance Test (KPT). It is utilized in homes where stoves are used and is made to evaluate the effects on household fuel consumption that actually occur. The greatest way to detect changes in the actual world is through KPTs, which are usually carried out during a dissemination operation with local populations cooking normally. Frequently, they take place over some few days (UC_Berkeley, 2004).

The KPT assesses the total amount of fuelwood used by a family repeatedly both traditional and ICS intervention. The advantage is that it can account for technological combinations that can indicate leaking. The drawback of KPTs is that, after acceptance, nothing is known about how they are actually used for cooking. Additionally, the usage of fuelwood must be practically entirely measured on-site; otherwise, measurement errors may be significant. Sample sizes often are limited since the required measurement is so intense (Lee *et al.*, 2013).

The CCT compares the performance of a stove to traditional cooking techniques while a cook makes a dish from the area. The CCT is intended to examine stove performance in a controlled setting using a common task selected to reflect local customs. It reveals what a household could accomplish in a perfect world but may not always reflect what a household actually accomplishes in real life. It should be carried out by someone who is knowledgeable with the dish being prepared, traditional cooking techniques, and the operation of the stove under test (Shell_Foundation, 2004).

The WBT calculates the time and amount of fuel required to boil a specific amount of water. It is the simplest test and ensures that cooking duties are precisely the same for traditional stoves, but it also has little to do with actual cooking and is normally carried out in laboratories. The CCT investigates the cooking of a regular meal prepared in the house by actual cooks, unlike the WBT, which additionally focuses on the amount of fuelwood consumed per unit of time. Data from CCTs show the amount of fuelwood needed per unit of food cooked and per unit of time. Despite being conducted on-site, the CCT only tracks the amount of wood used and saved for regular cooking. Therefore, CCTs are not very suitable when actual meals differ significantly from the "standardized" meal. In such cases, it's possible that the measured savings have no stronger connection to actual in-situ cooking than the WBT does (Weinbaum, 2010).

2.4 Ethiopian test protocol for cookstoves

Ethiopian standard of clean cookstove and clean cooking stoves requirement and test method ES-6085:2019 has been developed via revising of improved biomass cooking stoves performance requirements and Test Methods for household Biomass cooking stove (ES-6085:2017) and Biomass Baking stoves performance requirements and Test Methods for household Biomass Baking stoves (6086:2017) (ESA, 2017a; ESA, 2017b) in alignment with the international standard ISO-19867-1&3:2018 and in consideration of the country context. The cookstove system was tested using the Ethiopian standard ES 6085:2019 (ESA, 2019) guidelines for evaluating cookstove performance. The previous Shell Foundation for Household Energy Programs, WBT protocol specified that the stove be tested at high power (cold and hot start phases) and low power (simmer phase). According to Ethiopian standard for the cookstoves design for only one power level should be tested with fuel burning period of either approximately 30 min or approximately 60 min if the stoves tested are design for only one power so the cookstove system used only high power cold start. Therefore the tests were conducted for 60 min a fuel burning period plus the 5 min or 5 C^o for shout down period (ESA, 2019).

2.5 ICS performance, adoption and usability

ICSs in general have the thermal efficiency of 22% - 46% more effective than traditional stoves in terms of fuelwood use per household per year, according to research conducted in rural Uganda and Tanzania (Adkins *et al.*, 2010). The limited studies that were conducted to evaluate the impact of ICSs primarily relied on water boiling tests and controlled cooking tests. Due to multiple restricting circumstances, there is also a significant knowledge vacuum regarding the real impact of ICSs when used in the typical household rural scenario. This is due to the fact that, even while CCTs and WBTs imitate actual cooking operations, the effects of uncontrolled use of ICSs involving the concurrent use of many stove types and fuels may not be completely predicted by the approaches. Additionally, several variables outside of the controlled environment, such as access to and availability of energy, socioeconomic traits, location, and household cooking practices, can alter the effectiveness, usage, and impact of the use of the ICSs (Gebreegziabher *et al.*, 2018).

Bensch and Peters (2015) Contend that despite the potential advantages and significant international efforts to promote ICS, poor adoption rates are typically brought on by high initial investment costs. In a study that likewise highlights capital costs, Beltramo *et al.* (2015) use a randomized trial and Vickery second-price auctions to assess the impact of marketing and payments over time on willingness to pay for fuel-efficient cookstoves in rural Uganda. They found that marketing messages are ineffective, but that payments becoming available over time increase people's desire to pay within the constraints of their household's income.

In a randomized control study in urban Senegal, Bensch and Peters (2012) find fuel savings per meal cooked on the Jambar stove is 48%. They also learn that utilizing the burners almost exclusively has a variety of other benefits, like fewer eye infections and quicker cooking times. To better understand the effects of ICS in the field, more rigorous evaluation strategies, such as randomized distribution of improved cookstoves with control groups using conventional stoves, are quickly replacing less rigorous evaluation techniques (Bensch & Peters, 2012; Hanna *et al.*, 2012).

A wood burning cookstove in Ghana that was produced and designed locally is evaluated by (Burwen and Levine, 2012). They discover that the stoves, on average, require 12% less fuelwood to prepare a regular a meal. Using electronic stove usage monitors, they also learn that the stoves were generally used quite a little. An ex-post review of the Jambar charcoal stove was carried out in Senegal by Bensch and Peters (2011). They discover that the Jambar stove uses 25% less charcoal than conventional stoves to prepare normal meals by using OLS and propensity score matching. The same researchers discovered that fuel savings per meal cooked on the Jambar cooker compared to a control group were even higher at 48% in a randomised control study conducted in Senegal. They also find additional advantages, such as fewer eye infections and shorter cooking times, which come with the stoves being used almost exclusively. A tailored enhanced wood-burning stove and vent hood are evaluated by Thakuri (2009), in a sample of 400 Nepali households. He determines that improved cookstoves use 42% less wood than traditional stoves, despite the observational nature of the data and the fact that firewood use is based on 24-hour respondent stored information.

Poor ICS adoption is still a challenge, and it typically reflects the fact that stove designs and diffusion efforts have been unable to meet user requirements. Mobarak *et al.* (2012) and Bensch and Peters (2015) place emphasis on developing and marketing ICS with features that customers value highly, such as decreased running costs. According to Mobarak *et al.* (2012) one reason ICS are not commonly used in Bangladesh is because ICS are promoted as having health benefits, but many users—women in particular—do not consider the household air pollution caused by traditional stoves to be a severe health problem.

Experiments were carried out to determine the particular fuel consumption savings of *Mirt* compared to open fire baking, which ranged between 30 and 49% (Dresen *et al.*, 2014). The usage of the improved *Mirt* stove results in fuel savings of between 22% and 31% when compared to a typical open three-stone stove, according to a Controlled Cooking Test carried out in rural Ethiopia also found that on average one ICSs (*Mirt* stove) saves 634 kg of fuelwood per year, which translates to an estimated emissions reduction of 0.94 tons CO_2e per user household per year (Beyene *et al.*, 2015; Gebreegziabher *et al.*, 2018).

The study results by Wassie and Adaramola (2021) indicated that by separate analysis of the *Mirt*, *Gonziye*, and *Tikikil* stoves, on average, a *Mirt* stove user consumes 143 kg less fuelwood per month than a traditional open-fire user. When compared to users of traditional open fire, the average monthly fuelwood consumption of *Gonziye* and *Tikikil* users was lower by 161.6 kg and 173.5 kg, respectively. Based on these findings, they predicted that each home could save fuelwood of 2083.0 kg by *Tikikil*, 1939.1 kg by *Gonziye*, and 1716.5 kg by using one *Mirt* stove annually. In comparison to households that use traditional stoves, a home that has adopted a *Mirt* stove can cut its fuelwood consumption by 30%, *Gonziye* usage by 34% and *Tikikil* usage by 37% annually. Hence, ICS-using household consumes 3313.6 kg of fuelwood on average annually compared to 5435.6 kg for non-users. Similarly, although statistically negligible, ICSs users consume less agricultural (crop) residues on average 496.5 kg/year than non-users 541.2 kg/year.

Other improved *injera* baking stove in Awramba community in the Amhara Regional State uses Awramba *injera* baking stove since 1971. Along with making *injera*, this stove incorporates additional cooking functions. With respect to the open-fire *injera* baking stove, it uses 35% less fuel specifically (Adem & Ambie, 2017).

The data from the direct kitchen cooking studies and questionnaires were used to determine the fuel collection and cooking and baking time savings of each stove. The findings indicate that households using *Mirt*, *Gonziye*, and *Tikikil* might save, respectively, 1.12 hours, 1.26 hours, and 0.77 hours per week by reducing fuelwood collection. The investigation for time savings in cooking and baking also showed that *Mirt* stoves (estimated based on baking sessions and extrapolated to weekly basis) might offer an average time savings of 0.18 h/week; *Gonziye* stoves 0.74 h/week; and *Tikikil* stoves 1.03 h/week.

Hence, the thermal efficiency of the above mentioned stoves are better than traditional/ open fire cooking practice, energy leakages on the demand side needs to become an essential part of the overall energy picture. When it comes to the end-use thermal efficiency of biomass energy conversion technologies, where the majority of the population depends for their daily cooking, the picture is even worse in Ethiopia. Both government and non-governmental organizations in Ethiopia have taken initiatives in energy efficiency improvement measures as part of the solution for the national household cooking energy problem. However, these efforts have been limited by lack of sufficient resources such as finance, skilled personnel and time, to bring about a lasting impact at the national level.

Cookstove usability is one of the crucial player in determining the adoption, acceptance, and sustained use of cookstoves by households. Usability refers to the extent to which a cookstove is user-friendly, efficient, safe, and meets the needs and preferences of the users. It focuses on the ease of operation, performance, maintenance, and overall user satisfaction with the cookstove (D.Moses & A.MacCarty, 2018).

Existing definitions cover a wide range of ideas related to how users approach, think about, and evaluate the effectiveness of their interactions with products. Usability is defined by ISO 9241: Ergonomics of Human System Interaction as the effectiveness, efficiency, and satisfaction with which a system satisfies the needs of its users. Nielsen's well-known book, "Usability Engineering," expands the definition of usability to include memorability, learnability, and the consideration of user errors. Figure below presents a visual showing the parallels and discrepancies between various usability standards. The underlying concept behind all definitions of usability is that the demands of the intended users in a given environment must in some way influence the design of a product. Broader definitions of usability may also include elements like ease of access, learning curve, aesthetics, and safety (D.Moses & A.MacCarty, 2018).

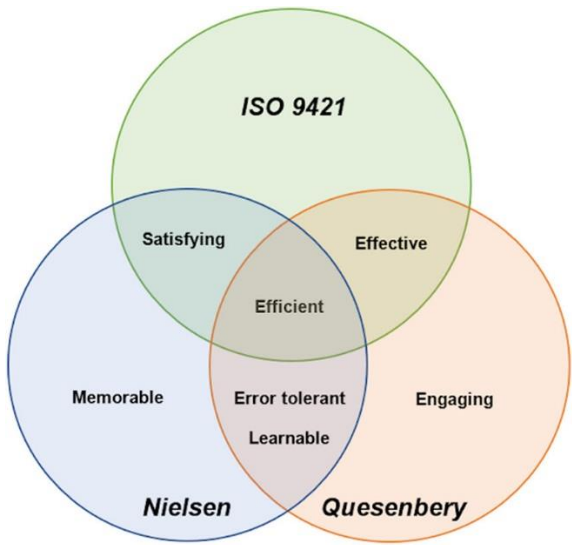


Figure 1: Common Definition of Usability (D.Moses & A.MacCarty, 2018)

2.6 Summary of research results from the stove test

2.6.1 Qualitative results

Table 1: Test results from ICS qualitative research output

	Title	Stove type	Qualitative Research output	Reference
1.	Field testing and survey evaluation of household biomass cook stoves in rural sub-Saharan Africa	• Ugastove • StoveTec • Advent	• The stove is too tall and unstable, making it easy to tumble over, the handles heat up, the stove surface gets hot, and it is difficult to move. • The stove's height and diameter prevent it from being used for a variety of cooking tasks and make it difficult to light and take extra time.	(Adkins *et al.*, 2010)
2	Fuel Savings, Cooking Time and User Satisfaction with Improved Biomass Cookstoves: Evidence from a Controlled Cooking Test in Ethiopia	• *Mirt*	• The stoves have a significant difference in fuelwood consumption. • The analyses reveal statistically significant regional disparities in fuelwood savings, particularly in Amhara and Oromia. • Cooks who are older, more educated, and have larger families use less fuelwood. • Fuelwood savings could increase with social network growth and incentives for utilizing better stoves. • Cooking while the wind is calm allows for greater fuelwood savings. • Cooks who work largely outside of the home and on non-agricultural tasks save more on fuel.100% of *Mirt* stove users rate the stove as good or very good in overall evaluation, especially in smoke reduction, and about 90% of respondents said they would buy it at full market price.	(Gebreegziabher *et al.*, 2018)

3	Analysis of potential fuel savings, economic and environmental effects of improved biomass cookstoves in rural Ethiopia	• *Mirt* • *Gonziye* • *Tikikil* • Non-users	• The location of the household is closely related to the use of ICS. • The amount of household gross annual cash income has a big impact on where ICS is used. • The cost of ICSs varies depending on how far you are from the manufacturers and sellers. • The distance between households' residences and their primary suppliers of wood (local forest regions) is highly and adversely related to the ICSs. • Almost all the households used the traditional three stones for baking, cooking, or both, regardless of whether ICS had been adopted. • For both ICS users and non-users, fuelwood and crop leftovers are the most popular sources of fuel.	(Wassie and Adaramola, 2021)
4	Field Testing of Alternative Cookstove Performance in a Rural Setting of Western India	• Envirofit • Greenway • BioLite • Philips • Eco-Chulha	• The TCS and the natural draft cookstoves both took the same amount of time to boil water. • The TCS took a lot longer to boil water than the forced-draft cookstoves made by Philips and Eco-Chulha.	(Muralidharan *et al.*, 2015)
6	Fuelwood Savings and Carbon Emission Reductions by the Use of Improved Cooking Stoves in an Afromontane Forest, Ethiopia	• *Mirt*	• 30% of ICS users occasionally bake *injera* on a three-stone fire. • When compared to other rural parts of Sub-Saharan Africa, the region has exceptionally high fuel usage.	(Dresen *et al.*, 2014)
7	Adoption and fuel use efficiency of *Mirt* stove in Dilla district, southern Ethiopia		• The main barriers to the Mirt stove's adoption in the evaluated sites were its fixed nature, a lack of availability, a lack of awareness of its advantages, and a distance from the market. • There was no noticeable difference in the amount of time it took the stoves to bake a certain quantity of *ii*between the traditional and Mirt	(Yayeh, Guadie and Gatew, 2021)
8	Fuel efficient technology adoption in Ethiopia: evidence from improved “M*irt*” stove technology: a case in selected kebeles from “adea” wereda		• 40% bake and cook in the open air and in their living rooms. • Approximately 37 to 44% of the families always utilize cow dung or wood as an alternative fuel source. • About 78% of rural households collect their own energy to suit their needs.	(Woubishet, 2009)

			• In urban areas, 42% of respondents must travel twice weekly to gather fuel sources, while 48% of households with two or more people must do so.	
9	Energy Efficient Biomass Cookstoves: Performance Evaluation, Quality Assurance and Certification	fuelwood cookstove	• 51% of 10 sample of firewood stoves tested satisfied the minimum standard of tier 2.	(Francis Okafor, 2019)
		Charcoal cookstove	• Out of 15 sample charcoal stoves tested, 62% satisfied the minimum standard of tier 2	
10	High Levels of Fine Particulate Matter ($PM_{2.5}$) Concentrations from Burning Solid Fuels in Rural Households of Butajira, Ethiopia		• The WHO 24-h suggested guideline level was up to 16 times greater than the 24-h mean $PM_{2.5}$ concentration. • When compared to locally made, improved cookstoves, the usage of traditional three-clay cooking stoves led to significantly greater quantities of emission of particulate matter	(Tamire *et al.*, 2021)

2.6.2 Quantitative results

Table 2: Test results for the quantitative research output of ICS

	Title	Stove type	Quantitative Research output					Reference
			Thermal Eff. (%)	**SFC (g/kg)**	**Time to boil (min)**	**CO (ppm)**	**$PM_{2.5}$ (µ g/m^3)**	
1.	Field testing and survey evaluation of household biomass cook stoves in rural sub-Saharan Africa	Ugastove	-	288	22	-	-	(Adkins *et al.*, 2010)
		StoveTec	-	326	18/206	-	-	
		Advent	-	-	47/224	-	-	
		Envirofit	-	-	215	-	-	
2	Fuel Savings, Cooking Time and User Satisfaction with Improved Biomass Cookstoves: Evidence from a Controlled Cooking Test in Ethiopia	*Mirt*	-	547	24	-	-	(Gebreegziabher *et al.*, 2018)
3	Analysis of potential fuel savings, economic and environmental effects of improved biomass cookstoves in rural Ethiopia	*Stove type*	Fuel wood saving (%)	Fuel wood saving (kg/yr)	Time saving from fuelwood collection (hrs/wk)	Total emission reduction (kg CO_2e/yr)	-	(Wassie and Adaramola, 2021)
		Mirt	30.3	1716.5	1.3	2825	-	
		Gonziye	34.3	1939.1	2.0	3191	-	
		Tikikil	36.8	2083.0	1.8	3428	-	
4	Field Testing of Alternative Cookstove Performance in a Rural Setting of Western India	Envirofit	11.7	-	-	16%	22%	(Muralidharan *et al.*, 2015)
		Greenway	11.9	-	-	42%	24%	
		BioLite	10.3	-	-	35%	40%	
		Philips	25.3	-	-	55%	66%	

		Eco-Chulha	16.9	-	-	42%	61%	
6	Fuelwood Savings and Carbon Emission Reductions by the Use of Improved Cooking Stoves in an Afromontane Forest, Ethiopia	*Mirt* *Three stone fire*	-	393.1 520	-	-	-	(Dresen *et al.*, 2014)
7	Adoption and fuel use efficiency of *Mirt* stove in Dilla district, southern Ethiopia	-	-	470	-	-		(Yayeh, Guadie and Gatew, 2021)
8	Energy Efficient Biomass Cookstoves: Performance Evaluation, Quality Assurance and Certification	fuelwood cookstove	26.4	-	-	0.61g/min	15.9mg/min	(Francis Okafor, 2019)
		Charcoal cookstove	38	33	42g/L	0.1-0.52	1.3-16.8	
9	High Levels of Fine Particulate Matter ($PM_{2.5}$) Concentrations from Burning Solid Fuels in Rural Households of Butajira, Ethiopia	-	-	-	-	-	410	(Tamire *et al.*, 2021)

CHAPTER THREE
METHDOLOGY

3.1 Methods

3.1.1 Field test standard

In this study, the technical characteristics of the intended cookstoves performance and usability were assessed in terms of their technical feasibility, acceptability and economic viability in the selected case study area, using clean cookstoves and clean cooking solutions-field testing methods for cookstoves (ISO 19869:2019), developed by the International Organization for Standardization (ISO).

The test standard offers field testing procedures to assess the performance of the cooking system in real-household conditions, and it aims to deal with: First, quantitative and qualitative evaluations of the cooking system's performance; the evaluation criteria and guidance are made for usage, usability, fuel and energy consumption, power, emissions, safety, and durability; Second, to provide guidance for measuring personal exposure to CO and $PM_{2.5}$ in the household; Third, to offer guidelines for field assessments that compare cooking system performance metrics to either defined performance levels or to a counterfactual scenario that allows assessment of whether the new cooking system is improved in comparison to what would have been observed if a new cooking system had not been implemented; fourth, to provide guidance for prioritizing measurements that balance comprehensiveness and feasibility (ISO, 2019).

3.1.2 Description of the study area

Gamo Zone, the Ethiopian ethnic group known as Gamo, is the one who speaks the "Gaammoththo" or Gamo language. It is one of the major zones in the Southern Nations, Nationalities, and Peoples' Region (SNNP) of Ethiopia. It is named for those whose homelands lie in this zone and for its identification of strength and respect. In the southwest of Ethiopia, the Gamo Highlands rise considerably above the African Rift Valley. Since agriculture was developed 10,000 years ago, this remote region has been successfully farmed and is one of rural Africa's most heavily populated regions. Despite colonialism and globalization, their culture and ecology have not changed. Despite the lack of roads in the area, it is remarkable for its ability to withstand the food shortages and famines that have wreaked disaster on most of the country's regions. This is because of a distinctive traditional food system that combines forestry and livestock raising with a wide variety of tree, root, cereal, and vegetable crops (Behran).

The administrative center of the Gamo zone is Arba Minch town. Arba Minch town is one of the districts located 505 km away from Addis Ababa, 275 km southwest of Hawassa town, and 200 km north of the Kenya border. The land's undulating terrain is a feature which favours the presence of many climate zones in the region. The region has a total land area of 7366.59 km^2 and is astronomically situated between 5^0 57" and 6^0 71" North latitude and 36^0 37" to 37^0 37" East longitude. The zone is bordered by South Omo in the southwest, Wolayta, Dawro, and Gofa zones in the north, Lake Abaya in the northeast, Amaro special woreda, and Dirashe special woreda in the southeast. It has one administrative town and 18 woredas (Mengistu, 2013).

According to CSA (2013) population projection values for 2017 at zonal and wereda levels by urban and rural residence and by sex, the total population of the former Gamo Gofa zone was projected at 2,043,668, among which 49.6% (1,013,533) were males and 50.4% (1,030, 135) were females. About, 1,709,028 (83.6%) were rural dwellers.

The study was conducted in *Arba-Minchi Zuria* and *Gacho baba* Woredas or District. Arba Minch Zuria is divided into 29 kebeles, which are the smallest administrative units in Ethiopia. It has a total population of 195,858, of which 97,905 are men and 97,953 are women (CSA, 2013). From the two districts the researcher choose *Chano Mile*, *Chano Dorga* and *Zigiti Meyche* kebeles peri-urban and rural districts in the zone. The three geographical and climatic zones in the selected districts are: Kolla (low land), Woina dega (mid land), and Dega (high land), which allow for the representation of people from different agro-ecological zones as well as three geographical and climatic zones.

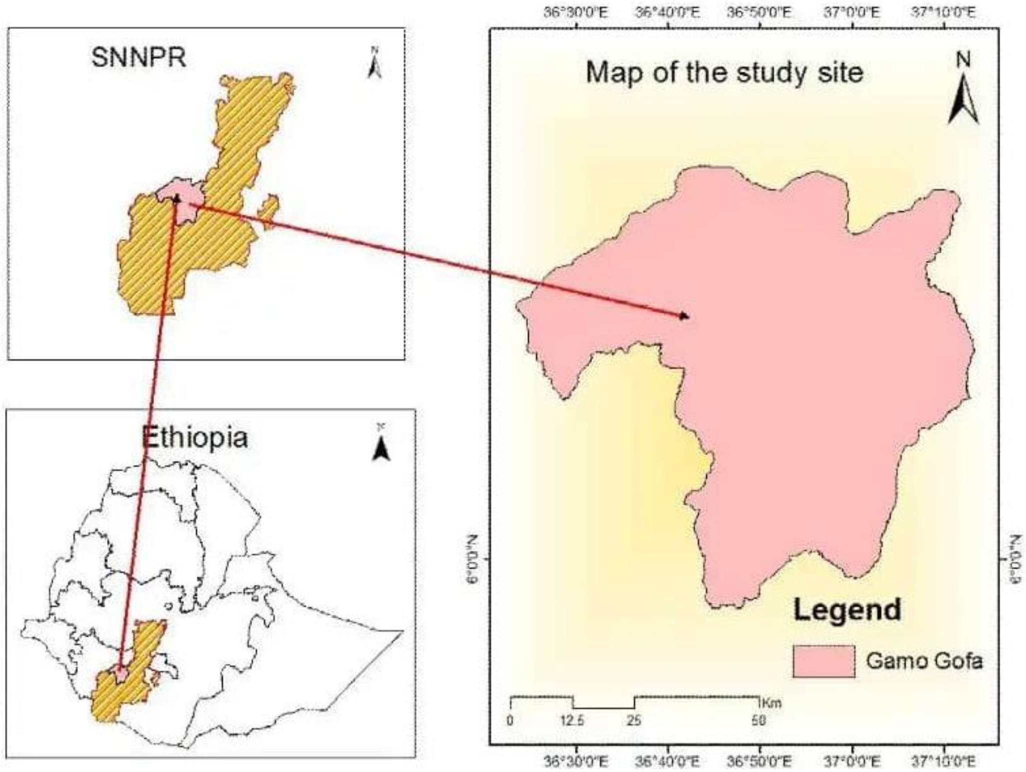


Figure 2: Administrative map of Gamo Zone

3.1.3 Description of the stove used

3.1.3.1 *Choche* cooking stove

Choche is a traditional cooking practice in Gamo Zone. The word *choche* in the Gamo language means "stove", and both cooking methods (dry heat cooking and moist heat cooking) are practiced on a daily basis in nearly every local home. The researcher noticed that it's quite different from the three-stone fire and other traditional cooking pracitce; it's commonly used across the community since they don't have access to improved or advanced cooking technology.

The cooking method or practice comprises, as shown in figure 3, digging the ground to a depth of 17 cm in the center and an upper width of 28 cm, then using locally made circular breaks inside the hole to protect the soil from dawn fall after some time of serving. This circular break covers the hole and serves as a combustion chamber for the fuelwood, keeping the flame for the subsequent cooking sessions by smothering it in the ashes. Additionally, the *Choche* was thought to act as insulation and a windbreak for the fire. For the pot rest, 16 cm in height, 21 cm in diameter at the top with the ear, and 18 cm in diameter at the bottom, locally produced breaks are used, and three pot rests are made around the hole. So, as seen in the figure below, the cook stacks the fuelwood inside the pit and begins to cook the meal.

Figure 3: *Choche* cooking and baking stove (picture: By Dawit T.)

The staple foods of Gamo populations are maize, Moringa oleifera (known locally as "Aleko"), and cabbage, which are often used as the major ingredients in "Kita," "Posese," and "Amicho," as shown in figure 4, which are typically found in local meals served with hot drinks made from a leaf of the coffee tree.

Figure 4: A) Aleko, Kita and Injera together B) boiling of leaves of the coffee tree (picture: By Dawit T.)

3.1.3.2 *Mirt Injera* backing stove

Mirt is made of mortar, a combination of cement and river sand, pumice, or scoria (red ash). The stovetop is made up of six connected pieces. The firewood is burned beneath a baking sheet in a cylindrical enclosure that is constructed from four sections and measures around 65 cm in diameter and 20 cm high. The cylindrical enclosure is attached to two more pieces by joining them together so that they sit on top of one another. These final two components give the cooking pot a rest and control the smoke flow on the burner. In addition to an *injera* baking plate (*mitad*[1]), the stove provides space for a cooking pot as well (Adem & Ambie, 2017).

There are two holes in the cylindrical casing. The enclosure's lower front has a first opening that is roughly 17-18 cm wide and 11 cm high and has a semi-elliptical shape. It serves as an air and fuel inlet. The second is at the enclosure's back, where a smoke exit and smoke-regulating components are installed. This opening is rectangular in shape and measures 19 cm in width and 7 cm in height. The stove is available in two variations: the conventional one, with walls that are 6 cm thick (here is what I used for the test) see figure 5 below, and the slim model with walls that are 4 cm thick (EREDPC, 2021).

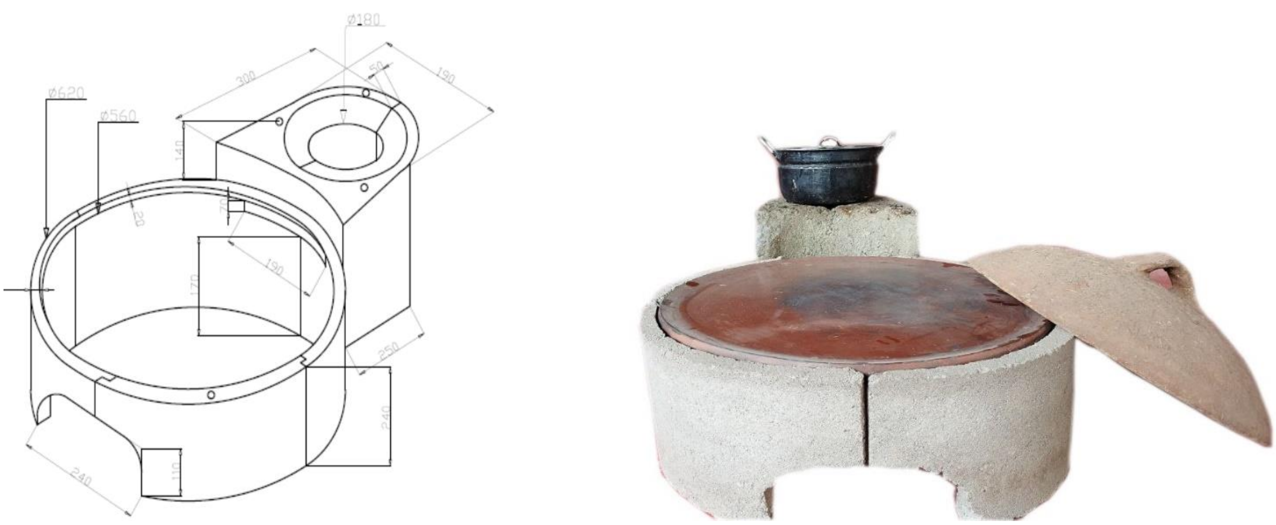


Figure 5: *Mirt Injera* baking stove (stove drawing:(EREDPC, 2021); picture: By Dawit T.)

[1] Mitad is a circular ceramic plate on which *Injera* is baked on

3.1.3.3 *Tikikil* cooking stove

The *Tikikil* stove has been widely promoted and implemented, as part of improved cookstove dissemination initiatives in Ethiopia, also known as the Ethiopian rocket stove, is a type of improved cookstove that is commonly used in Ethiopia. It is designed to be more efficient and cleaner than traditional or open-fire cooking methods, aiming to reduce fuel consumption and minimize harmful emissions (GTZ, 2010). The *Tikikil* stove is typically constructed using locally available materials such as clay and sheet metal. It consists of a combustion chamber, a cooking surface, and a chimney. The design incorporates a rocket-style combustion system, which enhances airflow and promotes efficient combustion. One of the primary advantages of the stove is its fuel efficiency. It is designed to optimize the burning of biomass fuels, such as wood or agricultural residues, by creating a controlled airflow that maximizes heat transfer to the cooking vessel. This results in reduced fuel consumption compared to traditional open fires (Wassie & Adaramola, 2021). The stove was also designed to minimize smoke emissions during cooking. The improved combustion process helps to burn the fuel more completely, resulting in reduced smoke production. This has significant health benefits, particularly by reducing exposure to indoor air pollution, which is a major concern associated with traditional cooking methods. The stove picture and design are seen in figures 6 below (GTZ, 2010).

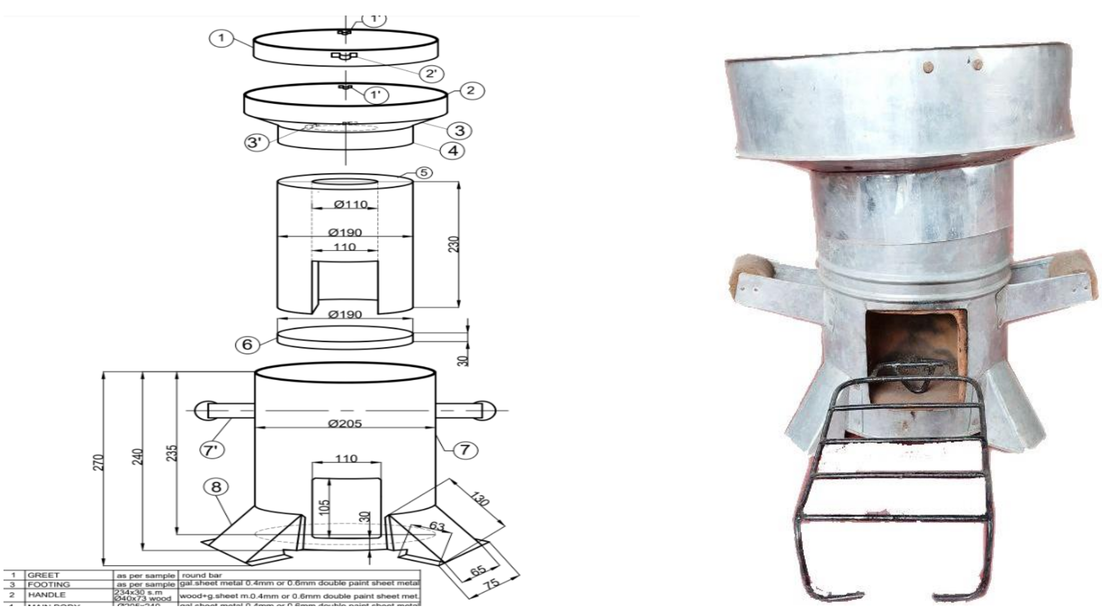


Figure 6: *Tikikil* fuelwood cooking stove (stove drawing: from EREDPC; picture: By Dawit T.)

3.1.4 Study design

According to the ISO (2019) test procedure, taking into account socioeconomic and agro-climatic characteristics, cooking systems was tested by comparing *Choche* and ICSs in Gamo Zone.

The sample size of the household for a field study is basically decided by the study design the researcher is selecting, which is a cross-sectional and paired study design. Hence, for this study, the researcher chose paried design because of the methods that enable the comparison of the *Tikikil* and *Mirt* in the actual kitchen at the households to C*hoche* cooking in order to reduce the inter-household variability in household air pollution, time to cook a meal, and fuel consumption levels related to different household practices, household size, and ventilation caused by house structure.

Both *Tikikil* and *Mirt* sample stoves were placed to the test in relation to *Choche* stoves in users' kitchens. The sampling takes place twice: the first three days with the *Choche* stove, and an additional three consecutive days with the new ICS stove.

How to determine the sample sizes for a field study is explained by Garland *et al.* (2016). With a two-tailed statistical test and a p-value of 0.05, the table in Appendix A that follows suggests that the power should be set at 80%. The study design, anticipated or planned difference in the means, and anticipated variability are the only factors remain to be considered in light of the assumption conventions.

The difference in means between the traditional and improved cookstove methods, as shown in the Appendix A, is the change in average performance between them that either expect or desire to see. As a result, the researcher estimate to base this study's comparison of the fuel consumption of the two cookstoves on an average performance of 35%. A relative measure of variability referred to as the coefficient of variation (CoV) is determined as the standard deviation to mean ratio for a given sample (CoV = SD/mean). In order to determine the minimal sample size for this study, an accurate calculation of the coefficient of variation in fuelwood and HAP reduction based on the ISO test method was not yet available. Due to the paired study design, the researcher selected a conservative COV estimate of 0.7 (Edwards *et al.*, 2007), which produced a minimum sample size of 31 households that would need to enroll for the test. However, in every household study that makes use of repeated measurements, there is a chance of participant fatigue or drop-out. When volunteers begin a study but are unable or unwilling to participate in follow-up visits, fatigue and dropout occur. In order to lessen the effects of participant dropout, it is calculated that a research should be oversized by 20%, making the total household thirty eight.

The study households were selected from *Chano Mile*, *Chano Dorga* and *Zigiti Meyche* Kebeles[2] of rural and peri-urban communities in *Arba-Minchi Zuria* and *Gacho Baba* Woredas using the convenience and proportional sample strategy, which involves using participants from the target community who voluntarily agree to participate and are qualified to do so. This approach is founded on convenience and accessibility. Women (cooks) who agreed to participate in the study were enrolled. A quick selection criteria survey is shown in Table 4 for use in the field to filter out candidates for a cooking test, and each sample household was systematically selected from each Kebele.

Table 3: household screening form for cookstove test

Omit the participant from the research if the response to any of the questions below [1-4] is 'No'	Yes	No
1. Is the main cook willing to participate? (Explain the necessary steps.)		
2. Does the participant regularly use the basic wood stove? (Note that it need not be for sole usage.)		
3. Does the participant prepare food in a secure area shielded from the wind, rain, and harsh sunlight?		
4. Will there be enough fuel available to cook during the performance tests?		
A participant should not be included in the baseline survey if any of the questions below [5–6] have a 'Yes' response.	Yes	No
5. Does the participant make food or beverages for sale in a shop?		
6. Are there any activities that would significantly alter the amount of cooking that will be done before, during, or right after the sampling*? Inquire about occasions like festivals, weddings, funerals, significant influxes of migrant workers and tourists, etc.		

*Or in the 1-2 days immediately after the study period if they are starting to prepare food early.

[2] The lowest administrative level in Ethiopia

3.1.5 Field study development

Household visits to the enrolled families were conducted in order to evaluate fuel wood consumption, the simplicity in the usage of ICSs, kitchen-level exposures to particulate matter ($PM_{2.5}$) over a 24-hour period, and cooking time for a single meal.

The houses were chosen at random, and the enumerators evenly distributed the households across the chosen kebeles. The main cook in the home was consulted, and if the cook did not have any additional plans or commitments that would require them to be away from the house for the ensuing six days, the enumerators gave them the *Tikikil* and *Mirt* stoves to test.

The main cooks in the household were asked to answer questions on their socioeconomic background, present use of traditional stoves, household smoke, and cooking habits before the *Tikikil* and *Mirt* were given and installed. Then the enumerators were given an initial orientation on the features of the stove and trained the women on how to use these two stoves. The women's traditional stove would still be in the house, but they should be encouraged to exclusively cook with the *Tikikil* and *Mirt* on a daily basis. Figure 7 below depict the enumerators during their initial training for the cook, getting basic information about households, and their opinions of the stoves.

Figure 7: Household preliminary survey and introduction of *Tikikil* and *Mirt* on how to operate in the kitchen

Data on daily fuel wood consumption and $PM_{2.5}$ emissions from Choche stoves were gathered for the first three days. Following three consecutive days, it was done on the *Tikikil* and *Mirt* daily fuelwood consumption, $PM_{2.5}$, and then after one-on-one interviews to find out more about how cook use the new stoves, how simple it is to use local cooking pots, how much smoke they recognise, how clean, safe, and crispy it is, how acceptable different cooking techniques are, how comfortable it is to make local dishes, and how they view fuel consumption generally.

According to. ISO (2019), making effective use of resources and ensuring that research topics are addressed both depend on an effective study design. The following tables display the approaches for evaluating various cooking system field performance components: The questions indicated in table 1 that are usually addressed in relation to the study goal serve as the basis for the field evaluation of cooking stoves, and the names of the pertinent metrics and their corresponding units are shown in the second and third columns.

Table 4: Field research question and respective metrics for measurement

Field research question	Relevant metric name	Unit
How is the cookstove performing in terms of energy and fuel consumption?	Percent difference specific energy consumption	% diff (MJ/kg)
	Percentage difference of household energy consumption	% diff (MJ/person/day)
What are the potential hazards to health?	$PM_{2.5}$ concentration 24 h average	$\mu g/m^3$
Is the cookstove likely to be used?	Usability assessment	Qualitative
How does the cookstove design relate to usage?		
How is the cookstove changing time use patterns?		
How much is the cookstove being used?	Average cooking events per day on a specific cooking device	events/day
	Average cooking events per day on all cookstoves in a household	events/day
	Average cooking duration per day on a specific cooking device	h/day
	Average cooking duration per day on all cookstoves in a household	h/day
	Displacement: fraction of cooking events on a specific cooking device	events/events
	Displacement: fraction of cooking duration on a specific cooking device	h/h

3.2 Materials

The following test instuments, materials, and facilities were used for this field test based on the instruments recommended by (ISO, 2019) and the stoves used for this study:

Figure 8: A) Particle and Temperature Sensor (PATS+) B) Electronic weighing balance; capacity of at least 6 kg and accuracy of ± 1g C) GPS Tracker D) Thermocouple E) Mobile phone (stop watch) F) IR thermometer G) Measuring tape H) Wood moisture meter; capable of measuring 6-40% humidity (optional) I) Choche stove J) *Tikikil* stove K) *Mirt* stove (Pictures By: Dawit.T)

3.3 Data collection

3.3.1 Fuel moisture measurement

A portable moisture meter was used to measure the specific fuel being measured using wood fuels. Three pieces of wood were chosen from the pile, and the moisture content was determined along each piece's length at three locations that were evenly spaced apart. The average of all single-point measurements for each home for a consecutive two to three days on *Choche* and ICSs was then determined by applying the equation below in Equation 3.1 (ISO, 2019).

$$w_{c,av} = \frac{\sum_{i=1}^{n} w_{c,i,1} + w_{c,i,2} + w_{c,i,3}}{n*3} \quad (3.1)$$

Where;

- $W_{c,av}$ is the average moisture content of the fuel, in %;
- $W_{c,i,1}$ is the moisture content at point 1 for the *i*th piece of wood, in %;
- $W_{c,i,2}$ is the moisture content at point 2 for the *i*th piece of wood, in %;
- $W_{c,i,3}$ is the moisture content at point 3 for the *i*th piece of wood, in %;
- n is the total number of pieces of wood measured (at least three).

If the moisture meter outputs moisture content on a dry basis, then the average shall be converted to a wet basis according to equation 3.2 (ISO, 2019).

$$w_{c,wb} = \frac{w_{c,db}}{1+w_{c,db}} \quad (3.2)$$

Where;

- $W_{c,wb}$ is the moisture content, wet basis, in %;
- $W_{c,db}$ is the moisture content, dry basis, in %.

3.3.2 Specific energy consumption

Specific energy consumption is the amount of energy used to cook a given mass of food, as determined by a single cooking event. The cooking task, type of fuel, cooking vessel, amount of food being cooked, and how the cook uses the stove all affect the precise amount of energy consumed (ISO, 2019)

The researcher selected baking *injera* for this particular type of test, compared, and computed the fuel consumption of both *Choche* and *Mirt* stoves. A typical cooking task is completed using one of the two cooking techniques. Each cook completed three repeats of the cooking activity, which was distributed among the seven cooks. The measurements taken were as follows: Consumed fuel mass, energy content (lower heating value), moisture content, and initial mass of raw food in each cooking vessel, initial mass of cooked food in each cooking vessel, and final mass of each cooking vessel with raw food. Equation 3.3 presents calculations for specific energy consumption as fired (ISO, 2019).

$$SC_{energy} = \frac{E_{fuel}}{M_{food}} \quad (3.3)$$

Where:

- SC_{energy} is the specific energy consumption, in MJ/ kg;
- E_{fuel} is the total energy consumed for all fuel types, in MJ;
- M_{food} is the total mass of food cooked, in kg.

As the equation 3.4 showed, the Energy consumed is defined as the total fuel energy in (raw and reused fuel) less the reused fuel remaining (ISO, 2019).

$$E_{Fuel} = \sum^{type}[(M_{type,i} - M_{type,f}) * LHV_{type,af} \quad (3.4)$$

Where;

- E_{fuel} is the total energy consumed, in MJ;
- $M_{type,i}$ is the initial mass of each fuel type;
- $M_{type,f}$ is the final mass of each fuel type;
- $LHV_{type,af}$ is the lower heating value of each fuel type, as fired, in MJ/kg.

Data has been gathered for twenty-one test replicates for each cooking methods that were conducted for specified fuel consumption metrics, which means that a total of seven cooks performed three repetitions each.

The mean, standard deviation, and coefficient of variation of the specific energy consumed SC_{energy} shall be calculated for the *Choche* and *Mirt* cookstoves test replicates. To calculate the percent difference of the two sample means, the equation 3.5 shall be used (ISO, 2019):

$$\%\text{diff} = \frac{mean(SC_{energy,2}) - mean(SC_{energy,1})}{mean(SC_{energy,1})} \tag{3.5}$$

Where;

- $SC_{energy,1}$ is the specific energy consumption of *Choche* baking;
- $SC_{energy,2}$ is the specific energy consumption of *Mirt* baking.

This calculation provides the percent difference in fuel consumption of *Choche* compared to cooking *Mirt injera* baking. A negative value indicates *Mirt* had a reduction in fuel consumption compared to *Choche*.

A flat, bread-like pancake made from the small grain *teff* is known as *injera* and is a common dish in Ethiopia. It takes three to four days to prepare *injera*. Yeast is added to *Teff* flour, water, and other ingredients to create batter or dough. After that, the batter or dough is placed in a tightly closed container and let to ferment for three to four days.

The mixture is stirred occasionally while fermenting, and any extra water that rises to the surface is skimmed off and discarded. In order to prepare *"Absit,"* a soup-like concoction, one to two liters of thoroughly mixed batter are taken and poured to boiling water. The *Absit* will be thoroughly stirred while it boils to thicken it. It is put into the batter that was previously kept in the container after boiling for 30 to 40 minutes, and additional water is added to make the batter lean.

Getting ready for baking, where it creates bubbles at the top, takes around 30 to 45 minutes. The dough will be poured into the baking pan when the *injera* pan's temperature reaches around 200°C. In order to swiftly fill any gaps that might be left behind, the batter is poured in a circular motion all the way around the griddle's surface. After the batter has been added, the cover is secured, enabling the *injera* to steam slightly while cooking. When the *injera* is finished cooking, it is taken out of the mitad using *sefed*, a grass-woven material resembling a plate (Adem & Ambie, 2017).

The selected seven households had undergone three tests. 16 kg of dough were utilized for each baking session, which is typical in Ethiopian households. *Injera* quantities often fall within the specified range 25 and 30 i*njeras* were baked during each session (Adem & Ambie, 2017). That is the average number of injeras that would be baked in a normal Ethiopian household during a session. However, the precise figure depends on how thick the *injera* is and how viscous the dough is. The person who makes the dough and does the baking, respectively, is responsible for these in turn.

The cooks have been well-oriented and agreed on the procedures of the test in such a way that both testers and cooks can understand and follow each other. The role of the testers during the baking session was only to record the data and make observations without any interference from the cookers. Before and after every test, fuel wood was weighed and recorded. Charcoal is knocked off the ends of the unburned wood while the wood is being weighed. The data sheet contains the weight and measurements of all the charcoal that was collected using the charcoal pan. It was also noted how long it took to complete the process of cooking. Additionally, the cook's comments and relevant observations for the test have been recorded.

3.3.3 Kitchen energy consumption

The amount of energy used for cooking in a household per person per day is known as per capita kitchen energy consumption. It measures the following factors: all of the household's cooking fuels, all of its cooking appliances, and all of its regular cooking tasks (ISO, 2019).

The Kitchen Performance Test (KPT) measures the rate of daily fuel consumption per person in the average household environment over the course of three days in order to show variations in the fuel consumption of *Choche* and ICSs (*Tikikil* and *Mirt*) stoves in households. The primary objective of the KPT is to quantify fuel consumption under typical household and stove usage conditions (Bailis, 2004).

The amount of fuel used on a daily basis for cooking determines the amount of energy used. Figure 9 below illustrates the measurement of the weight of wood used over the previous 24 hours and the moisture content of the three sample woods for calculating the daily fuel wood consumption of the household.

Figure 9: Moisture and daily fuel wood measurements

3.3.3.1 Effective fuel heating value

The energy content of the fuel utilized during a cooking event is the effective fuel heating value. The carbon balancing approach calls for the use of this metric to calculate fuel energy-based emission factors. The effective heating value *EHV* (MJ/kg_{fuel}) is an expression of fuel heat energy per unit mass that relates the fuel mass consumed to the fuel energy contained in it. For the simple case of a single fuel type that burns homogeneously, the effective heating value is equal to the lower heating value, as-fired LHV_{af} (ISO, 2019):

$$EHV = LHV_{af} \quad (3.6)$$

Where:

- *EHV* is the effective heating value, in MJ/kg;
- LHV_{af} is the lower heating value as-fired, in MJ/kg.

The above formula is valid for liquid and gas fuels as well as biomass fuels that burn to completion with no net change in reused fuel. For more complex cases of multiple fuel types and/or a net change in reused fuel, the effective fuel heating value can be calculated as (ISO, 2019):

$$EHV = \frac{\sum type[(M_{type,i} - M_{type,f}) * LHV_{type,af}}{\sum type(M_{type,i} - M_{type,f})} \quad (3.7)$$

Where;

- EHV is the effective heating value, in MJ/kg;
- $M_{type,i}$ is the initial mass of each fuel type, in kg;
- $M_{type,f}$ is the final mass of each fuel type, in kg;
- $LHV_{type,af}$ is the lower heating value of each fuel type, as fired, in MJ/kg

3.3.3.2 Effective fuel carbon fraction

The amount of carbon in the fuel that was used, measured in terms of mass, is known as the effective fuel carbon fraction. This metric is necessary to calculate the carbon balance's energy-based emission factors.

The effective fuel carbon fraction $CFrac_{eff}$ is a conversion factor between carbon released and fuel mass consumed. For the simple case of a single fuel type that burns homogeneously, the effective fuel carbon fraction is equal to the fuel carbon fraction (ISO, 2019):

$$CFrac_{eff} = CFrac_{fuel.af} \tag{3.8}$$

Where;

- $CFrac_{eff}$ is the effective fuel carbon fraction, in g/g;
- $CFrac_{fuel,af}$ is the as fired fuel carbon fraction, in g/g.

The above formula is valid for liquid and gas fuels as well as biomass fuels that burn to completion with no net change in reused fuel and no residual fuel. For more complex cases of multiple fuel types and/or a net change in reused fuel or residual fuel, the effective fuel carbon fraction can be calculated as (ISO, 2019):

$$CFrac_{eff} = \frac{\sum type[CFrac_{fuel.af.type} * (M_{type,i} - M_{type,f})]}{M_{fuel}} \tag{3.9}$$

Where;

- $CFrac_{eff}$ is the effective fuel carbon fraction, in g/g;
- $CFrac_{fuel,af,type}$ is the as fired fuel carbon fraction for each fuel type, in g/g;
- $M_{type,i}$ is the initial mass of each fuel type, in kg;

- $M_{type,f}$ is the final mass of each fuel type, in kg;
- M_{fuel} is the total mass of fuel consumed, in kg

This study utilized fuelwood consumption to CO_2 emission conversion equation developed by Intergovernmental Panel on Climate Change (IPCC, 2006): The IPCC provides comprehensive guidelines and emission factors for estimating greenhouse gas emissions, including CO_2 emissions from biomass combustion. First the average daily fuel wood consumption is need to be converted to average annual fuelwood consumption per household. To convert daily fuelwood consumption per household to annual fuelwood consumption, multiply the daily consumption by the number of days in a year (IPCC, 2006). Here is the equation 3.10 below.

$$\text{Annual Fuelwood Consumption} = \text{Daily Fuelwood Consumption x Number of Days in a Year} \quad (3.10)$$

Where:

- Daily Fuelwood Consumption: the measure or observed the amount of fuelwood consumed by a household in a single day. This can be done by weighing the amount of fuelwood used over a typical day or by using any available records or data.
- Number of Days in a Year: Typically, a year consists of 365 days. However, if you want to account for leap years, you can use the value of 366 days.
- Annual Fuelwood Consumption: Multiply the daily fuelwood consumption by the number of days in a year using the above formula.

The conversion of fuelwood consumption to CO_2 emissions depends on several factors, including the type and moisture content of the fuelwood and the efficiency of the cooking device. The general formula for estimating CO_2 emissions from fuelwood consumption is show in equation 3.11 (IPCC, 2006).

$$CO_2 \text{ Emissions (Kg)} = \text{Fuelwood Consumption (kg) x Carbon Content (\%) x Emission Factor} \quad (3.11)$$

Where:

- Fuelwood Consumption (kg): This refers to the amount of fuelwood consumed in kilograms per day.
- Carbon Content (%): The carbon content represents the portion of the fuelwood's weight that is composed of carbon. The carbon content varies depending on the type of wood but is typically around 50%.
- Emission Factor: The emission factor represents the amount of CO_2 emitted per unit of carbon burned. The emission factor also varies depending on factors such as fuelwood type and combustion efficiency. The emission factor for well-dried hardwood can be estimated to be around 3.67 (kg CO_2 emitted per kg of carbon burned).

3.3.4 Household Air pollution measurement

Field emission measurements can be performed using the total capture method by adopting the laboratory-based total capture measurement described in ISO 19867-1. Since whole capture measurements can be performed in the field, but there are other factors to take into account and practical challenges involved, so the partial capture survey with carbon balancing calculations was also done to get the GHG emission reduction potential of *Tikikil* and *Mirt* from field measurements (ISO, 2019).

Emissions samples were taken during cooking tests in the participants' houses, where cooks were told to make a meal as usual without changing the way their stoves operated or their cooking methods. Pollutants from cooking appliances can have an impact on both health and the environment. With respect to cooking technology, fuel type, and fuel condition, there can be significant variations in the pollutant composition and emission rate. In order to compare different types of cooking systems, track performance changes over time, and contribute to studies that are pertinent to human health and the environment, emission measurements are used (Smith *et al.*, 2007).

In this study, Berkeley Air Monitoring Group's Platform for Integrated Cook Stove Assessment (PICA) software and the Particle and Temperature Sensor (PATS+) device were used to measure the concentration of $PM_{2.5}$. PATS+ is a battery-powered, portable device that records data and measures particulate matter ($PM_{2.5}$) concentrations in real time. With a lower and higher particulate matter detection limit of 10–20 g/m^3 and 30,000–50,000 g/m^3, respectively, PATS+ light-scattering particle sensors has a photometer that measures a very wide range of particle concentrations and responds to an average concentration of particles (Berkeley, 2016) (Look at Appendix C2).

In accordance with the manufacturer's instructions, initial and end zeroing were performed before and after each sample measurement using an airtight zeroing box with a high-efficiency particulate absorbing (HEPA) filter, and $PM_{2.5}$ concentrations were measured over the course of a 24-hour period using one-minute logging intervals. Given that they react continuously and reliably to increased particulate matter concentrations, PATS+ photoelectric signals are practical and affordable for use in rural areas of low-income countries (Tamire *et al.*, 2021).

Maximum, mean and median $PM_{2.5}$ levels were measured in the 20 households using PATS+. The PATS+ devices were in place in households' cooking/baking areas for 24 hours. Because most of households typically cook their meal three time per day, all households should have cook at least three time during the 24-hour monitoring period.

Continuous emission measurements would be made during the whole cooking process, including the background conditions before lighting, lighting during cooking, burnout, and background conditions after burning out under controlled cooking method of specifying the cookstove in the household. Alternately, a typical burn cycle should be picked in the event that the cookstove is continuously used, such as when heating cookstoves.

To ensure the accuracy of the measurements, PATS+ were placed out on the wall inside the kitchen in accordance with the location recommendations made by Berkeley Air Monitoring Group. Hence, particle monitoring equipment's was installed in the kitchen at a height of 1.5m, which is approximately equivalent to a standing woman's breathing zone, with free airflow, away from doors and windows to prevent measuring ambient air entering the space, at least one meter away from the edge of an active cooking stove to prevent undue influence from a point source, and in a safe and dry location. The data collector and field guides explained the processes to the mother and the male family leaders. They maintained an eye on the devices to prevent data loss caused by instrument failures in the field (Berkeley, 2005).

The data collector needed the mother's 24-hour schedule because she usually prepares meals for the family before starting the device installation process. Families were given a different appointment if they planned to travel, attend any events, or participate in any community holiday celebrations. This is due to the likelihood that the cooking procedures don't occur or that their neighborhoods uses unusual cooking techniques, which raises the particulate matter concentration inside their home that is derived from the ambient environment. And also Fridays were specifically excluded because they are practically the only day that rural women in attendance at the city market. All of the households provided 24-hour measures, despite the fact that the measurements began at various times for practical reasons. Peak $PM_{2.5}$ concentrations were compared to meal preparation times during the data collection period (the mother was asked to record cooking activities that had occurred within the previous 24 hours) (Pillarisetti *et al.*, 2017).

Before and after being deployed in each households, the instruments (n = 4) were zeroed in a zeroing box for 30 minutes. In this study, we did not compare our results to gravimetric readings. Bluffstone *et al.* (2019) Performed calibration using gravimetric filters co-located for 25 hours in 50 households of rural Ethiopia and discovered an adjustment factor of 0.8065, which we used for all PATS+ readings.

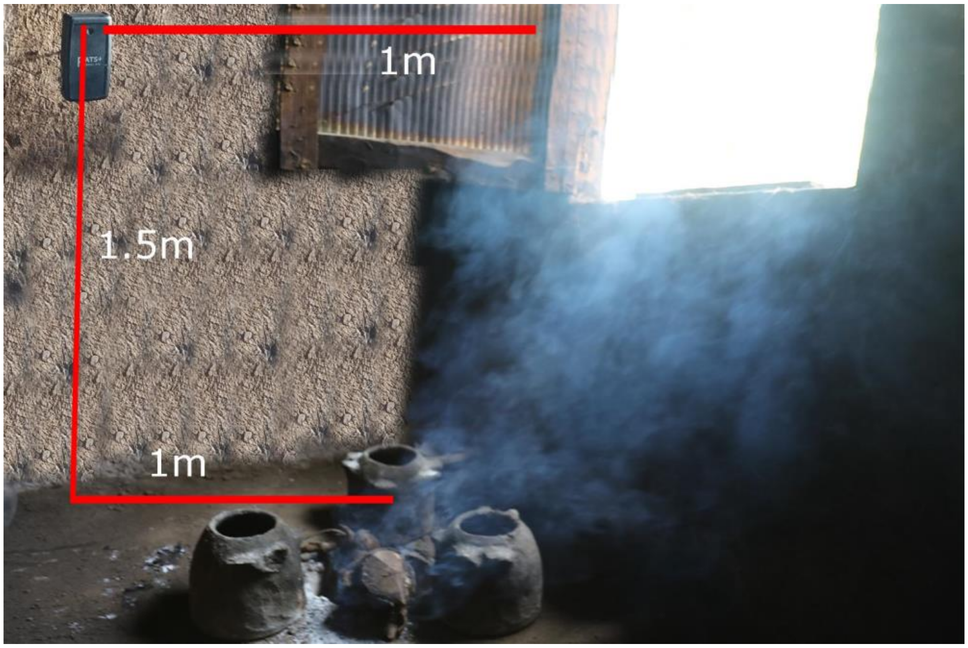


Figure 10: kitchen instrumentation for measuring cookstove emissions (picture credit: Dawit T.)

The single-box model forecasts room concentrations using kitchen characteristics and stove emissions. Equation 3.12 provides a mathematical description of the model (ISO, 2019):

$$C_t = \frac{Gf}{\alpha V}(1 - e^{-\alpha t}) + C_O(e^{-\alpha t}) \tag{3.12}$$

Where;

- C"= Concentration of pollutant within the kitchen at time t (mg/m3);
- G= Emission rate (mg/min);
- f= fraction of fugitive emissions (measured as a fraction of total stove emissions);
- α= Nominal air exchange rate (min-1);
- V= Kitchen volume (m3);
- t= Time (min).

3.3.5 Cookstoves usability

Usability is a crucial consideration when deciding whether to buy or adopt an improved cookstove and whether to use it regularly in the future. Usability can be expressed in terms of effectiveness, efficiency, and user satisfaction. It assesses whether or not a cooking system can meet a cook's needs within a specific setting. A cookstoves usability may vary depending on the end user, thus measurements should be made among a variety of target populations. The cost and effort involved in sourcing and preparing fuel; variety, control, and speed all come into play while cooking; are a few usability factors. Operational aspects include fault tolerance, ease of use, and simplicity of learning. Perceived comfort and aesthetic components; the cost and time necessary for both short- and long-term maintenance, as well as site-specific requirements, including usage other than cooking.

Therefore, to obtain the most insightful results, the results of an observation and interview survey were triangulated in order to evaluate the usability of the stoves. Appendices D1 and D2 consist of respectively, the observational and interview questions.

3.4 Data analysis

In order to determine the effects of each variable on the daily fuel and energy use of the household as well as the acceptability of the stoves, the characteristics of the sample households were studied using a descriptive statistics model. The Shell Foundation's Excel-based data and computation software was used for the Control Cooking Test and Kitchen Performance Test. PICA software was used to analyze the household's collected particulate matter concentration over 24 hours.

Paired t-test using IBM SPSS version 26 were also used to compare the means of the dependent variables between *Tikikil* and *Mirt* stoves users and *Choche* stove in order to identify statistical differences. The statistical significance of the relationship between ICS adoption and household cooking time, specific fuelwood consumption, and the amount of wood the stoves consume was also determined. The typical household fuel usage was determined via measurements and a direct energy use survey. The results were also used to determine the typical fuelwood and time savings as well as the reduction in CO_2 emissions for both *Tikikil* and *Mirt* stoves and *Choche* stove. $P \leq 0.05$ was used to determine the statistical significance level.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Household preliminary survey results

Among the households sampled (n = 38), only 6 (15%) were in the age group of above 53. The study found that the mean (SD) age of the respondents was 41.29± 12.9 years, indicating a relatively wide age range. However, the majority of the respondents (84%) fell within the age group of 21–52 years old of the main cook for the family, suggesting that this age range was the most represented in the study.

Figure 11: Tikikil Stove ready for dissemination

Out of the total surveyed respondents, 33 (86.8%) were male-headed, while 5 (13.2%) households self-identify as female-headed. About 71.1% of respondents are protestant, and 28.9% are Ethiopian Orthodox. Regarding their educational background, 12 (31.6%) respondents entered secondary school, 15 (39.5%) began off in primary school, and 11 (29%) were found to be illiterate. The spouses' levels of education were: 4 (10.5%) were illiterates, 10 (26.3%) started elementary school, and 19 (50%) started secondary school. 31 (81.6%) women self-identify as housewives, compared to only 7 (18%) who have worked on farms or in retail business. Above 84% of the household is engaged in farming and wage work as primary income-generating activities, and the average monthly income is 5055 birr. Table 5 shows that of the households' total population, 10 (26.3%) are between the ages of 5 and 6 and have greater than 9 family members for each, while 11 (28.9%) of the households have more between 7 and 8 family members.

Despite having more than three rooms in the main house of an average home, 71% of cooks do their cooking in a separate kitchen house. The kitchen was constructed separately from the main house. 24 percent of houses cook in the main house except for their bedrooms. only 2% do their cooking outside on the uncovered land, and 90% of the households cook in the same place all year round. The cooking area is 13.2 m^2 in average size. Although almost all cooks open the kitchen door and windows when cooking, 97% of households have black soot deposits on the kitchen's wall and ceiling. However, only 45% of kitchens also feature a ventilation opening for air flow between the wall and the roof in addition to the door and windows.

All the surveyed households uses *Choche* stoves for cooking a meal for their family, irrespective of cooking for sell or animal foods. A little more than half of the families had two or more cooking stoves, and just 34% had just one *Choche* stove the charcoal stoves that were sometimes used to boil coffee in the main homes. Only 21% of households have ever bough improved appliance for cooking, yet 87% of cooks are aware of its availability and importance. Almost all cooks have plans to purchase improved stoves, but 90% of them must consult their husbands before making any house purchases.

For daily activities, fuelwood and charcoal are used in almost 95% of families. Girls and women collect the fuel (84%), carrying it on their backs, while 16% do so using a cart. Cooking takes an average of 3.3 hours, and 70% of cooks light their stove three times per day.

Table 5: Socio-demographic characteristics of the households, 2023 (n=38)

Variable	**Frequency**	**Percent (%)**
Age		
21-36	16	42.1
37-52	16	42.1
>=53	6	15.8
Household head		
Male headed	33	86.8
Female headed	5	13.2
Education status of women		
Illiterates	11	29.0

Began Primary school	15	39.5
Entered secondary school	12	31.6
Education status of spouse's		
Illiterate	4	10.5
Began primary school	10	26.3
Entered secondary school	19	50.0
Religion		
Orthodox Tewahido	11	28.9
Protestant	27	71.1
Income		
farming and wage work	32	84.2
Labor and small business	5	13.2
Family size		
3 – 4	7	18.4
5 – 6	10	26.3
7 – 8	11	28.9
>=9	10	26.3

As Soromessa *et al.* (2004) and visual inspection the community relied heavily on the natural forests that were likely found in the highlands of the area and regularly used Acacia Abyssinica, Terminalnalia Brownie, Eucalyptus Globulus, Eucalyptus Camaldulensis, Cuppressus Lustanica, Gravilla Robusta, Cordia Africana, and Croton microstaches as their primary fuelwood for cooking. The majority of households collect fuelwood from surrounding forests.

4.2 Kitchen energy consumption

Thirty eight households participated in a paired sample test that was conducted in accordance with the guidelines, which called for testing to be done on the *Choche* stove for three days straight to measure daily fuel wood consumption, and then on the *Tikikil* and *Mirt* stoves in the kitchens of the households for an additional three days.

4.2.1 Household daily fuel uses

Tables 6 shows compare the daily fuel and energy use of the *Choche* stove with that of the *Tikikil* and *Mirt* stoves in the home after gathering the household's daily mass of fuel consumption, the number of people in the household over the previous 24 hours, and the moisture content of the sampled fuelwood. These calculations were done using the excel-based software developed by the Shell Foundation. The *Tikikil* and *Mirt* stoves, as well as the C*hoche*, use an average of 5.8 Kg and

8.7 Kg of fuelwood each day, respectively. As a result, the *Tikikil* and *Mirt* in this study reduced fuelwood use on average by 33.3%. According to Fekadu *et al.* (2021), this means that the improved stoves can reduce deforestation and forest degradation by 20.2 to 42% compared to traditional stoves.

Table 6: Daily household fuelwood and energy consumption

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Choche Daily fuel use (Kg)	38	4.30	12.50	8.723	2.262	5.120
Tikikil & Mirt Daily fuel use (Kg)	38	3.10	11.50	5.805	2.063	4.260
Choche Daily Energy use (MJ)	38	78.40	236.00	163.839	42.943	1844.132
Tikikil & Mirt Daily Energy use (MJ)	38	57.40	216.70	108.771	39.330	1546.850

4.2.2 The paired sample t-test comparing the daily fuel use

The paired sample t-test was used to compare the daily fuel use of *Choche* cooking stove and *Tikikil and Mirt* cookstoves. The results showed that the mean daily fuel use for *Choche* cooking stove was 8.7237 kg (SD = 2.262), while the mean daily fuel use for *Tikikil and Mirt* cookstoves was 5.805 kg (SD = 2.063). The paired differences between the two means were 2.91842 kg (SD = 2.651), which was statistically significant ($t(37) = 6.784$, $p < .001$).

The 95% confidence interval of the difference in means was 2.046 to 3.790 kg, which did not include zero. This indicates that the difference in means was statistically significant and that the *Tikikil and Mirt* cookstoves were more fuel-efficient than *Choche* stove.

The correlation between the two variables was positive but weak ($r = .251$, $p = .128$), indicating that there was some association between the two variables, but it was not strong enough to affect the results of the paired sample t-test.

4.2.3 The paired sample t-test comparing the daily energy use

The paired sample t-test was used to compare the daily energy use of *Choche* stove and *Tikikil and Mirt* cookstoves. The results showed that the mean daily energy use for *Choche* stove was 163.839 MJ (SD = 42.943), while the mean daily energy use for *Tikikil and Mirt* cookstoves was 108.771 MJ (SD = 39.330). The paired differences between the two means was 55.068 MJ (SD = 49.179), which were statistically significant ($t(37) = 6.903$, $p < .001$) (see Table 7).

The 95% confidence interval of the difference in means was 38.903 to 71.233 MJ, which did not include zero. This indicates that the difference in means was statistically significant and that the improved cook stoves used less energy than *Choche* stove.

Table 7: paired samples t-test of daily fuel and energy use of the stoves

	Variable	Mean	Paired difference SD	Paired difference mean	SD	t(df)	p-value
Pair 1	*Choche* stove daily fuel use (kg)	8.723	2.651	2.918	2.26	6.784(37)	< .001
	Tikikil and *Mirt* stove daily fuel use (kg)	5.803			2.06		
Pair 2	*Choche* stove daily energy use (MJ)	163.84	49.179	55.068	42.94	6.903(37)	< .001
	Tikikil and *Mirt* stove daily energy use (MJ)	108.77			39.33		

4.2.4 GHG emission reduction potential of the stove

Average fuelwood consumption per year per household was calculated using the amount of daily wood used and the 366 days per year utilizing equation 3.10.

The typical annual fuel usage of the *Choche* vs. *Tikikil* and *Mirt* stoves is 3,192.87 kg/year/HH and 2,124.74 kg/year/HH, respectively. By employing *Tikikil* and *Mirt* stoves in homes, households save 1,068.13 kg of fuel annually, this result is appear to be slightly lower than to what Wassie and Adaramola found in their independent analyses of the Mirt, Gonziye, and Tikikil stoves (Wassie & Adaramola, 2021) This might be brought on by the traditional stove used as a baseline and various estimating techniques. But in the study carried out in southern Ethiopia by (Dresen *et al.*, 2014), the usage of Mirt stoves might save 1280kg per household per year, and this result is more similar to this study's findings.

The amount of CO_2 emission of the fuelwood was calculated by using the mean annual fuelwood consumption of the stove in Kg, the carbon content of the wood, taking 0.5% and emission factor 3.67 (kg CO_2 emitted per kg of carbon burned) calculated as Equation 10.11.

The household would therefore emit 5,858.9 kg of CO_2e per year from using the *Choche* stove, while 3,898.89 kg of CO_2e would be released into the environment by users of the *Tikikil* and *Mirt* stoves. The difference between the two types (*Choche* and *Tikikil and Mirt*) of stoves in CO_2 emissions is 1.96 metric tons per year per household.

Wassie and Adaramola found that Mirt, Gonziye, and Tikikil stoves can reduce emissions by 2.82–3.43 tCO_2e per stove per year when compared to three-stone fires or open fires. However, this study differs from their findings in that it used the *Choche* stove. The mean adult equivalent in the sampled home is 5.4, and the yearly CO_2 emission reduction caused by ICS is thought to be 0.36 tCO_2 per person (Wassie & Adaramola, 2021).

4.3 Relative fuel consumption of the stoves

The equivalent dry fuel and specific fuel consumption and also total cooking time of *Choche* and *Mirt* stoves was evaluated by taking 21 subsamples from the 38 total household to bake *injera* in the in the selected household kitchen with three replication tests. Data was collected from the household kitchen by applying the control cooking test (CCT).

4.3.1 Equivalent dry wood consumption

In this measurement the fuel wood consumption in each cooking session in the households and the paired samples t-test was conducted to compare the mean equivalent dry wood consumed (in grams) between *Choche* and *Mirt* cooking methods. The results show in Table 8 that the mean equivalent dry wood consumed for the *Choche* stove was 6657.00 grams with a standard deviation of 779.55, while the mean equivalent dry wood consumed for *Mirt* stove was 5333.38 grams with a standard deviation of 778.83.

Table 8: Equivalent dry wood consumption of *Choche* and *Mirt*

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Choche equivalent dry wood consumed (g)	6657.00	21	779.55	170.11
	Mirt equivalent dry wood consumed (g)	5333.38	21	778.83	169.95

The paired differences between the two cooking methods was 1323.62 grams with a standard deviation of 632.92 and a standard error mean of 138.12. The 95% confidence interval of the difference was between 1035.51 and 1611.72 grams (Table 9). The t-value was 9.58 with 20 degrees of freedom, and the p-value was .000, which is less than the alpha level of .05, indicating that the difference in mean equivalent dry wood consumed between the two methods is statistically significant.

Table 9: paired sample t-test between *Choche* and *Mirt* equivalent dry wood consumption

		Paired Differences					t	df	Sig(2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	*Choche* equivalent dry wood consumed (g) *Mirt* equivalent dry wood consumed (g)	1323.61	632.92	138.11	1035.52	1611.72	9.58	20	.000

Therefore, as other literature concluded that this study also find that the *Mirt* method consumes significantly less equivalent dry wood compared to the *Choche* method (Wassie & Adaramola, 2021).

4.3.2 Specific fuel consumption

The paired samples t-test was conducted to compare the mean specific fuel consumption of *injera* baking in households (grams of fuelwood consumed per kilogram of *injera* baked) between the *Choche* and *Mirt* methods. The results show that the mean specific fuel consumption for the *Choche* stove was 609.52 grams of wood used per one kilogram of *injera* baked, with a standard deviation of 65.83, while the mean specific fuel consumption for *Mirt* stove was 444.95 grams of fuelwood used over one kilogram of *injera* baked, with a standard deviation of 59.48 (Table 10).

Table 10: *Mirt* and *Choche's* respective specific fuel consumption

	N	Minimum	Maximum	Mean	Std. Deviation
Choche specific fuel consumption (g/kg)	21	455.00	770.00	609.52	65.84
Mirt specific fuel consumption (g/kg)	21	316.00	530.00	444.95	59.49

The paired differences between the two cooking practice were 164.571 grams per kilogram with a standard deviation of 54.367 and a standard error mean of 11.864. The 95% confidence interval of the difference was found between 139.823 and 189.319 grams per kilogram (Table 11).

The t-value was 13.87 with 20 degrees of freedom, and the p-value was .000, which is less than the alpha level of .05, indicating that the difference in mean specific fuel consumption between the two methods is statistically significant.

Table 11: Paired sample t-test of specific fuel consumption of *Choche* and *Mirt* stoves

		Paired Differences					t	df	Sig(2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	*Choche* specific fuel consumption (g/kg) - *Mirt* specific fuel consumption (g/kg)	164.57	54.37	11.86	139.82	189.32	13.87	20	.000

The result in the mean difference (equation 3.5) from the two variable tests is 27%, which is in the range of 20–30% difference in specific fuel consumption.

Therefore, it can be concluded that the *Mirt* method has a significantly lower specific fuel consumption compared to the *Choche* method and according to Adem and Ambie (2017), the lowest result of specific fuel consumption of traditional stoves from the Werkenesh study is 630 g/kg, while the average is 929 g/kg baking *injera*, on contrary to this study on *Choche* average specific fuel wood consumption is 609 g/kg. The specific fuel consumption result of three-stone open-fire stoves' differ significantly from *Choche*.

4.3.3 Total cooking time of the stoves

The paired samples t-test was conducted to compare the mean total cooking time (in minutes) between *Choche* and *Mirt* methods.

The results show that the mean total cooking time for Choche method was 99.90 minutes with a standard deviation of 4.51, while the mean total cooking time for Mirt method was 95.47 minutes with a standard deviation of 7.51.

The paired differences between the two methods were 4.42 minutes with a standard deviation of 5.88 and a standard error mean of 1.28. The 95% confidence interval of the difference was between 1.75 and 7.12 minutes (Table 12).

The t-value was 3.45 with 20 degrees of freedom, and the p-value was .003, which is less than the alpha level of .05, indicating that the difference in mean total cooking time between the two methods is statistically significant.

Table 12: Parred differences in total cooking time of *Choche* and *Mirt* stoves

	Variable	Mean	Paired difference		SD	t(df)	p-value
			SD	mean			
Pair 1	*Choche* total cooking time (min)	99.90	5.89	4.43	4.52	3.447(21)	< .003
	Mirt total cooking time (min)	95.48			7.51		

Thus, it can be stated that as compared to the *Mirt* cookstove, the *Choche* stove significantly increases the total cooking time.

4.3.4 Specific energy consumption

The researcher calculated the total energy consumption each session from equations 3.3 and 3.4, using the energy content (lower heating value) of Eucalyptus globulus, which is 18.84 MJ/kg, and an average *Choche* equivalent dry wood consumption is 6.66 kg of wood. The average energy intake would be of 125,474 KJ, which is used to prepare 10.91 kg of *injera*. As shown in Figure 12, a specific energy consumption of 125,474 KJ/10.91 kg, or 11,498 KJ/kg, would result from this. When using the same species of wood for baking *injera*, the *Mirt* stove requires 5.33 Kg of dry wood per session. The average energy consumption would be 100,417 KJ and specific energy consumption would be 8,389 KJ/kg. The percent difference in energy consumption between the two variables is 27% based on the equation 3.5.

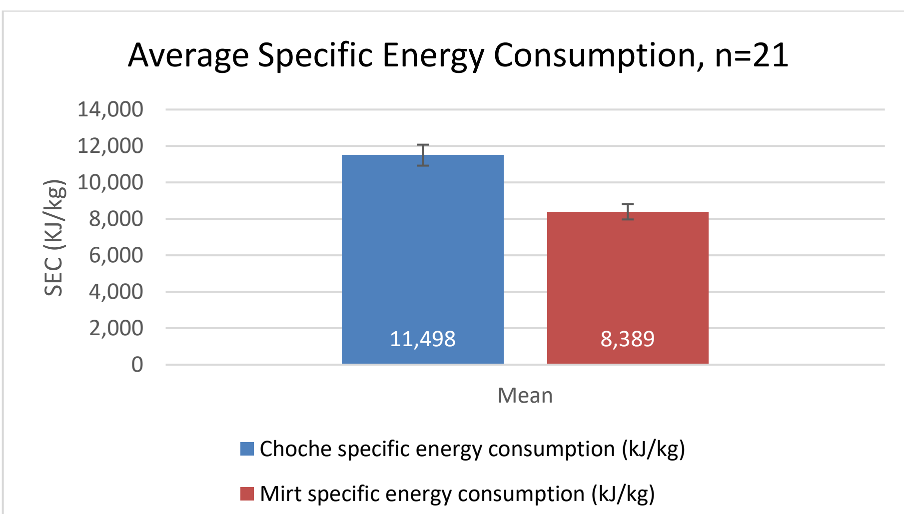


Figure 12: The average specific consumption of energy of *Choche* and *Mirt*

4.4 Household air pollution (HAP)

The study used data from 20 households in three villages. Two of the 20 households selected were excluded from the *Tikikil* and *Mirt* stove tests because they did not follow their normal cooking routines. The kitchen of almost every home has a *Choche* stove, which is used for daily cooking. As Table 13 shows, the summary statistic for the $PM_{2.5}$ emission measured during the cooking events in households that were subjected to HAP monitoring (n = 20) for the kitchen $PM_{2.5}$ concentrations. The average $PM_{2.5}$ concentration with the *Chocho* stove is 1102±408.6 µg/m^3, while it is 749.6±225.1 µg/m^3 with the *Tikikil* and *Mirt* stoves, this figure is about 45 times and 30 times the WHO 24-hour guideline of 25 µg/m^3 of household air pollution. The relative difference in mean between the two variable stove types is 32.6 % emission reduction by *Tikikil* and *Mirt* stoves. The result of the data is generally in line with the previously reported estimate by Bluffstone *et al.* (2019). The average maximum $PM_{2.5}$ concentration for the two variables is 42,939 µg/m^3. Average maximum concentrations in households using *Tikikil* and *Mirt* stoves are lower than those using *Choche* stoves (39,195 µg /m^3 vs. 46,683 µg /m^3).

Table 13: Paired sample statistics of PM2.5 emissions from ICS and *choche* stoves in the kitchen

	Mean	**Median**	**Maximum**
Choche $PM_{2.5}$ emission	1,102.1 (419.3) [20]	28.3 (21.5) [20]	46,683.8 (4,783.1) [20]
Tikikil & *Mirt* $PM_{2.5}$ emission	742.6 (217.3) [18]	22 (10.8) [18]	39,195 (6796) [18]

Standard deviations in parentheses and sample size in brackets.

A typical time series for a 24-hour monitoring period is shown in this line graph, with all plots showing minute-by-minute data, as shown in Figure 13. The green line shows the $PM_{2.5}$ concentration data from the PATS+ devices placed in the kitchen and the associated concentrations from the PATS+ monitors in the given rooms. The greatest concentrations coincided with the times that the household typically cooks and meals (lunch, breakfast, and supper), and they also matched the activity report that the mother of the home provided.

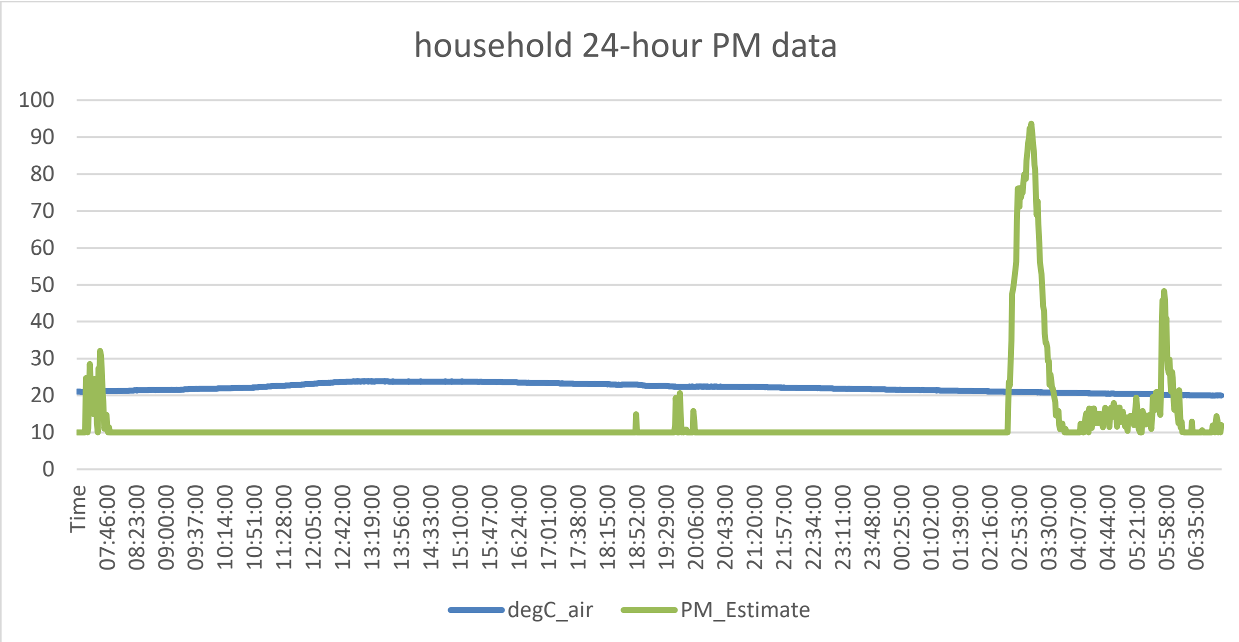


Figure 13: 24-hour typical household kitchen $PM_{2.5}$ concentration

4.5 *Tikikil* and *Mirt* stove usability

Observation and household stove survey is an important tool for determining whether the new cookstove model is acceptable by the cook. The planned method of observation was carried out in 38 houses by applying the serious observation questions as shown in appendix E. A serious observation was conducted after three days of use of the *Tikikil* and *Mirt* stoves that were provided to the home following an interview with the cook on the first day. It's believed that observation results are crucial for understanding the real-world dynamics of cookstove adoption.

The results of the t-test showed in Table 14 that the mean fuel preparation time for the *Chocho* stove was 0.00 minutes and for the Mirt stove was 14.52 minutes. The paired differences between the two stoves were -14.524 minutes, with a standard deviation of 5.297 and a standard error mean of 1.156. The 95% confidence interval of the difference was between -16.935 and -12.112 minutes. The t-value was -12.564 with 20 degrees of freedom, and the p-value was .000, which is less than the alpha level of .05, indicating that the difference in mean fuel preparation time between the two methods is statistically significant. Thus, from user's observation of cooking events using the Mirt stove, thinning the wood before beginning the baking process takes an additional mean of 14.52 minutes for fuel preparation time compared to the *Chocho* stove.

From the observational records, a paired sample t-test was conducted to compare the mean lighting time required (in minutes) between *Choche* and *Mirt* methods. The results show that the mean lighting time required for the *Choche* method was 0.00 minutes, while the mean lighting time required for the Mirt method was 13.29 minutes. The paired differences between the two stoves were -13.29 minutes, with a standard deviation of 4.75 and a standard error mean of 1.04. The 95% confidence interval of the difference was between -15.45 and -11.13 minutes. The t-value was -12.83 with 20 degrees of freedom, and the p-value was .000, which is less than the alpha level of .05, indicating that the difference in mean lighting time required between the two methods is statistically significant.

On a *Choche* stove, there is no need to light it every cooking time; however, a *Mirt* stove needs to be lit for an average of 13.29 minutes. Additionally, the majority of them (60%) ignite the stove with plastic bags to light each session.

Therefore, lighting is an essential factor for the cook and has an impact on time. It requires a significantly longer lighting time compared to the *Choche* stove and has the environmental negative consequence of air pollution from the burning of plastic bags.

The *Choche* stove mean tending and refueling period was 1.81 moments while the *Mirt* stove mean tending and refueling period was 6.38 moments, the results of the paired sample t-test. With a standard deviation of 2.36 and a standard error mean of 0.52, the mean differences between the two stoves were -4.57. The difference's 95% confidence interval ranged from -5.64 to -3.49. The difference in mean tending and refueling periods between the two stoves is statistically significant, as shown by the t-value of -8.89 with 20 degrees of freedom and the p-value of .00, which is less than the alpha level of .05. Hence, The Mirt stove requires substantially more tending and refueling than *Choche* stoves; the average difference is 4.57 times. This is because the Mirt stove consumes little, tiny fuelwood.

In response to the error made when baking, the *Choche* stove's mean user error was 3.62, whereas the *Mirt* stove's mean user error was 1.86. The averaged differences between the two stoves were 1.76, with a 1.48 standard deviation and a 0.32 standard error mean. Between 1.09 and 2.43 was the difference's 95% confidence interval. The difference in the mean user error between the two stoves is statistically significant, as shown by the t-value of 5.45 with 20 degrees of freedom and the p-value of.000, which is less than the alpha level of .05 and therefore, *Mirt* stove can reduce the user's error significantly lower compared to the *Choche* stove users. The majority of mistakes were caused by fires went out outside of the stove surface area, cooks supplying too much fuel, and improper refueling techniques.

Table 14: cook observation of cooking activities in *Chocho* and *Mirt* stoves

	Variable	**Mean**	**Paired difference SD**	**Paired difference mean**	**SD**	**t(df)**	**p-value**
Pair 1	*Choche* stove fuel preparation time (min)	.00			.00		
	Mirt stove fuel preparation time (min)	14.52	5.29	14.52	5.29	12.56(20)	.00
Pair 2	*Choche* stove lighting time (min)	.00			.00		
	Mirt stove lighting time (min)	13.29	4.75	13.29	1.04	12.83(20)	.00
Pair 3	*Choche* stove tending and refueling average (x)	1.81			.75		
	Mirt stove tending and refueling average (x)	6.38	2.36	4.57	2.16	8.89(20)	.00
Pair 4	*Choche* stove user error average (x)	3.62	1.48	1.76	1.28	5.45(20)	.00
	Mirt stove user error average (x)	1.86			.79		

The frequency tables, as shown in figures 14 and 15, indicate the distribution of observations for the visibility of fire and soot deposited on the pot for the Mirt and Choche cooking methods. On Mirt, 71.4% rated the fire visibility as "Best," while 28.6% claimed it was "Good." 47.6% felt the soot on the pots was "good," and 52.4% found it was "Fair." The visibility of fire was rated as "Poor" by 66.7% of *Choche* residents and "Fair" by 33.3%. 38.1% of respondents rated the soot that had been left on pots as "Fair," while 61.9% felt it was "Poor." Therefore, it was also evidence of fire visibility, and the *Choche* stove produced far more soot in the pot than the *Mirt* stove.

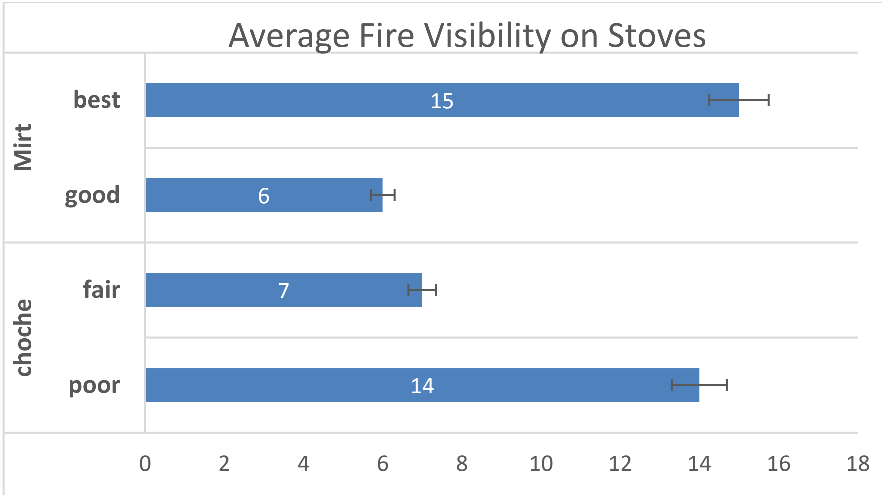


Figure 14: Frequency table observation of fire visibility in *Mirt* and *Chocho* stoves

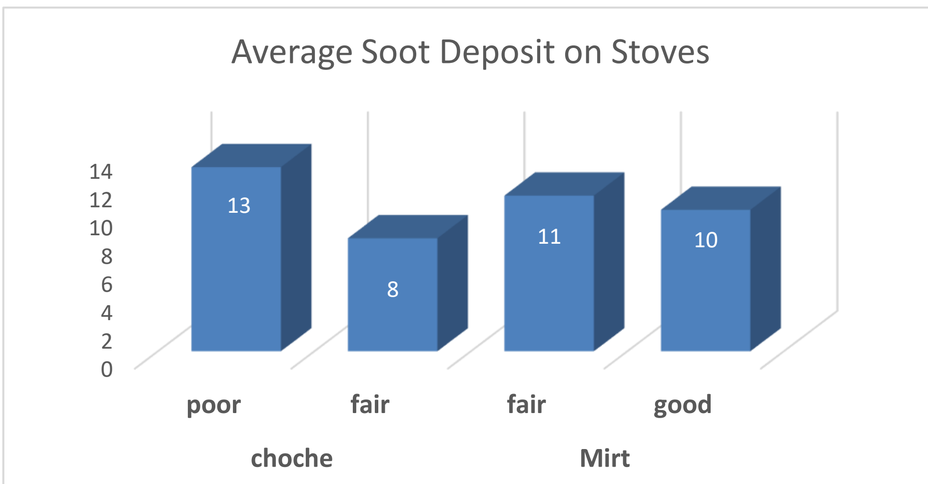


Figure 15: Frequency table observation of soot deposited in *Mirt* and *Chocho* stoves

When the cook was asked about what they liked about the primary stove, the majority of respondents (86.9%) said that it cooked food quickly, did not require regular lighting, and was unaffected by the wind. The responders, when asked what they didn't like about it, all agreed that it uses a lot of firewood and emits a lot of smoke 86.8% of the respondents had heard of ICS, and no one of the households has this advanced technology. The reasons given were: 71.1% don't have much money to buy the product; 10% don't know where to find the products; and the remaining were comfortable with the *Choche* stove and cooking habits. As a result, a number of reasons, such as a lack of stove availability, a lack of knowledge about the stove's benefits, the stove's producer's shade or home distance from the market, and its fixed character, prevented the *Mirt* stove from being widely adopted at the surveyed sites.

The economical barrier is one of the main impediments to the household implementing the improved cookstoves. According to this study, the husband is the one who decides whether to purchase household goods. Only 40% of the respondents made their own decision, whereas the husband or both partners typically decide on household purchases that mean the cook are economically dependent on the spouse. Other researches were also indicate socioeconomic impacts have negative effect on the adoption of improved cookstoves (Asfaw, 2011; Beyene & Koch, 2013; Kebede *et al.*, 2022).

User acceptance and satisfaction are also another crucial factors influencing improved cookstove adoption. From the surveyed household the cook were asked which design more preferred by them and their preference is more flexible type to support any type of pot and studies were also have highlighted the importance of considering user preferences, cultural practices, and cooking habits when designing and promoting improved cookstoves. User involvement and feedback in the design process have been found to increase acceptance and sustained use of the stoves (Jeuland *et al.*, 2020; Yayeh *et al.*, 2021).

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclustion

The new field testing standard is an effective tool for evaluating the performance of the improved cookstove in real world kitchen of the households. The performance of the *Tikikil* and *Mirt* improved cookstoves demonstrates their enhanced efficiency compared to the *Choche* stove. The Improved cookstoves show better fuel utilization, reduced cooking time, and improved heat distribution, resulting in more efficient and effective cooking. These cookstoves exhibit lower emissions of harmful pollutants such as particulate matter (PM). As a result, these improved cookstoves have a positive impact on household health by reducing exposure to indoor air pollution.

The test confirms their ability to mitigate indoor air pollution, thereby reducing health risks for household members. The test reveals that improved cookstoves achieve significant fuel savings due to their enhanced combustion efficiency. This can be translated into cost savings for households and reduces the reliance on biomass fuels, leading to environmental benefits and a lower economic burden.

The acceptability test highlights positive user feedback and acceptance of *Mirt* stove. Users appreciate the improved performance, reduced smoke emissions, and time-saving benefits. The cookstoves are seen as reliable, convenient, and easy to operate, which contributes to user satisfaction and encourages sustained adoption. Users express high satisfaction with the *Mirt injera* baking stove's performance and overall usability. *Tikikil* cooking stove were not found to align well with local cooking habits and preferences, negatively impacting their overall acceptability. *Chocho* is a traditional cooking method that is well recognized and practiced in every home, and it is more acquainted and comfortable with the assessed households' traditional cooking methods.

The test results highlight barriers or challenges to the widespread adoption of improved cookstoves. In the surveyed households, affordability, cultural preferences, availability of cookstoves, and lack of awareness were the major barriers to the adoption of improved cookstoves.

5.2 Recommendation

Based on the test results, further research is needed to evaluate the long-term durability, safety, maintenance requirements, and acceptability of ICS in various agro-ecological, cooking habit, tradition, fuel and food type, and socioeconomic characteristics of diverse societies prior to the large-scale dissemination of the stoves. Major suggestions from this study include the following:

- Understand cooking practice of the community prior to design and development of the stove. Involve end-users in the design and development process of improved cookstoves to ensure their usability, acceptability, and cultural appropriateness. Gather feedback and insights from users to refine stove designs, taking into account cooking habits, preferences, and local culinary practices.
- Advocate for supportive policies and regulations that enhance the adoption and affordability of improved cookstoves. This can include incentives, tax breaks, or subsidies for households or manufacturers involved in the production and use of improved cookstoves.
- Effort should be made to increase awareness and adoption of improve cookstove. Increase awareness and education programs to inform communities about the benefits of improved cookstoves, including their fuel efficiency, health benefits, and environmental impact. This can be done through community outreach, demonstrations, and informative campaigns targeting households, local leaders, and relevant stakeholders.
- Foster partnerships and collaborations between government agencies, non-governmental organizations, private sector entities, and research institutions to leverage resources, knowledge, and expertise. Collaborative efforts can accelerate the adoption and scale-up of improved cookstoves through coordinated interventions, policy support, and shared learning.

REFERENCE

Abbasi, T., & Abbasi, S. A. (2009). Biomass energy and the environmental impacts associated with its production and utilization. *Renewable and Sustainable Energy Reviews, 14*(2010), 919-937. doi:10.1016/j.rser.2009.11.006

Adem, K. D., & Ambie, D. A. (2017). <A review of injera baking technologies in Ethiopia Challenges and gaps.pdf>. *Energy for sustainable, 41*(2017), 12. doi:10.1016/j.esd.2017.08.003

Adkins, E., Tyler, E., Wang, J., Siriri, D., & Modi, V. (2010). Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. *Energy for Sustainable Development, 14*(3), 172-185. doi:10.1016/j.esd.2010.07.003

Afrane, G., & Ntiamoah, A. (2011). Comparative Life Cycle Assessment of Charcoal, Biogas, and Liquefied Petroleum Gas as Cooking Fuels in Ghana. *Journal of Industrial Ecology, 15*(4), 539-549. doi:10.1111/j.1530-9290.2011.00350.x

Alem, Y., Hassen, S., & Köhlin, G. (2013). The Dynamics of Electric Cookstove Adoption panel data evidence from Ethiopia. In *WORKING PAPERS IN ECONOMIC No 557* (pp. 26). Göteborg, Sweden: School of Business, Economics and Law at University of Gothenburg.

Asfaw, Z. (2011). Adoption and use of improved cookstove in ethiopia. *research gate*, 34.

Bailis, R. (2004). Kitchen Performance Test (KPT). In (pp. 31): University of California-Berkeley.

Bailis, R., Berrueta, V., Chengappa, C., Dutta, K., Edwards, R., Masera, O., . . . Smith, K. R. (2007). Performance testing for monitoring improved biomass stove interventions: experiences of the Household Energy and Health Project. *Energy for Sustainable Development, 11*(2), 1-15.

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. *Nature Climate Change, 5*(3), 266-272. doi:10.1038/nclimate2491

Balat, M., & Ayar, G. (2005). Biomass Energy in the World, Use of Biomass and Potential Trends. *Energy Sources, 27*. doi:10.1080/00908310490449045

Behran, T. Gamo Fact sheet [Press release]. Retrieved from https://www.globalonenessproject.org/sites/default/files/lesson-plans/gamo_fact_sheet.pdf

Beltramo, T., Blalock, G., Levine, D. I., & Simons, A. M. (2015). The effect of marketing messages and payment over time on willingness to pay for fuel-efficient cookstoves. *Journal of Economic Behavior & Organization, 118*, 333-345. doi:10.1016/j.jebo.2015.04.025

Benka-Coker, M. L., Tadele, W., Milano, A., Getaneh, D., & Stokes, H. (2018). A case study of the ethanol clean cookstove intervetion and potetial scale-up in Ethiopia. *Energy for Sustainable Development, 46*(2018), 53-64. doi:10.1016/j.esd.2018.06.009

Bensch, G., & Peters, J. (2011). Combating Deforestation? - Impacts of Improved Stove Dissemination on Charcoal Consumption in Urban Senegal. *econstor*. Retrieved from http://hdl.handle.net/10419/48312

Bensch, G., & Peters, J. (2012). A Recipe for Success? Randomized Free Distribution of Improved Cooking Stoves in Senegal. *Ruhr Economic Papers, 325*, 40. Retrieved from http://ssrn.com/abstract=2030746

Bensch, G., & Peters, J. (2015). The Intensive Margin of Technology Adoption Experimental Evidence on Improved Cooking Stoves in Rural Senegal. *Ruhr Economic Papers, 494*. doi:10.4419/86788563

Berkeley. (2005). Standard Operating Procedure

Installing Indoor Air Pollution Instruments in a Home. In *Installing IAP Instruments in a Home* (pp. 1-6): University of California.
Berkeley. (2016). PATS+ and PICA Operation and Service Manual In (pp. 1-25). USA, California: Berkeley University.
Beyene, A., Bluffstone, R., Gebreegzhiaber, Z., Martinsson, P., Mekonnen, A., & Vieider, F. (2015). Do Improved Biomass Cookstoves Reduce Fuelwood Consumption and Carbon Emissions? *Policy Research Working Paper, 7324*, 1-41.
Beyene, A. D., & Koch, S. F. (2013). CLEAN FUEL-SAVING TECHNOLOGY ADOPTION IN URBAN ETHIOPIA. *Energy economics, 36*, 24.
Bluffstone, R., LaFave, D., Mekonnen, A., Dissanayake, S., Beyene, A. D., Gebreegziabher, Z., & Toman, M. A. (2019). Do Improved Biomass Cookstoves Reduce PM2.5 Concentrations? ? If So, for Whom? *Policy Research Working Paper*, *8930*.
CSA. (2013). *Pupulation Projection of Ethiopia for All Regions At Werada Level from 2014-2017*. Retrieved from
D.Moses, N., & A.MacCarty, N. (2018). A Practicical Evaluation for Cookstove Usability. *ASME*, 1-11.
Demirbas, A. (2009). Pyrolysis Mechanisms of Biomass Materials. *Energy Sources*(1556-7036 print/1556-7230 online), 1186-1193. doi: 10.1080/15567030801952268
Dresen, E., DeVries, B., Herold, M., Verchot, L., & Müller, R. (2014). Fuelwood Savings and Carbon Emission Reductions by the Use of Improved Cooking Stoves in an Afromontane Forest, Ethiopia. *Land, 3*(3), 1137-1157. doi:10.3390/land3031137
Edwards, R., Hubbard, A., Khalakdina, A., Pennise, D., & Smith, K. R. (2007). Design considerations for field studies of changes in indoor air pollution due to improved stoves. *Energy for Sustainable Development, 11*(2), 71-81.
EPA. (2011). Ethiopia's Climate-Resilient Green Economy In *Green economy strategy*. Addis Ababa: Federal Democratic Rupublic of Ethiopia.
EREDPC. (2021). *Report on Thermal Performance of Mirt Stove*. Retrieved from Addis Ababa:
ESA. (2017a). Biomass Baking Stoves – Performance Requirements and Test Methods for Household Biomass Baking Stove. In *ICS:97.040.20* (Vol. ES 6086:2017, pp. 1-32). Ethiopia: Ethiopian Standard Agency
ESA. (2017b). Improved Biomass Cooking Stoves – Performance Requirements and Test Methods for Household Biomass Cooking Stoves. In (Vol. ES 6085:2017, pp. 1-26). Ethiopia: Ethiopian Standard Agency
ESA. (2019). Clean Cook Stove and Clean Cooking Solution Performance Requirements and Test Methods. In (Vol. ICS:97.040.020). Addis Ababa: Ethiopian Standard Agency
ESMAP. (2021). *Energy Sector Management Assistance Program Annual Report-2021*. Retrieved from https://documents1.worldbank.org/curated/en/615511640189474271/pdf/Energy-Sector-Management-Assistance-Program-ESMAP-Annual-Report-2021.pdf
Fekadu, M., Mekonnen, Z., Manaye, A., & Tesfaye, M. (2021). Kitchen Performance Test for Mirt and Improved Gonzie Cook stoves in Ethiopia. 250-265.
Garland, C., Johnson, M., Jagoe, K., & Ramanathan, T. (2016). *Cookstove Field Study Resources*. Retrieved from
Gebreegziabher, Z., Beyene, A. D., Bluffstone, R., Martinsson, P., Mekonnen, A., & Toman, M. A. (2018). Fuel savings, cooking time and user satisfaction with improved biomass cookstoves: Evidence from controlled cooking tests in Ethiopia. *Resource and Energy Economics, 52*, 173-185. doi:10.1016/j.reseneeco.2018.01.006

Gebreegziabher, Z., Mekonen, A., Kassie, M., & Kohlin, G. (2012). Urban Energy Transition and Technology Adoption the Case of Tigray.
Grieshop, A. P., Marshall, J. D., & Kandlikar, M. (2011). Health and climate benefits of cookstove replacement options. *Energy Policy, 39*(12), 7530-7542. doi:10.1016/j.enpol.2011.03.024
GTZ. (2010). *Water Boiling Test Results Institutional Rocket and Tikikil Stoves*. Retrieved from Addis Ababa:
Guta, D. D. (2012a). Application of an almost ideal demand system (AIDS) to Ethiopian rural residential energy use: Panel data evidence. *Energy Policy, 50*, 528-539. doi:10.1016/j.enpol.2012.07.055
Guta, D. D. (2012b). Assessment of Biomass Fuel Resource Potential And Utilization in Ethiopia: Sourcing Strategies for Renewable Energies. *RENEWABLE ENERGY RESEARCH, 2*(1), 9.
Guta, D. D. (2014). Effect of fuelwood scarcity and socio-economic factors on household bio-based energy use and energy substitution in rural Ethiopia. *Energy Policy, 75*, 217-227. doi:10.1016/j.enpol.2014.09.017
Hanna, R., Duflo, E., & Greenstone, M. (2012). Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. *NBER WORKING PAPER SERIES, 18033*, 71.
Healy, J. D., & Clinch, J. P. (2004). Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland. *Energy Policy, 32*(2), 207-220. doi:10.1016/s0301-4215(02)00265-3
IEA. (2019). *Africa Energy Outlook 2019*. Retrieved from Paris: www.iea.org/africa2019
IEA. (2022a). *Africa Energy Outlook 2022*. Retrieved from Paris: https://www.iea.org/reports/africa-energy-outlook-2022
IEA. (2022b). *World Energy Outlook 2022*. Retrieved from Paris:
IPCC. (2006). Methodological tool Project and leakage emissions from biomass. Retrieved from https://unfccc.int/gcse?q=biomass%20emission%20calculation
ISO. (2019). Clean cookstoves and clean cooking solutions — Field testing methods for cookstoves. *ISO 19869:2019.* Retrieved from https://www.iso.org/standard/66521.html
Jeuland, M. A., Bhojvaid, V., Kar, A., J.J.Lewis, Patange, O., Pattanayak, S. K., . . . Ramanathan, V. (2015). Preferences for improved cook stoves: Evidence from rural villages in north India. *Energy Economics, 52*, 287-298. doi:10.1016/j.eneco.2015.11.010
Jeuland, M. A., & Pattanayak, S. K. (2012). Benefits and costs of improved cookstoves: assessing the implications of variability in health, forest and climate impacts. *PLoS One, 7*(2), e30338. doi:10.1371/journal.pone.0030338
Jeuland, M. A., Pattanayak, S. K., Samaddar, S., Shah, R., & Vora, M. (2020). Adoption and impacts of improved biomass cookstoves in rural Rajasthan. *Energy for Sustainable Development, 57*, 149-159.
Karekezi, S., Lata, K., & Coelho, S. T. e. (2004). *Traditional Biomass Energy: Improving its Use and Moving to Modern Energy Use.* Paper presented at the International Conference for Renewable Energies, Bonn 2004 Bonn.
Kebede, N., Tolossa, D., & Tefera, T. (2022). Adoption of improved cook stoves by households in informal settlements of Woreda 12, Yeka subcity, Addis Ababa. *Energy Sustain Soc, 12*(1), 45. doi:10.1186/s13705-022-00370-4
Kilawe, E., & Habimana, D. (2016). *FORESTRY CONTRIBUTION TO NATIONAL ECONOMY AND TRADE IN Ethiopia, Kenya and Uganda*. Retrieved from

Lee, C. M., Chandler, C., Lazarus, M., & Johnso, F. X. (2013). Assessing the Climate Impacts of Cookstove Projects: Issues in Emissions Accounting. *Challenges in Sustainability, 1*(2), 53-71. doi:10.12924/cis2013.01020053

Mainali, B., Pachauri, S., Rao, N. D., & Silveira, S. (2014). Assessing rural energy sustainability in developing countries. *Energy for Sustainable Development, 19*, 15-28. doi:10.1016/j.esd.2014.01.008

Megen_Power. (2008). *Impact Assessment of Mirt Impact Assessment of Mirt*. Retrieved from

Mekonnen, B. Y., & Hassen, A. A. (2019). Design, Construction and Testing of Hybrid Solar-Biomass Cook Stove. *274*, 225-238. doi:10.1007/978-3-030-15357-1_18

Mengistu, H. (2013). Gamo Society Vernacular House Typologies and Their Science, Southern Ethiopia. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS), 3*, 1-29.

Mobarak, A. M., Dwivedi, P., Bailis, R., Hildemann, L., & Miller, G. (2012). Low demand for nontraditional cookstove technologies. *Proc Natl Acad Sci U S A, 109*(27), 10815-10820. doi:10.1073/pnas.1115571109

MoEFCC. (2017). *Ethiopia Forest sector review*. Retrieved from Addis Ababa:

Mondal, M. A. H., Bryan, E., Ringler, C., Mekonnen, D., & Rosegrant, M. (2018). Ethiopian energy status and demand scenarios: Prospects to improve energy efficiency and mitigate GHG emissions. *Energy, 149*, 161-172. doi:10.1016/j.energy.2018.02.067

MoWE, E. (2022). *Ethiopian Energy outlook 2022*. Retrieved from Addis Ababa:

MWE. (2012). *Ethiopia Energy policy Draft*. Addis Ababa

Padam, G., Rysankova, D., Elisa Portale, Koo, B. B., Keller, S., & Fleurantin, G. (2018). *Energy Access Diagnostic Report Based on the Multi-Tier Framework Ethiopia*. Retrieved from

Pillarisetti, A., Allen, T., Ruiz-Mercado, I., Edwards, R., Chowdhury, Z., Garland, C., . . . Smith, K. R. (2017). Small, Smart, Fast, and Cheap: Microchip-Based Sensors to Estimate Air Pollution Exposures in Rural Households. *sensors, 17*, 1-18.

Puzzolo, E., Pope, D., Stanistreet, D., Rehfuess, E. A., & Bruce, N. G. (2016). Clean fuels for resource-poor settings: A systematic review of barriers and enablers to adoption and sustained use. *Environ Res, 146*, 218-234. doi:10.1016/j.envres.2016.01.002

Shell_Foundation. (2004). Controlled Cooking Test (CCT). In *CCT_Version_2.0* (pp. 1-8): Shell foudation

Shell_Foundation. (2007). The Water Boiling Test (WBT). In *WBT_VERSION_3.0*: Shell foundation.

Smith, K. R., Dutta, K., Chengappa, C., Gusain, P. P. S., Berrueta, O. M. a. V., Edwards, R., . . . Shields, K. N. (2007). Monitoring and evaluation of improved biomass cookstove programs for indoor air quality and stove performance: conclusions from the Household Energy and Health Project. *Energy for Sustainable Development 6*.

Soromessa, T., Teketay, D., & Demissew, S. (2004). Ecological study of the vegetation in Gamo Gofa zone, Southern Ethiopia. *researchgate, 45(2):209-221*, 14.

Tamire, M., Kumie, A., Addissie, A., Ayalew, M., Boman, J., Skovbjerg, S., . . . Lärstad, M. (2021). High Levels of Fine Particulate Matter (PM2.5) oncentrations from Burning Solid Fuels in Rural Households of Butajira, Ethiopia. *Environmental Research and Public Health, 2021*(18), 1-11. doi:10.3390/ijerph18136942

Tesfaya, A. H., Kahsay, M. B., & Nydala, O. J. (2014). Design and development of solar thermal Injera baking: steam based direct baking. *ScienceDirect, 57*(Energy Procedia 57 (2014) 2946 – 2955), 2946-2955.

Thakuri, M. B. M. (2009). Revisiting the Need of Improved Stoves: Estimating Health, Time and Carbon Benefits. *44*(09), 1-37.
UC_Berkeley. (2004). Kitchen Performance Test (KPT). In (pp. 31): University of California-Berkeley.
UN. (2015). *The 2030 Agenda for Sustainable Development*. (A/RES/70/1). UN Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf
UNEP. (2019). *SUSTAINABILITY OF BIOGAS AND SOLID BIOMASS VALUE CHAINS IN ETHIOPIA*. Retrieved from
UNFCCC. (2012). Report of the Conference of the Parties on its eighteenth session, held in Doha from 26 November to 8 December 2012. In *United Nations*.
Wassie, Y. T., & Adaramola, M. S. (2021). Analysis of potential fuel savings, economic and environmental effects of improved biomass cookstoves in rural Ethiopia. *Journal of Cleaner Production*, *280*, 124700. doi:10.1016/j.jclepro.2020.124700
WB. (2022). *RISE 2022 Report Building Resilience*. Retrieved from Washington, DC: https://rise.esmap.org/reports
WB, IEA, IRENA, UNSD, & WHO. (2022). *Tracking SDG7 the energy progress report*. Retrieved from Washington DC: https://trackingsdg7.esmap.org/downloads
Weinbaum, K. (2010). Standard Stove Performance Testing. *UC Berkeley, 1*, 1-2.
WHO. (2022, 28 November 2022). Household air pollution. *Key facts.* Retrieved from https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health
Yayeh, T., Guadie, A., & Gatew, S. (2021). Adoption and fuel use efficiency of mirt stove in Dilla district, southern Ethiopia. *Cleaner Engineering and Technology, 4*(https://doi.org/10.1016/j.clet.2021.100207), 1-9. doi:https://doi.org/10.1016/j.clet.2021.100207
Zheng, Y. H., Li, Z. F., Feng, S. F., Lucas, M., Wu, G. L., Li, Y., . . . Jiang, G. M. (2010). Biomass energy utilization in rural areas may contribute to alleviating energy crisis and global warming: A case study in a typical agro-village of Shandong, China. *Renewable and Sustainable Energy Reviews 14*(2010), 8. doi:10.1016/j.rser.2010.07.052

APPENDICES

Appendix A: **Household sample size table for a before and after study design (Edwards *et al.*, 2007)**

Difference in means	Coefficient of Variation												
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	110%	120%	130%
5%	31	126	283	502	785	1130	1538	2009	2543	3140	3799	4521	5306
10%	8	31	71	126	196	283	385	502	636	785	950	1130	1326
15%	3	14	31	56	87	126	171	223	283	349	422	502	590
20%	2	8	18	31	49	71	96	126	159	196	237	283	332
25%	1	5	11	20	31	45	62	80	102	126	152	181	212
30%	1	3	8	14	22	31	43	56	71	87	106	126	147
35%	1	3	6	10	16	23	31	41	52	64	78	92	108
40%	0	2	4	8	12	18	24	31	40	49	59	71	83
45%	0	2	3	6	10	14	19	25	31	39	47	56	66
50%	0	1	3	5	8	11	15	20	25	31	38	45	53
55%	0	1	2	4	6	9	13	17	21	26	31	37	44
60%	0	1	2	3	5	8	11	14	18	22	26	31	37
65%	0	1	2	3	5	7	9	12	15	19	22	27	31
70%	0	1	1	3	4	6	8	10	13	16	19	23	27
75%	0	1	1	2	3	5	7	9	11	14	17	20	24
80%	0	0	1	2	3	4	6	8	10	12	15	18	21
85%	0	0	1	2	3	4	5	7	9	11	13	16	18
90%	0	0	1	2	2	3	5	6	8	10	12	14	16
95%	0	0	1	1	2	3	4	6	7	9	11	13	15
100%	0	0	1	1	2	3	4	5	6	8	9	11	13

Appendix B1: Consent form

<u>የመረጃና የስምምነት ቅጽ</u>

ጤና ይስጥልኝ፣ ስሜ_____________________________________ይባላል። አሁን እዚህ የመጣሁት በአቶ ዳዊት ጥበቡ (በአ.አ ዩኒቨርሲቲ ቴክኖሎጂ ኢንስቲትዩት በታዳሽ ኃይል ማዕከል የማስትሬት ዲግሪ ተማሪ) ለሚካሄደው ጥናት መረጃ ለመሰብሰብ ነው። የጥናቱ ዓላማ የተሻሻሉ የምግብ ማብሰያ ምድጃዎችን በሚጠቀሙና በማይጠቀሙ መኖሪያ ቤቶቸ ላይ የሚታዩ የማገዶ አጠቃቀም እና የቤት ውስጥ ጭስ የመፍጠር አቅምን ላይ ያለውን ልዩነት ለማወቅነው። በዚህም መሰረት በባህላዊ ወይም በሦስት ጉልቻ የማገዶ አጠቃቀምን ለሦስት ተከታታይ ቀናት የአንድ ቀን የቤተሰብ ምግብ ከመብሰሉ በፊት እና በኋላ ልኬት የሚካሄድ ይሆናል፡፡ በተጨማሪም በሚሰጥዎት የምርጥ እና ትክክል ምድጃዎች እንዲሁ ለሦስት ቀናት ልኬት የሚከናወን ይሆናል፡፡ በመኖሪያ ቤት የሚፈጠርን በካይ ጥቃቅን ንጥረ-ነገሮችን ለመለካል በቤት ውስጥ ለሃያ አራት ሰዓት በPATS+ ልኬት በተጨማሪ ይሰበሰባል፡፡

በዚህ ጥናት ውስጥ በቀበሌው ከተመረጡ ቤተሰቦች መካከል እርስዎም በመሆንዎ እርሰውም እንዲሳተፉ ተጋብዘዋል ፡፡ ነገር ግን በዚህ ጥናት ላይ እንዲሳተፉ የምንጠይቅዎት ለመሳተፍ ፈቃደኛከሆኑ ብቻ ነው፡፡ መሳተፍ ያለመሳተፍ መብት አለዎት፡፡ ምክንያቱን ሳያቀርቡ ጥናቱን በማንኛውም ጊዜ ለመተው ይችላሉ። ለዚህ ምርምር የሚሰጡት መረጃ ሚስጥርነቱ የተጠበቀ ነው። ይህ መረጃ ወደ ኮምፒዩተር የመረጃ ቋት ሲተላለፍ የእርስዎን ስም ወይም አድራሻ ሳይካተቱ ይተላለፋሉ፡፡ ይህ የመረጃ ቋትበአጥኚው ብቻ ይተነትናል ፡፡ የዚህ ጥናት ውጤቶችን ለእርስዎ እና ለማህበረሰብዎ ፣ በሚዘጋጁ መድረኮች ላይ እናጋራለን። በተጨማሪም በአገር አቀፍ እና በዓለም አቀፍ ኮንፈረንስ እና በመጽሔቶች ላይ ግኝቱን እናቀርባለን፡፡ እርስዎ እንዲለዩ የሚያስችለውን ማንኛውንም መረጃ አናጋራም። ስለዚህ ጥናት ማንኛውም ጥያቄ ካለዎት የጥናት ባለቤት አቶ ዳዊት ጥበቡን በ (09---------) ያነጋግሩ።

ስለ ጥናቱ አስፈላጊው መረጃ በሚገባኝ ቋንቋ ተሰጥቶኛል እንዲሁም ጥቅማጥቅሞችን ሳይነካ በማንኛውም ጊዜ ፈቃዴን ማንሳት እንደምችል ተረድቻለሁ። በተጨማሪም ከላይ የተጠቀሱትን መረጃዎች በተገቢው በመረዳት በጥናቱ ለመሳተፍ ፈቃደኛ ነኝ ካሉ ፊርማዎትን ያስቀምጡ።

- ፊርማ /________________________/
- ፈቃደኛ አይደለሁም (ቃለመጠይቁን ያቋርጡ እና አመሰግነው ይሰናበቱ)

Appendix A2: consent form

Consent Form

Selam, my name is ____________________. We are working for Dawit Tibebu, (Addis Ababa University, Addis Ababa Institute of Technology) Master Thesis study. We are conducting research on acceptability assessments and performance measurement for cookstoves (Tikikil and Mirt). The goal is to determine how well various cookstoves perform in homes in terms of lowering fuel and wood use. Only half of the study's involved residences will have their emissions and CCT assessed. If you agree to participate in the study, a member of the research team will come to your home 15 to 30 minutes before you intend to start cooking to measure the amount of fuel used and perhaps the amount of smoke produced by your cookstove. Weighing your fuel inventory before and after you cook will allow us to determine the total amount of fuel consumed to accomplish the cooking event.

We will set up equipment to measure the air pollution just above the cookstove if emissions are measured during the event. Once cooking is finished, the setup will take about 30 minutes, remain in place for 24 hours, and then dismantle again in about 15 minutes. The equipment is secure and won't annoy you or interfere with your cooking. We may also quiz you on your cooking habits and take pictures of your hob, fuel sources and kitchen space.

You have the right to stop participating at any moment if you decide to do so. You or any member of your family cannot be identified in the reports that are generated from the study since all of the data we gather will be kept anonymous. You will receive Mirt and Tikikil free of charge for testing purposes and to encourage your involvement in this study. You can call us at the numbers below if you have any queries about the study at any time. If you're interested in participating or have any queries, please let me know today.

(Select one)

Accepted Declined

Participant Name ________________________ HH Code ___________

Participant Signature ____

Husband Signature if required ____

Date:___________________

Appendix B: Field work data collection and FGD with the households

Focus group discussion

Field Data Collection

Appendix B: BASELINE HOUSEHOLD SURVEY QUESTIONS

Field Testing of Improved Biomass Cookstoves (*Tikikil* and *Mirt*) in Rural Households of Southern Ethiopia: The Case of Gamo Zone

Tools for Baseline Data Collection

General information

Household ID: /______________________________________/

GPS Co-ordinates:/___________________________________/

Kebele : /__________________________________/

Sub Kebele (Got):/____________________________________/

Name interviewer:/____________________________________/

Date of interview: /___________________________________/

Season of the year: /___________________________________/

- Rainy (it has rained in the last two weeks) :/________/
- Dry (it has not rained in the last two weeks) :/_______
- Interview Start time /________/End time /__________/

አጠቃላይ መረጃ

የቢቱ መለያ ቁጥር: /__________________________________/

የጂፒኤስ መገጣጠሚያ:/___/ የቀበሊዉ ስም: /_

_________________/ የለዩ ቦታዉ/ጎጥ ስም: /_____________________/

የጠያቂዉ ስም : /____________________________________/

የተጥየቀበት ቀን: /_____________________________________/

የተጥየቀበት ወቅት: /____

- ዝናባማ (ባልፉት ሁለት ሳምንት ዉስጥ ዘንቦ ነበር): /_______________/
- ደረቃማ (ባልፉት ሁለት ሳምንት ዉስጥ አልዘነበም: /_______________/
- ቃለመጠይቁ የጀመረበት ሰዓት/____________/ያለቀበት ሰዓት/________/

Part-I : Socio Demographic and Economic Status Respondents				ክፍል-I : የተሣታፊው ማህበራዊና ኢኮኖሚያዊ ሁኔታ			
No	**Questions**	**Responses**		**ተ.ቁ**	**ጥያቄዎች**	**የተሰጡ መልሶች**	
101	Age in complete years	/________________/ Years		101	የሴትዮዋ ዕድሜ በተጠናቀቀ ዓመት	/__________________/ ዓመት	
102	Marital status of the woman	1. Married 2. Single 3. Widowed	4. Divorced 5. Separated 6. Cohabited	102	የሴትዮዋ የትዳር ሁኔታ	1. ያገባች 2. ያላገባች 3. የሞተባት	4. የተፋታች 5. ተለያይተው የሚኖሩ 6. ደባልነት
103	Religion of the woman	1. Orthodox 2. Muslim	3. Protestant 99. Other/___/	103	የሴትዮዋ ሃይማኖት	1. ኦርቶዶክስ 2. ሙስሊም	3. ፕሮቴስታንት 99. ሌላ /___________/
104	Educational status of the woman	1. Unable to read and write 2. Read and write only 3. /______/ th Grade completed		104	የሴትዮዋ የትምህርት ሁኔታ	1. ማንበብ እና መጻፍ የማትችል 2. ማንበብ እና መጻፍ ብቻ 3. /______/ ኛ ክፍል ያጠናቀቀች	
105	Educational status of the husband	1. Unable to read and write 2. Read and write only 3. /_____/th Grade completed		105	የባል የትምህርት ሁኔታ	1. ማንበብ እና መጻፍ የማይችል 2. ማንበብ እና መጻፍ ብቻ 3. /____/ ኛ ክፍል ያጠናቀቀ	
106	What best describes woman employment status?	1. Housewife 2. Farmer	3. Business 99. Other/___/	106	የሴትዮዋን የሥራ ሁኔታ በተሻለ የሚገልፀው የቱ ነው?	1. የቤት እመቤት 2. አርሶ አደር	3. ንግድ 99. ሌላ /___________/
107	Individuals permanently living in the household	Male /_____/ Female/____/	U_5 /________/ Total /______/	107	በቋሚነት የሚኖሩ አጠቃላይ የቤተሰብ ብዛት	ወንድ /_______/ ሴት /_______/	ከ5 በታች /___________/ ጠቅላላ /___________/
108	Monthly/yearly income of the family-- *(in cash or in kind) write all mentioned*	In cash: /_______________/ birr In kind: /____________________ ______________________________/		108	የቤተሰቡ ወርሃዊ/ ዓመታዊ ገቢ (በጥሬ ገንዘብ ወይም በአይነት) የተጠቀሱትን ሁሉ ይጻፉ	በጥሬ ገንዘብ: /____________________/ብር በአይነት: /______________________________ ______________________________/	
109	Are you a member of any women groups?	1. Yes /____________/	2. No	109	እርስዎ አባል የሆኑበት የሴቶች ቡድን/ማህበር አለ?	1. አዎ /______________/	2. የለም
110	Do you have or own any of the following?	Bicycle 1. Yes 2. No Radio 1. Yes 2. No Mobile 1. Yes 2. No Watch 1. Yes 2. No		110	ከሚከተሉት ውስጥ አለዎት ወይም ባለቤት ነዎት?	ብስክሌት 1. አዎ 2. የለም ሬዲዮ 1. አዎ 2. የለም ሞባይል 1. አዎ 2. የለም	

		Solar 1. Yes 2. No Modern Bed 1. Yes 2. No Cows 1. Yes 2. No Oxen 1. Yes 2. No Hens 1. Yes 2. No Horses 1. Yes 2. No Honey bees 1. Yes 2. No Chairs 1. Yes 2. No Goat/sheep 1. Yes 2. No Cart 1. Yes 2. No Farm land 1. yes 2. No Bank account 1. Yes 2. No				ሰዓት 1. አዎ 2. የለም ሶላር 1. አዎ 2. የለም ሞዝቦልድ አልጋ 1. አዎ 2. የለም የወተት ላሞች 1. አዎ 2. የለም በሬዎች 1. አዎ 2. የለም ዶሮዎች 1. አዎ 2. የለም ፈረሶች 1. አዎ 2. የለም የማር ንብ 1. አዎ 2. የለም ወንበሮች 1. አዎ 2 የለም ፍየል/በግ 1. አዎ 2. የለም ጋሪ 1. አዎ 2. የለም የእርሻ መሬት 1. አዎ 2. የለም የባንክ ደብተር 1. አዎ 2. የለም	
Part-II: Housing Condition				**ክፍል-II: የመኖሪያ ቤቱ ሁኔታ**			
111	How many years since this house is constructed?	/_______________/ years		111	ይህ ቤት ከተሰራ ስንት ዓመት ሆነው?	/_______________/ ዓመት	
112	Was there any maintenance for the house so far?	1. Yes	2. No	112	ይህ ቤት እድሳት ተደርጎለት ያዉቃል?	1. አዎ	2. አልተደረገለትም
113	House floor material	1. Earthen/Mud 2. Plastic cover	3. Cement 99. Others	113	የቤቱ **ወለል** የተሠራበት ቁሳቁስ	1. አፈር/ጭቃ 2. የፐላስቲክ	3. ሲሚንቶ 99. ሌላ /____________/
114	Wall material of the house	1. Wood/bamboo 2. Wood/Mud	3. Blocks 99. Others	114	የቤቱ **ግድግዳ** የተሠራበት ቁሳቁስ	1. እንጨት / የቀርከሃ 2. እንጨት/ጭቃ	3. ጡቦች / ድንጋዮች 99. ሌላ /___________/
115	Roof material of the house	1. Thatch roof 2. CIS/ metal sheet 99. Others /_________________/		115	የቤቱ **የጣሪያ** የተሠራበት ቁሳቁስ	1. የ ሣር ጣሪያ 2. የቆርቆሮ ጣሪያ 99. ሌሎች /________________________/	
116	If CIS, the number of CIS	/____________________/ CIS		116	ከቆርቆሮ ከተሰራ የዚንጎ ብዛት	/________________________________/ዚንጎ	

117	The number of rooms in the home	1. One room 2. Two rooms	1. ≥ 3 rooms	117	በቤት ውስጥ ያሉት ክፍሎች ብዛት	1. አንድ ክፍል 2. ሁለት ክፍሎች	3. ከሶስት ክፍሎች በላይ
118	How many windows are there in the house?	Able to open /_______________/ Unable to pen /______________/		118	በቤት ውስጥ ስንት መስኮቶች አሉ?	መከፈት የሚችሉ /________________________/ መከፈት የማይችሉ /________________________/	
119	Are there any openings between wall and roof?	1. Yes	2. No	119	በቤቱ በግድግዳ እና ጣሪያ መካከል ክፍተት አለ?	1. አዎ	2. የለም
Part- III: Kitchen and Stove Conditions				**ክፍል-III: የኩሽና ቤቱ እና የማብሰያ ምድጃዉ ሁኔታ**			
120	Location of kitchen	1. Separated from the main house 2. Room attached to main house 3. In the main living area in house 99. Other /___________________/		120	የኩሽና ቤቱ የሚገኝበት ቦታ	1. ከዋናው ቤት የተለየ ሌላ ቤት 2. ከዋናው ቤት ተያይዞ የተለየ ክፍል 3. ከዋናው የመኖሪያ ቤት ውስጥ 99. ሌላ /________________________/	
121	What best explain the kitchen structure?	1. Four walled structure 2. Three walled structure 3. Two walled structure 4. No walls, but a covered roof 5. In the open 'courtyard'		121	የኩሽና ቤቱ መዋቅር ምን ይመስላል?	1. አራት ግድግዳ ያለው ባለጣሪያ 2. ሶስት የግድግዳ ያለው ባለጣሪያ 3. ሁለት የግድግዳ ያለው ባለጣሪያ 4. ግድግዳ የሌለዉ፣ ጣሪያ ብቻ 5. ግቢው ውስጥ ክፍት ቦታ	
122	Size of the kitchen area	Area /_____/m^2		122	የኩሽና ቤቱ ስፋት	ስፋት/__________/ሜ^2	
123	Kitchen door open to…	1. Outside of the house 2. Inside of the house 3. Both inside and outside		123	የኩሽና ቤቱ በር የሚከፈተዉ	1. ወደ ዉጭ ነዉ 2. ወደ ዉስጥ ነዉ 3. ወደ ሁለቱም አቅጣጫ ነዉ	
124	Are there any openings between wall and roof?	1. Yes	2. No	124	በኩሽና ቤቱ ግድግዳ እና ጣሪያ መካከል ክፍተት አለ?	1. አዎ	2. የለም
125	Is the cooking done in the same place all year round?	1. Yes	2. No	125	ምግብ ማብሰሉ ዓመቱን በሙሉ በተመሳሳይ ቦታ ይከናወናል?	1. አዎ	2. አይደለም

126	Where did most of the cooking practice would be done during the dry season?	1. Separate kitchen from house 2. Separate kitchen with a roof 3. Outside in the open fire 4. Inside in a separate room 5. Inside in a living room 99. Other /______________/	126	በደረቃማ ወቅት (በጋ) አብዛኛው ምግብ የማብሰል ተግባር የት ይከናወናል?	1. ከቤት ውጭ ግድግዳ እና ጣሪያ ያለው 2. ከቤት ውጭ ጣሪያ ብቻ ያለዉ 3. ከቤት ውጭ ባዶ ቦታ ላይ 4. ቤት ዉስጥ በተለየ ክፍል 5. ቤት ሳሎን ውስጥ 99. ሌላ (ይፃፉ) /________________________/
127	Where did most of the cooking practice would be done during the rainyseason?	1. Separate kitchen from house 2. Separate kitchen with a roof 3. Outside in the open air 4. Inside in a separate room 5. Inside in a living room 99. Other /_________________/	127	በዝናባማ ወቅት (ክረምት) አብዛኛው የማብሰያ ተግባር የት ይከናወናል?	1. ከቤት ውጭ ግድግዳ እና ጣሪያ ያለው 2. ከቤት ውጭ ጣሪያ ብቻ ያለዉ 3. ከቤት ውጭ ባዶ ቦታ ላይ 4. ቤት ዉስጥ በተለየ ክፍል 5. ቤት ዉስጥ ሳሎን ውስጥ 99. ሌላ (ይፃፉ) /________________________/
128	Which types of stove do you use most frequently to cook your meals (*observe*)	1. Three stone or traditional stove 2. Other local modified stove 99. Other /_________________/	128	ምግብዎን ለማብሰል በብዛት የሚጠቀሙት ምን ኣይነት ምድጃ ነዉ?	1. ባልሶስት ጉልቻ ባህላዊ ምድጃ 2. ሌላ በአካባቢዉ የተሻሻለ ምድጃ 99. ሌላ /______________________/
129	How many stoves are actively in use in your home? *(observe all types)*	1. One only 2. Two only 3. Three and more	129	በቤትዎ ውስጥ ስንት ምድጃዎችጥቅም ላይ ናቸው? (ያረጋግጡ)	1. አንድ ብቻ 2. ሁለት ብቻ 3. ሶስትና ከዚያ በላይ
130	Does the current kitchen has a chimney? (observe)	1. Yes 2. No	130	አሁን የሚጠቀሙበት ኩሽና ቤት የጭስ ማውጫ አለው? (ይረጋገጥ)	1. አዎ 2. የለዉም
131	Is there black soot deposit in the ceiling/walls visibly? (*check*)	1. Yes 2. No	131	ጣሪያዉ ወይም ግድግዳዉ ላይ በግልጽ የሚታይ ጥቁር ጥላሸት አለ? *(ይረጋገጥ)*	1. አዎ 2. የለም
132	What do you like about this primary stove?	1. Uses little firewood 2. Cooks food quickly 3. Emits little smoke 4. Easy to light; wind not affect 5. Safe to use while cooking	132	በብዛት የሚጠቀሙበትን ምድጃምኑን ወደዱለት?	1. አነስተኛ የማገዶ ይጠቀማል 2. ምግብ በፍጥነት ያበስላል 3. የጭስ መጠን ይቀንሳል 4. ለማቀጣጠል ቀላል ነው በነፋስ ኣይጠፋም

						5. አደጋ የለዉም 99. ሌላ/______________________________/	
133	What do you NOT like about this primary stove?	1. Uses lots of firewood 2. Takes a long time to cook 3. Emits lots of smoke 4. Difficult to light 5. Not safe while cooking 99. Other /____________/		133	በብዛት ስለሚጠቀሙበት ምድጃ የማይወዱ ምንድን ነው ?	1. ብዙ የማገዶ እንጨት ይጠቀማል 2. ለማብሰል ረጅም ጊዜ ይወስዳል 3. ብዙ ጭስ ያስወጣል 4. ለማቀጣጠል ከባድ ነው 5. አደጋ ያስከትላል 99. ሌላ (ይፃፉ) /________________________/	
134	Have you ever heard of the improved biomass fuel stove?	1. Yes	2. No	134	ስለ የተሻሻሉ ምድጃዎች ሰምተዉ ያውቃሉ?	1. አዎ	2. ሰምቸ አላውቅም
135	If yes, why haven't you acquired an improved stove?	1. No interest 2. No money 3. Don't know where to find 99. Other /__________________/		135	አዎ ከሆነ - ለምን የተሻሻሉ ምድጃዎችን አይጠቀሙም?	1. ፍላጎት የለኝም 2. ገንዘብ የለኝም 3. የት እንደሚገኝ አላውቅም 99. ሌላ /_____________________________/	
136	Have you ever owned a different new type of stove in the past?	1. Yes	2. No	136	ከዚህ በፊት የተለየ አዲስ ዓይነት ምድጃ ነበራችሁ?	1. አዎ	2. አልነበረኝም
137	Are you planning to buy an improved stove in the future?	1. Yes	2. No	137	ለወደፊቱ የተሻሻለ ምድጃ ለመግዛት አቅደዋል?	1. አዎ	2. አላቀድኩትም
138	If your household wanted to buy a new improved stove, who would make the decision?	1. Myself 2. My husband	3. Me & My husband 99. Other/___/	138	ቤተሰቦዎ አዲስ የተሻሻለ ምድጃ መግዛት ቢፈልግ ውሳኔውን የሚወስነው ማን ነው?	1. እራሴ 2. ባለቤቴ	3. እኔ እና ባለቤቴ 99. ሌላ /____________/
Part-IV: Type of Fuel Use and smoke Exposure				**ክፍል-IV: የማገዶ ዓይነት እና የጭስ ተጋላጭነት**			
139	What type of fuel does your household mainly used for cooking? (*Write in order*)	1. Primary /______________/ 2. Secondary /______________/ 3. Tertiary /______________/		139	ቤተሰቦችዎ በዋናነት ለማብሰያ የሚጠቀሙበት ማገዶ በቅደም ተከተል	የመጀመሪያ /________________________/ ሁለተኛ /__________________________/ ሶስተኛ ደረጃ/________________________/	

140	Have you use more than one fuel per cooking?	1. Yes	2. No	140	በአንድ ማብሰያ ከአንድ በላይ የማገዶ ዓይነት ይጠቀማሉ?	1. አዎ	2. አልጠቀምም
141	If yes, different fuel combinations during **dry** season	/____________________________ ____________________________ ___________________________/		141	በበጋ ወቅት የተለያዩ የማገዶ ጥምረቶችን ይጻፉ	____________________________________ ____________________________________ _________________________________/	
142	Different fuel combination during **raining** season	/____________________________ ___________________________ /		142	በክረምት ወቅት የተለያዩ የማገዶ ጥምረቶችን ይጻፉ	____________________________________ ____________________________________ /	
143	Who is collecting the fuel most of the time?	1. Boys 2. Girls	3. Women 4. Men	143	አብዛኛዉን ጊዜ ማገዶ የሚሰበስበዉ ማነው?	1. ወንድ ልጆች 2. ሴት ልጆች	3. እናቶች 4. አባቶች
144	Do you dry the firewood prior to using it?	1. Yes	2. No	144	የማገዶ እንጨቱን ከመጠቀምዎ በፊት ያደርቁታል?	1. አዎ	2. አላደርቀዉም
145	Is another fuel used to light the stove?	1. Yes (specify) /____________/ 2. No		145	ምድጃውን ለማቀጣጠል ሌላነዳጅ ጥቅም ላይ ይውላል?	1. አዎ (ይግለጹ) /__________________/ 2. አልጠቀምም	
146	How many times a day do you light the stove for cooking?	1. Once 2. Twice	3. Three times 4. ≥ 4 times	146	በአንድ ቀን ውስጥ ምግብ ለማብሰል ምን ያህል ጊዜ እሳት ያቀጣጥላሉ?	1. አንዴ 2. ሁለት ጊዜ	3. ሶስት ጊዜ 4. ከ 4 ጊዜ በላይ
147	How many meals do you cook each day?	1. One meal 2. Two meals	3. ≥ 3 meals	147	በቀን ስንት ምግብ ያዘጋጃሉ?	1. አንድ ምግብ 2. ሁለት ምግብ	3. ≥3 ምግቦች
148	What is the average time spent per day in cooking?	/_____________________/ hours		148	ምግብ ለማብሰል በየቀኑ አማካይ ስንት ሰዓታት ያጠፋሉ?	/________________________/ ሰዓታት	
149	How often times you bake **Injera** in a week?	1. Once 2. Twice	3. ≥ 3 times	149	በሳምንት ውስጥ ስንት ጊዜ እንጀራ ይጋገራሉ?	1. አንዴ 2. ሁለት ጊዜ	3. ≥ 3 ጊዜ
150	Do you keep the windows or doors open when you cook?	1. Always 2. Most of the times	3. Sometimes 4. No at all	150	ምግብ በሚበስሉበት ጊዜ መስኮቶቹን ወይም በሮቹን ክፍት ያደርጋሉ?	1. ሁል ጊዜ 2. ብዙ ጊዜ	3. አልፎ አልፎ 4. በፍፁም

151	What did you do to reduce exposure from smoke?	1. Increased Ventilation 2. Adopt cleaner stove 3. Dry fuel before using 4. Adopt cleaner fuel 5. Cooking Outside 6. Nothing 99. Other /__________________/	151	ከጭስ ተጋላጭነትን ለመከላከል/ ለመቀነስ ምን ያደርጋሉ?	1. የአየር ማናፈሻ እገጥማለሁ 2. የተሻሻለ ምድጃ እጠቅማለሁ 3. ማገዶዉን አደርቃለሁ 4. ጭሳማ ያልሆኑ ማገዶዎችን እጠቀማለሁ 5. መግብ ከቤት ውጭ አበሰላለሁ 6. ምንም አላደርግም 99. ሊላ /__________________________/
152	Are children usually present in the kitchen during cooking?	1. Yes 2. No	152	ምግብ በሚበስልበት ጊዜ ልጆች አብዛኛውን ጊዜ በኩሽና ውስጥ ይገኛል?	1. አዎ 2. አይገኙም
153	Is there a habit of carrying a child while cooking?	1. Always 2. Sometimes 3. Never	153	ምግብ በሚበስልበት ጊዜ ልጅን የማዘል ልምድ አለ?	1. ሁል ጊዜ 2. አንዳንድ ጊዜ 3. በጭራሽ
154	When you are cooking,where are your children whoare still too young to walk?	1. On my back 2. Near me in the kitchen 3. In the same building 4. In a separate building 5. Coming in and out in kitchen 6. Playing in the open courtyard 7. Not Applicable	154	ምግብ በሚያበስሉበት ጊዜ ገና ለመራመድ ያልበቁ ልጆችዎ የት ይቆያሉ?	1. ጀርባዬ ላይ 2. በኩሽና ውስጥ በአጠገቤ 3. በተመሳሳይ ቤት ውስጥ 4. በተለየ ቤት ውስጥ 5. ወደ በኩሽና መግባትና መውጣት 6. ግቢ ውስጥ መጫወት 7. ተፈጻሚ አይሆንም
155	Where are the children under 5 who can walk?	1. On my back 2. Near me in the kitchen 3. In the same building, 4. In a separate building 5. Coming in and out in kitchen 6. Playing in the open courtyard 7. Not Applicable	155	ዕድሜያቸው ከ 5 ዓመት በታች የሆኑና መራመድ የሚችሉ ልጆችየት ሊቆዩ ይችላሉ?	1. ጀርባዬ ላይ 2. በኩሽና ውስጥ በአጠገቤ 3. በተመሳሳይ ቤት ውስጥ 4. በተለየ ቤት ውስጥ 5. ወደ በኩሽና መግባትና መውጣት 6. ግቢ ውስጥ መጫወት 7. ተፈጻሚ አይሆንም

156	Apart from cooking, are you exposed to any other sources of smoke *(check all that apply)*	1. Burning rubbish 2. Making local beer 3. making bricks 4. Making charcoals 5. Kerosene lamps 6. Not exposed 99. Others /________________/	156	ከማብሰያ ውጭ ለሌሎች የጭስ ምንጮች ይጋለጣሉ? *(የሚመለከታቸውን ሁሉ ምልክት ያድርጉ)*	1. የሚቃጠል ቆሻሻ 2. መጠጥ ማዘጋጀት(አረቄ፣ጠላ ወዘተ) 3. ሸክላ ማምረት 4. ከሰል ማምረት 5. የኩራዝ መብራቶች 6. አልተጋለጥኩም 99. ሌላ (ይግለጹ) /______________________/
157	What space heating system does this household mainly use to heat the home when needed?	1. Burning wood 2. Burning other fuel 3. Nothing	157	ይህ ቤተሰብ አስፈላጊ በሚሆንበት ጊዜ ቤቱን ለማሞቅምን ይጠቅማል?	1. እንጨት ማንደድ 2. ሌላ ማገዶ ማቃጠል 3. ምንም አይደረግም
158	At night, what does this household use for lighting?	1. Solar light 2. Kerosene lamps 3. Burning wood 99. Other/_________________/	158	ይህ ቤተሰብ ማታ ለመብራትነት ምን ይጠቀማል?	1. የፀሐይ ብርሃንን በማጠራቀም 2. ኩራዝ ማብራት 3. እንጨት በማንደድ 99. ሌላ /____________________________/

Part V Perception on Benefits of improved stoves							**ስለተሻሻለ ምድጃ ጥቅሞች ያላቸው ግንዛቤ**						
159	Improved stoves can lead to health benefits for the family						159	የተሻሻሉ የማብሰያ ምድጃን መተቀም የጤና ጥቅሞች አሉት					
160	Improved stoves take too short time to cook food than the traditional stoves						160	የተሻሻሉ ምድጃዎችን ስንጠቀም ባጭር ጊዜ ዉስጥ ብዙ ምግቦችን ምስራት እንችላለን					
161	Improved stoves take too few fuel to cook food than traditional stoves						161	የተሻሻሉ ምድጃዎች ከባህላዊ ምድጃዎች ያነሰ ማገዶ ይፈልጋሉ					
162	improved stoves reduce burn injuries to children than the traditional stoves						162	የተሻሻሉ ምድጃዎች በልጆች ላይ የሚደርሰዉን የእሳት አደጋ ይቀንሳሉ					
163	I'm readily welcome any technology of improved stove which reduces smoke emission for use in my house						163	ጭስ ልቀትን የሚቀንስ ማንኛውንም የተሻሻለ ምድጃ ለመጠቀም ዝግጁ ነኝ					

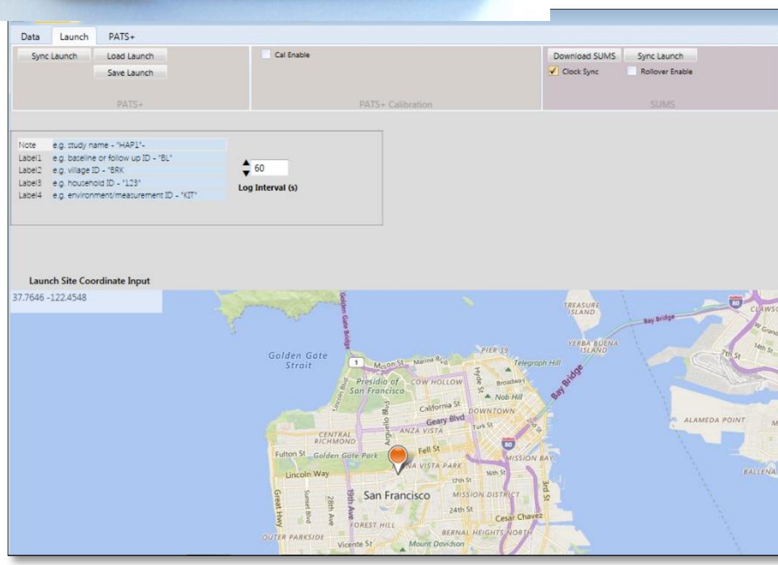
164	Most people think that cooking with improved stove is good for their family						164	ብዙ ሰዎች በተሻሻለ ምድጃ ማብሰል ለቤተሰባቸው ጥሩ ነው ብለው ያስባሉ					
165	Most people think that cooking with improved stove is a sign of higher social status						165	ብዙ ሰዎች በተሻሻለ ምድጃ ማብሰል የቅንጦት ምልክት ነው ብለው ያስባሉ					
166	Food cooked with improved stoves tasted the same or better than food cooked with a traditional stove						166	በተሻሻሉ ምድጃዎች የበሰለምግብ በባህላዊ ምድጃ ከበስለው ምግብ ተመሳሳይ ወይም የተሻለ ጣዕም አለው					

Appendix C1: PATS+ Instrument usage data (HH Code, GPS Reading, Date, Time)

Type of stove use:_________________

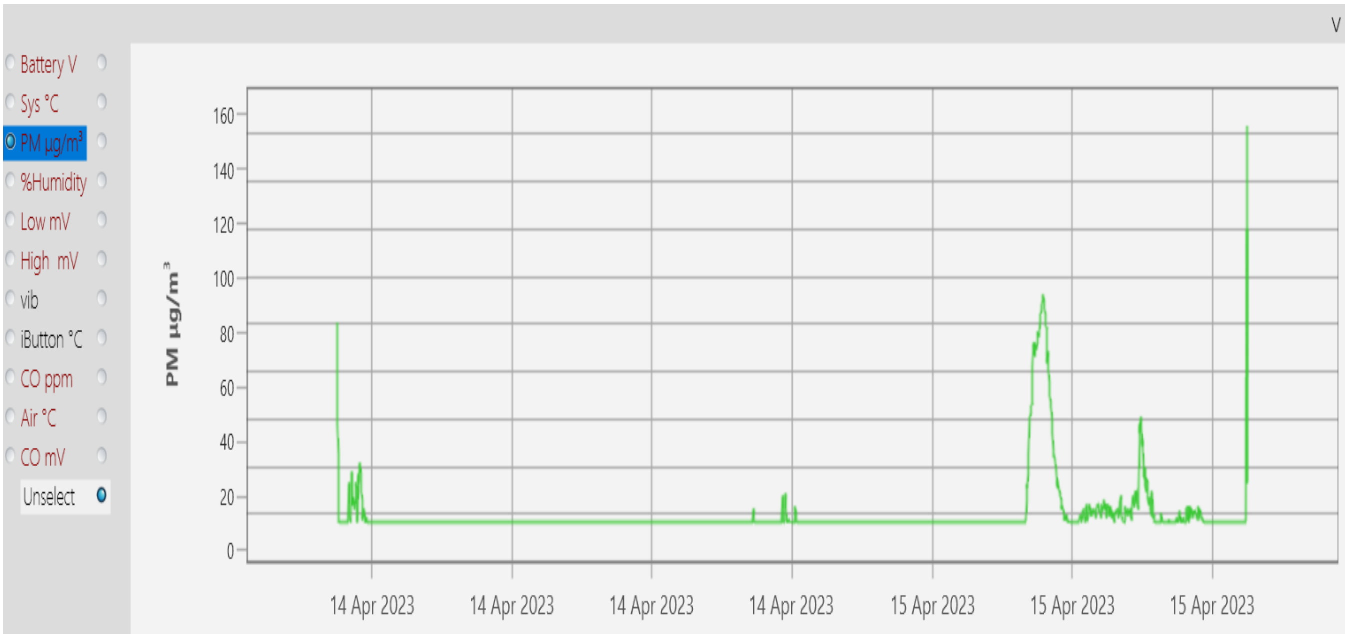
HH Code	GPS Reading	Serial No	Initial Date	Start Time	Ending Date	Ending Time	Charging state (no. of HH in use)	Remark
		#						

Appendix C2: PATS+ integrated instrument and software

Name	Description	Item
PATS+	Particle and temperature sensor plus	
PICA (Platform for integrated cookstove assessment)	For programming the PATS+; downloading, viewing, and processing data; generating statistical reports; creating graphs; and merging PATS+ and SUMs data.	
Zero box	For clean air zero calibrations of PATS+s	
Hand pump	For clean air zero calibrations of PATS+s	

Micro USB to USB Data cable	For charging and data transfer	

Appendix C3: 24-hour PM2.5 and temperature reading in sample household



Appendix C4: SAMPLE HOUSEHOLD $PM_{2.5}$ ICS MEASURMENT

	N	Minimum	Median	Maximum	Mean	
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
PM_ICS1	1444	11.007	20.0	17900.739	641.83430	58.617188
PM_ICS2	1444	11.007	22.0	18900.739	694.72626	64.505409
PM_ICS3	1444	11.114	25.0	32195.023	835.92854	91.826439
PM_ICS4	1444	11.042	23.5	23528.593	253.66013	31.231112
PM_ICS5	1444	11.102	18.3	31939.493	1204.05936	98.425247
PM_ICS6	1444	11.042	47.0	27917.135	381.44416	52.956946
PM_ICS7	1444	11.114	22.0	33537.204	891.53646	102.325300
PM_ICS8	1444	11.114	17.0	20971.447	743.52054	75.900077
PM_ICS9	1444	11.874	26.0	31025.367	661.90863	69.164256
PM_ICS10	1444	11.007	35.0	17420.909	635.55239	53.102795
PM_ICS11	1444	11.114	16.0	29806.771	736.11957	77.537247
PM_ICS12	1444	11.114	52.0	25971.447	799.54893	82.851790
PM_ICS13	1444	11.114	29.0	31661.836	806.50738	84.112167
PM_ICS14	1444	10.039	18.3	22574.467	1075.37723	79.550348
PM_ICS15	1444	11.000	11.0	39195.023	845.72760	96.193540
PM_ICS16	1444	10.000	10.0	12900.739	578.41948	49.076464
PM_ICS17	1444	11.007	25.0	23147.028	777.69025	80.629550
PM_ICS18	1444	11.114	33.0	29537.204	794.35710	82.744361

Appendix C5: SAMPLE HOUSEHOLD $PM_{2.5}$ CHOCHE MEASURMENT

	N	Minimum	Median	Maximum	Mean	
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
PM_CHO1	1444	16.258	92.08	31939.493	1138.38684	95.554382
PM_CHO2	1444	10.000	26.57	38998.014	1813.83159	136.409468
PM_CHO3	1444	10.000	10.00	31337.491	627.77314	62.898393
PM_CHO4	1444	10.000	10.00	38972.138	761.65874	93.965291
PM_CHO5	1444	11.338	31.00	40619.908	567.17597	101.597207
PM_CHO6	1444	30.043	31.00	39619.908	634.89065	109.503626
PM_CHO7	1444	10.000	10.00	39195.023	833.68051	96.101817
PM_CHO8	1444	10.000	26.57	43425.353	1604.10306	116.628622
PM_CHO9	1444	10.000	10.84	41939.493	975.33913	76.132971
PM_CHO10	1444	10.000	10.00	46683.832	1685.04694	141.288253
PM_CHO11	1444	12.000	47.48	34939.493	1244.83637	99.859972
PM_CHO12	1444	14.139	45.83	26574.467	1146.05798	83.854625
PM_CHO13	1444	15.291	57.00	33815.509	802.23769	89.451573
PM_CHO14	1444	11.102	17.44	33923.062	1102.89800	89.603388
PM_CHO15	1444	11.134	14.00	36777.193	1277.63187	129.163225
PM_CHO16	1444	20.157	34.00	39990.278	1994.30777	188.334925
PM_CHO17	1444	14.139	59.50	31939.493	1343.58776	111.249812
PM_CHO18	1444	12.040	30.00	39859.384	833.55362	94.565326
PM_CHO19	1444	15.291	52.00	42888.719	1034.32495	128.449742
PM_CHO20	1444	11.338	10.00	39619.908	619.74246	97.065102

Appendix D1: household cooking event observation

User Cooking Event Observation

Tester instructions: Begin this stage as soon as the cook starts preparing the dish and keep going until it is finished. Enter timings in a format of 24 hours [hr:min]. Fill in any blanks with additional notes as needed.
A metric scale and a stopwatch or clock are necessary tools.

3.1	Fuel preparation	Start time: ____ : ____ Completion time: ____ : ____ (Includes clearing brush, picking up twigs, etc.; does not include constructing and lighting the fire.) Specialized skills or equipment needed for fuel preparation: Y / N
3.2	Lighting time required	Start time: ____ : ____ Completion time: ____ : ____ (When the cook starts adding fuel to the burner, it begins. When the stove is lighted and keeps burning without constant monitoring, the task is complete.)

3.2 Lighting notes *[describe lighting process, difficulties, and fire starting materials used]*:

3.3	Fuel consumption	Initial mass: _____ (kg) Final mass: _____ (kg)
3.4	Cooking time	Start time: ____ : ____ Completion time: ____ : ____ (Begins when food, water, etc. is heated on the fire for the first time. finished when the final dish is taken out of the heat.)
3.5	Tending and refueling frequency *[Note the minute and hour of each tending occurrence. Draw a circle around each time fuel was replenished, including the time the fire was started.]*	1. ____ : ____ 8. ____ : ____ 15. ____ : ____ 22. ____ : ____ 2. ____ : ____ 9. ____ : ____ 16. ____ : ____ 23. ____ : ____ 3. ____ : ____ 10. ____ : ____ 17. ____ : ____ 24. ____ : ____ 4. ____ : ____ 11. ____ : ____ 18. ____ : ____ 25. ____ : ____ 5. ____ : ____ 12. ____ : ____ 19. ____ : ____ 26. ____ : ____ 6. ____ : ____ 13. ____ : ____ 20. ____ : ____ 27. ____ : ____ 7. ____ : ____ 14. ____ : ____ 21. ____ : ____ 28. ____ : ____
3.6	User error *[Make a tally mark for each occurrence]*	Fire went out: ________ Cook removed functional part(s) of stove: ________ Cook fed too much fuel: ________ Incorrect refueling practices: ________ Incorrect ash cleanout: ________ Other: ___________________________ : ________
3.7	Visibility of fire *[Circle the most appropriate option, 0-3]*	**(3)** Best: Highly visible (combustion zone can be seen from a distance from anywhere within the cooking area) **(2)** Good: Moderately visible (combustion zone can be seen from a distance, but from a limited angle or direction, only) **(1)** Fair: Minimally visible (cook must bend down within reach of the stove to see combustion zone) **(0)** Poor: Combustion zone is never visible while stove is in operation
3.8	Soot deposited on pot *[Circle the most appropriate option, 0-3]*	**(3)** Best: No soot on pot after cooking **(2)** Good: Soot covers bottom of pot, only, after cooking

		(1) Fair: Soot covers bottom and less than 1/2 of sides of pot after cooking **(0)** Poor: Soot covers bottom and more than 1/2 of sides of pot after cooking
3.9	Other people present during testing	
3.10	Other stove model(s) present in household	
General notes:		

Appendix D2: Household stove use questions

Stove use

C1	Currently, how many different kinds of stoves do you use at least once a week? [Note that this is the quantity of stoves, not the kind of stoves. That is, mark 2 should be used if a family has two stoves of the same sort.				
C2	Please list all the stoves that you use at least once per week. *[Use stove codes. MA allowed. Ensure they list the same amount as the number given for C1. Describe here if other]*	1st stove type	2nd stove type	3rd stove type	4th stove type
Primary cooking device					
C3	What would **you say** is the stove type you **currently** use **most of the time**? [SA]	*[Single answer. Use stove codes. Describe here if other]*			
C4	What fuel do you usually use on that stove at this time of year?	*[Use fuel codes]*			
C5	On average, how many days per week do you use this stove?	*[Enter number of days per WEEK]*			
C6	On the days it is used, how many meals per day do you use this stove?	*[Enter number of meals per day]*			
C7	What do you like **the most** about this cookstove, if anything?	*[Record one answer. DO NOT PROMPT. Use code sheet]*			
C8	What else do you like about the cook stove you value apart from what you have mentioned?	*[MA. DO NOT PROMPT. Use code sheet]* *[If they do not like more than the one thing entered in C7, enter 66]*			
C9	If any, what is the **biggest challenge** you experience with this cookstove?	*[Record one answer. DO NOT PROMPT. Use code sheet]*			
C10	Are there any other challenges with this cookstove?	*[MA. DO NOT PROMPT. Use code sheet. If they do not have more than the one challenge entered in C9, enter 66]*			
C11	How long ago did you purchase, receive or build this stove?	*[Record in months. If stove is the three stone fire, enter 99]]*			

C12	Did you purchase, receive or self-build this cookstove?	Purchased	1
		Self-built	2
		Received as gift from family	3
		Received as donation from non-family i.e. NGO	4
		Other [*describe*]	99
C13	How much did this stove cost to buy or build?	*[If it was a gift enter 0 and go to the next question If the stove is a three stone fire, enter 99 and go to C17]*	
C14	Have you ever repaired this stove?	No [go to C17]	0
		Yes	1
C15	How long ago was the last repair?	*[months]*	
C16	How much did that last repair cost you?	*[ENTER CURRENCY]*	
C17	Does the type of stove you use as your primary stove change during year? If yes, please describe in what way and why it changes.	No	0
		Yes [*please describe*]	1
Secondary cooking device			
C 18	What is type is your secondary stove? [*If no secondary stove enter 77 and go to C35*]	*[Use stove codes. Record one answer. Describe here if other]*	
C 19	How many **days per week** do you use this 2nd stove?	*[Enter number of days per WEEK]*	
C 20	On the days it is used, how many meals per day do you use this secondary stove?	*[Enter number of meals per day]*	
C 21	When did you purchase/receive/build this stove?	*[Record month and year. If stove is the three stone fire, enter 99]*	
C22	What do you like **the most** about this cookstove, if anything?	*Record one answer. Use code sheet]*	
C23	If any, what is the **biggest challenge** you experience with this cookstove?	*Record one answer. Use code sheet]*	
Tertiary cooking devices			
C24	Do you have any other stoves that you use **less than once per week?**	Yes	1
		No [Go to C27]	2
C 25	What stove types is it (are they)?	*[Use codes. MA allowed. Describe here if other]*	
C 26	On what occasions are they used? *[MA. Do not prompt]*	Weddings/festivals	1
		When visitors come	2
		When there is no dry/good wood available	3
		When I have the fuel I need	4
		Other [describe]	99
Simultaneous stove use			
C27	Do you ever use TWO STOVES at the SAME TIME?	*1=Yes 2=No – go to C29*	
CX	On average how many times per week do you use TWO STOVES at the SAME TIME?	*[Times per WEEK]*	
C28	Why do you need to use two stoves at the SAME TIME?	To make two dishes at the same time	1
		When I am in a rush	2

		When cooking for large numbers	3
		When heating water and cooking	4
		When making animal feed and cooking	5
		Other [describe]	99
C29	Which stove do you usually use to cook?	[*Use stove codes. If they don't make this food enter '88'*]	
C30	Which stove do you usually use to cook?	[*Use stove codes. If they don't make this food enter '88'*]	
C31	Which stove do you usually use to cook/	[*Use stove codes. If they don't make this food enter '88'*]	
C32	Which stove do you usually use to cook?	[*Use stove codes. If they don't make this food enter '88'*]	
C33	Which stove do you usually use to cook hot drinks such as tea/coffee?	[*Use stove codes. If they don't make this food enter '88'*]	
C34	Which stove do you usually use to warm bathing water?	[*Use stove codes. If they don't do this task enter '88'*]	
Seasonal patterns			
C35	Do you use your stoves for different amounts of time throughout the year? This can involve making food for your family as well as performing other duties involving a cooker, such as boiling water for bathing or preparing feed for animals.	Yes	1
		No [Go to C38]	2
C36	Do you currently use the stove more or less frequently than you do at other times of the year?	More [Answer C37]	1
		Less [Answer C3X]	2
C37	What causes you to use your cooker more frequently now than at other times of the year?	To heat the rooms for people	1
		To heat rooms for animals	2
		To heat bathing water	3
		Making more animal feed	4
		Fuel is plentiful	5
		Cook different types of food	6
		Cook for more people	7
		Many festivals happening at this time of year.	8
		Other *[Circle 99 and describe below]*	99
C3X	What causes you to use the stove less frequently now than you would at other times of the year?	Do not need to heat room(s) for people	1
		Do not need to heat rooms for animals	2
		There is less fuel available	3
		Do not need to make animal feed.	4

		Cook different types of food	5
		Cook for less people	6
		We spend most of the day in the fields.	7
		There is little food available	8
		There are no festivals happening this time of year.	9
		Other *[Circle 99 and describe below]*	99
Other stove uses			
C38	Do you ever heat your home or your rooms with a fire or a stove?	No [*go to C42*]	0
		Yes	1
C39	What type of stove do you presently use to heat your home or your rooms?	[*Use stove codes. If no current space heating, put 99*]	
C40	When not being used for cooking, do you ever use this stove just for heating?	No	0
		Yes	1
C41	How many months a year do you typically keep your rooms warm? [Assistance with this computation using the seasons, if needed]		[Months]
C42	Do you use your stove or fire for any of the aforementioned activities? If so, what kind of fire or stove do you use? [As you go down the list, please enter a 1 in the first column followed by the code for the type of cooker used if the person used their cooker for that purpose. Then inquire as to whether they use their stove for anything else.]	Enter 1 if do task. 0 if not	Stove code
	C42.1	Insect repellent	
	C42.2	Lighting	
	C42.3	Making animal feed	
	C42.4	Warming bathing water	
	C42.5	Making medicines	
	C42.6	Other [*describe*]:	
	C43	Comments and observations	
XXX	Who decides what major household purchases will be made in this home?	I do alone	1
		I do with my spouse	2
		My mother does alone	3
		My father does alone	4
		My parents do together	5
		Other [describe]	99