DETERMINANTS OF IMPROVED STOVE ADOPTION AND ITS CONTRIBUTION TO CARBON EMISSION: THE CASE OF KILTE-AWLALO WEREDA, TIGRAY, ETHIOPIA

M.SC. THESIS

KAHSU GEBREHIWOT GEBREKIDAN

HAWASSA UNIVERSITY, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCE, WONDO GENET, ETHIOPIA

June, 2019

DETERMINANTS OF IMPROVED STOVE ADOPTION AND ITS CONTRIBUTION TO CARBON EMISSION: THE CASE OF KILTE-AWLALO WEREDA, TIGRAY, ETHIOPIA

KAHSU GEBREHIWOT GEBREKIDAN

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL SCIENCE, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCE, SCHOOL OF GRADUAT STUDIES, HAWASSA UNIVERSITY, WONDO GENET, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN RENEWABLE ENERGY UTILIZATION AND MANAGEMENT

June, 2019

AKNOWLEDGEMENT

First of all, I would like to express my sincere thanks to the almighty God for being with me and helping me through my life. My truly heartfelt gratitude goes to my advisor Dr. Yemiru Tesfaye for helping me by giving his invaluable scientific guidance, constructive comments and suggestions starting from the proposal preparation to the end of this research thesis.

My Gratitude also goes to the MRV capacity building coordination office of Wondo Genet College of Forestry and Natural Resource, Hawassa University for giving me this chance and financial support. A deep gratitude also goes to the Tigray Region Mines and Energy Agency for giving me an opportunity to attend my MSc. Program and to carry out my research work.

I would like also to thank Mr. Mahri W/kiros in Tigray region Mines and Energy Agency directorate director of study and dissemination of energy technology, Mr. Mikeal G/her senior expert of energy study for their cooperation in giving me the necessary documents and other facilities during my study and data collection. Special thanks and appreciations also go to all my staff members for their help and encouragement throughout my research work.

My special gratitude goes to the kebele administration managers for their help in organizing the focus group discussion and key informant interviews and supporting me in giving different data's necessary for my research study.

Finally, my deepest thanks and appreciations go to all my family and friends for their insistent support and encouragement for successful completion of this research.

DECLARATION

I declare that this MSc. Thesis entitled "Determinants of Improved Stove Adoption and Its Contribution to Carbon Emission, the case of Kilte-Awlalo Wereda, Tigray, Ethiopia" is my original work and has not been submitted for a degree of award in any other university, and all sources of material used in this thesis have been duly acknowledged.

Kahsu Gebrehiwot Gebrekidan	________________	__________________
Name of Student	Signature	Date

APPROVAL SHEET 1

This is to certify that the thesis entitled "Determinants of Improved Stove Adoption and Its Contribution to Carbon Emission, the case of Kilte-Awlalo Wereda, Tigay, Ethiopia" submitted in partial fulfillment of the requirements for the degree of master of science in Renewable energy utilization and management, the graduate program of the Department of Environmental science, and has been carried out by Kahsu Gebrehiwot Gebrekidan Id. Number MSc.REUM/R012/10, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Dr.Yemiru Tesfaye	____________________	________________
Name of Main Advisor	Signature	Date

APPROVAL SHEET 2

We, the Undersigned, members of the board of examiners of the final open defense by Kahsu Gebrehiwot Gebrekidan have read and evaluated his thesis entitled "Determinants of Improved Stove Adoption and Its Contribution to Carbon Emission, the case of Kilte-Awlalo Wereda, Tigray, Ethiopia" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in renewable energy utilization and management.

______________________	______________	__________
Name of the Chairperson	Signature	Date
______________________	______________	__________
Name of External Examiner	Signature	Date
______________________	______________	__________
Name of Internal Examiner	Signature	Date
______________________	______________	__________
Name of the Major Advisor	Signature	Date
______________________	______________	__________
SGD Approval	Signature	Date

ABBREVIATIONS

CDM	Clean Development Mechanism
CO_2e	Carbon Dioxide Equivalent
CRGE	Climate Resilient Green Economy
CSA	Central Statistics Agency of Ethiopia
FDRE	Federal Democratic Republic of Ethiopia
FGD	Focus Group Discussion
GHG	Greenhouse Gas
GWP	Global Warming Potential
HHs	Households
IAP	Indoor air pollution
ICS	Improved Cook Stove
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
Kg	kilogram
Kwh	kilowatt hour
MJ	Mega joule
Mt	Mega Tons (i.e. Million Metric tons)
MWE	Ministry of Water and Energy, Ethiopia
S.D	Standard Deviation
S.E	Standard Error Mean
SPSS	Statistical Package for Social Science
TMEA	Tigray Mines and Energy Agency
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WHO	World Health Organization

Table of Contents Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The dependence on traditional biomass energy sources for household use using traditional cooking stoves exacerbates deforestation and forest resource degradation and enhancing the global climate change. This research is intended to identify the determinants of improved cookstove adoption and their implication to biomass fuel saving and climate change mitigation. To collect all the necessary data for this research cross sectional survey method was used. A simple random sampling technique was employed to select 254 sample households for this study. The binary logistic regression model was used to identify the major determinants of improved cookstove adoption. To estimate the greenhouse gas emission due to burning of biomass fuel for household use IPCC guide line tier one method was used. Results of the analysis indicated that improved cookstove adopter households significantly consume less biomass energy than the non-adopter households. Mirt improved cookstoves had a capacity to save approximately 817.58 kg or 0.82 tons of biomass per year per household. Moreover, the average annual greenhouse gas emission savings due to the adoption and use of Mirt improved cookstove technology was approximately about 1353.21kg or 1.35 tons of carbon dioxide equivalents per household. The binary logistic regression analysis results also shows that education level, annual cash income, access to credit, fuel saving and awareness were found to positively and significantly influence the adoption of Mirt improved cookstove. Furthermore, the sex of household head, the price of improved cookstove and the distance to improved cookstove market were found to negatively and significantly influence the adoption of the Mirt improved cookstove. Improved cookstoves have the capacity to reduce biomass energy consumption and greenhouse gas emission. Therefore, the dissemination of improved cookstoves to the wider community has a positive effect on fuel saving and GHG emission reduction, and should be undertaken by giving due attention to those determinant factors.

Keywords: *Cookstove, Adoption, Biomass energy, Greenhouse gas*

1. INTRODUCTION

1.1. Background

Energy plays a vital role to ensure sustainable development because, it is a key input for all economic, social and environmental development activities (Dawit Guta, 2016). However, inappropriate energy exploitation can have significant impacts on the natural environment and their goods and services (UNEP, 2017). More than 3 billion people, i.e. almost 40% of the world population still depends on biomass fuels such as fuelwood, charcoal, agricultural residues, dung and coal for household use as energy (Balakrishnan et al., 2011; Kanangire et al., 2016; WHO, 2014).

Traditional biomass energy also serves as the main domestic energy source for most African households primarily for cooking and heating (Janssen and Rutz, 2012). Africa has the world's lowermost per capita energy consumption having 16% of the world's population, i.e., 1.18 billion out of 7.35 billion populations, which consumes about 3.3% of global primary energy. Biomass energy has a share of more than 30% of the energy consumed in Africa (UNEP, 2017) and in most sub-Saharan African countries is accounted for 90-98% of household energy consumption. As a result, 600,000 people die every year in sub-Saharan Africa due to indoor air pollution (Lambe et al., 2015; UNEP, 2017).

Access to clean energy supply is vital for sub-Saharan Africa development which accounts for 13% of the world's population. More than 620 million people have no access to electricity and nearly 720 million people entirely depend on traditional solid biomass with inefficient stoves for cooking in sub-Saharan Africa (IEA, 2014; UNEP, 2017). Existing approaches estimate that clean and efficient stoves can save anywhere from 1-3 tons of CO_2e/stove/year, with 1-2 tons being most common (USAID, 2017). "Improved cookstoves (ICS) can reduce fuel use by 30-60% as compared to the traditional cookstoves" (USAID, 2017).

The energy balance of Ethiopia has been mostly dominated by two types of energy sources i.e., hydropower and biomass. Biomass has a share of 90 percent of the total energy demand. Due to this massive depletion of its biomass resources the country has been facing degradation of its forest resources (Dawit Guta, 2012). Combustion of solid biomass fuels for cooking emits pollution which has substantial addition to climate change, and unmanageable wood harvesting leads to deforestation and forest degradation. However, enhanced fuel efficiency, dissemination of improved cookstoves can diminish significantly the emissions caused by cooking as well as deforestation and forest degradation via saving fuelwood consumption (USAID, 2017).

To address the challenges associated with households cooking energy demand in developing countries; promotion and diffusion of more energy efficient improved cookstoves and encouraging switching to other modern cooking energy alternatives are the two main feasible solutions (Urmee, and Gyamfi, 2014). Accordingly, the government of Ethiopia has been making so many efforts to promote and disseminate improved cookstove technologies in all parts of the country.

However, yet the adoption rate of improved cookstove technologies, such as Mirt and Tikikle[1] are still very low at the rural household level in Tigray region, Ethiopia. Therefore, why the rural households are adopting or not adopting the improved cookstove technologies and what their contribution to biomass fuel saving and carbon emission reduction at the rural household level is a big question so far not adequately answered with substantial evidence in the study area. Thus, this study endeavored to analyze the determinants of improved cookstove adoption and its contribution to biomass fuel saving and carbon emission reduction, the case of Kilte-Awlalo wereda, Tigray, Ethiopia.

[1] "Mirt" and "Tikikle" are local languages which mean 'best' and 'right' respectively.

1.2. Statement of the Problem

Ethiopia's, energy sector is highly dominated by biomass energy such as firewood, charcoal, crop residues and animal dung (Geissler et al., 2013; Kanangire et al., 2016). This very high degree of dependence on wood and agricultural residues for household energy use has a significant impact on the environmental resources (Geissler et al., 2013).

Several studies indicated that the traditional burning of solid biomass for energy needs make a contribution to deforestation and forest degradation as well as to climate change through greenhouse gas (GHG) emissions that results from the overexploitation of fuelwood (Venkataraman et al., 2005). There is high deforestation and forest degradation due to unsustainable harvesting of biomass fuel for household energy use using traditional cooking stoves in the study area. To reduce this problem the governmental and non-governmental organizations involved in promotion and dissemination of improved cookstove technologies in the region as well as in the study area.

According to Tigray mines and energy Agency (TMEA) adoption rate of improved cookstove in the study area as well as in Tigray region, remained as low as 34% while 66% of the households still using traditional cooking stoves. This entails a better understanding of the context of household energy consumption in relation to adoption of improved cookstoves and the implications of using improved stoves to reduce deforestation and forest degradation as well as climate change mitigation. Therefore, this study attempts to assess the actual adoption status of improved stove technology together with its determinants and estimate the potential contribution of improved stoves to biomass fuel saving and climate change mitigation taking the case of Kilte-Awlalo wereda[2], Tigray, Ethiopia.

[2] Wereda is an administrative division comprised of several Kebeles within, equivalent to a district.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this study is to identify the determinants of improved cookstove adoption and its implication to biomass fuel saving and Greenhouse gas emission reduction.

1.3.2. Specific Objectives

1. To identify the type of energy source and estimate the amount of domestic energy consumption at the rural household level.
2. To identify the major determinants of improved cookstove technology adoption at the rural household level.
3. To assess the awareness and attitude of rural households towards the benefits of improved cookstoves.
4. To estimate the implication of improved cookstoves to greenhouse gas emission reduction.

1.4. Research Questions

1. What is the type of energy source and amount of domestic energy consumed at the rural household level?
2. What are the major determinants of improved cookstove technology adoption decision at rural household level?
3. What looks like the level of awareness and attitude of the rural households towards the benefits of improved cookstove?
4. What is the implication of improved cookstove for greenhouse gas emission reduction?

1.5. Significance of the Study

The findings obtained from this study could be used by policy makers and development planners for developing integrated policies, plans, programs and projects which have a significant contribution for ensuring sustainable energy development for rural households. It also assists regional bureaus and wereda level rural development offices for making informed decisions to take remedial actions against domestic energy resource, health, and environmental related problems. Moreover, this study will also be useful for energy researchers, higher educational institutions, stakeholders, donors, and individuals working in energy sector development. Finally, an understanding of the determinant factors for the adoption of new improved cookstove technology and their implication to biomass fuel saving and carbon emission mitigation at the rural household level would be important for the successful implementation of energy programs and projects.

1.6. Scope and Limitation of the Study

The study was delimited to Kilte-Awlalo Wereda located in the Eastern Zone of Tigray region, Ethiopia. However, the findings of the study may be useful and applicable to similar areas in the region or beyond. The study focused on determinant factors affecting rural household's adoption of improved cookstove technology such as socio-economic factors, stove characteristic factors, institutional factors as well as knowledge and attitude. The major source of energy, amount of energy consumed at the rural household level and perceived benefits of the improved cookstove technology, its contributions to carbon emission reduction also covered.

The limitation of the study is that country-specific emission factors for GHG emission inventory (Ethiopia) were not used due to the absence of such information. Instead, the IPCC default emission factors were used. Additionally, factors such as fuel type used, fuel combination, operating condition, and age of the stove used to burn the fuel were not considered into account to estimate more precise GHG emission due to budget constraint.

1.7. Definition of Terminologies

In this study the following definitions were adopted for major terms used in this study.

Adoption: In this study, refers to the decision to accept and use of improved cookstove technology by rural households.

Improved cookstove: refers to a stove technology which is more fuel efficient and emit fewer fuel emissions as compared to the traditional mud closed stove or open fire stove.

Traditional stove: in this study traditional stove refers to the use of mud closed stove constructed by the rural household themselves, which principally consume much fuelwood and leads to environmental degradation and human health impacts.

Mirt cookstove: refers to a stove made from cement, was designed to reduce deforestation and forest degradation, and environmental pollution through reducing the amount of biomass fuel consumption by households.

1.8. Organization of the Thesis

This document is organized into five chapters. The first chapter includes the introduction, background of the study, statement of the problem, general and specific objectives, research questions, and significance and scope of the study. The second chapter consists of a literature review related to this research topic. The Third chapter encompasses research methodology includes study area description, methods of data collection and data analysis, sampling technique and sample size determination. The fourth chapter consists of results and discussions, and the fifth and final chapter comprises conclusions and recommendations.

2. LITERATURE REVIEW

2.1. Biomass Energy Consumption Pattern

Ethiopia, the energy sector is highly reliant on the biomass energy source such as fuel-wood, charcoal, dung and agricultural residue. The share of biomass energy is estimated to be more than 90% of the total domestic energy demand (Dagninet Amare et al., 2015; Kanangire et al., 2016). Furthermore, about 95% of the total population in Ethiopia uses biomass energy as their main energy source for cooking and heating. Even if urban households have better access to modern energy, the difference in biomass energy use is not that much compared to rural households. That is estimated 99% of rural and 94% of urban households use biomass energy respectively (Kanangire et al., 2016).

According to the Central Statistics Agency (CSA) of Ethiopia, almost 98% of rural households used biomass fuels as their main energy sources for cooking. As a country, about 84.4% of the households use firewood, around 8.2% use dung cake, 4.7% crop residue or leaves, 0.1% charcoal, and only 2.7% use others including gas, electricity for cooking (CSA and WB, 2013). When coming to the Tigray region its annual biomass energy consumption is 69.98% fuelwood, 23.04% animal dung, 4.43% crop residue and 2.54% charcoal respectively (Dawit Guta, 2012).

The results of a research conducted in rural Tigray, Ethiopia by Melaku Berhe et al. (2017) indicate that the main energy sources for rural households were animal dung with an average consumption of 19.3 kg and firewood consumption was 14.6kg per week per household, whereas consumption of charcoal was 1.5kg per week per household. The consumption of kerosene was found negligible.

2.2. The Heat Value of Different Energy Sources

Different biomass energy sources have a different degree of efficiency. For example, "heating value and consumption factors can be used to compare the efficiency level of different kinds of biomass fuel categories" (Dawit Guta, 2012). Fuel efficiency can be measured in terms of Mega Joules (MJ) per unit of Kilogram of given energy consumed. Therefore, the thermal value of different fuel resources can be measured and compared using standard units (MJ/Kg). Fuel efficiency is measured based on the input-output approach. This indicates how much Joules of energy is gained as output from a given amount of biomass or other fuels consumed. It also denotes heat values and conversion factors of biomass fuels (Dawit Guta, 2012). According to the MWE of Ethiopia, the heat value/efficiency measures of traditional biomass and some modern energy sources are herein below.

Table 1:- Heat value of biomass and other household energy sources

S. No	Fuel type	Heat value
1	Air dried Fuel-wood	15.5 MJ/Kg
3	Air dried branches, leaves and twigs (BLT)	15.5 MJ/Kg
2	Charcoal (5.25% mc dry basis, 5% wet basis, 4% ash)	29 MJ/Kg
3	Air dried Crop residue	15 MJ/Kg
4	Animal Dung (15% mc dry basis, 13% wet basis, 22.5% ash)	13.8 MJ/Kg
6	Electricity	3.6MJ/kWh
7	Kerosene	36MJ/L

Sources: MWE (as cited in Dawit Guta, 2012) and IPCC (2006)

2.3. Biomass Energy and GHG Emission

Overexploitation of biomass resources for cooking can have an influence on the climate since the traditional way of fuel combustion emits products of incomplete combustion such as methane and carbon monoxide that have higher global warming potential than carbon dioxide (Lewis and Pattanayak, 2012). "Recent analysis estimate that traditional wood fuel, via unsustainable harvesting and incomplete combustion, contributes approximately 2% of global greenhouse gas (GHG) emission including 20-30% of global black carbon (BC) aerosols" (Bailis et al., 2015).

More than half of the amount of wood harvested worldwide is used as fuel. By depleting stocks of woody biomass, unsustainable harvesting can contribute to forest degradation, deforestation, and climate change. Approximately 275 million people live in wood fuel depletion “hot spots” concentrated in South Asia and East Africa where the most demand is unsustainable. Emission from wood fuel is 1.0–1.2 Gt CO2e per year (1.9–2.3% of global emissions) (Bailis et al., 2015).

The combustion of fuels produces emissions of the following greenhouse gases, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon dioxide accounts for the majority of greenhouse gas emissions from most stationary combustion units (Gillenwater, 2005). The default greenhouse gas emission factors for these principal gases are herein below.

Table 2: Default greenhouse gas emission factors in kg per TJ

Fuel type	CO_2 ($kgTJ^{-1}$)	CH_4($kgTJ^{-1}$)	N_2O($kgTJ^{-1}$)
Fuelwood	112,000	30	4
charcoal	112,000	30	4
Dung fuel	100,000	30	4
Crop residue	100,000	30	4
Biogas	54,600	5	0.1
kerosene	71,900	10	0.6

Source: IPCC, 2006

2.4. Fuel Saving Potential of Improved Cookstoves

Dissemination and sustained uses of improved cookstoves have significant potential to reduce the amount of fuelwood consumed (Vahlne and Ahlgren, 2014). More efficient use of solid biomass fuels through the use of improved cooking stove technologies have a potential advantage in reducing per capita energy consumption (Dawit Guta, 2012).

A study conducted in Senegal indicated that improved cookstoves have a potential 25-30% fuelwood consumption reduction as the user began to use improved cookstove technology (Molnar, 2017). Similarly, a study undertaken in Senegal by Kazzi (2016) confirms that improved clay stoves consumed significantly less fuel wood than the traditional three-stone cookstoves. Furthermore, a study conducted in Senegal by Bensch and Peters (2012) was found that for all meals and dish types the improved cookstoves consumes substantially less firewood than the traditional cookstoves, the saving ranges between 39% and 46%.

According to the environmental protection authority, if all rural and urban households (estimated to be about 14.44 million) in Ethiopia shifted to the improved Lakech and Mirt stove, a saving of about 7,778,800 tons of fuelwood which requires clear-cutting of 137,192.24 hectares of forest will be achieved on an annual basis As cited on (Abebe Damte and Koch, 2011). Another study conducted by Zenebe Gebreegziabher (2006) found that adopters of improved biomass cookstoves collected 68.3 kg of less wood each month per household and more dung will become available in the form of manure as 19.89kg less dung is collected each month per household.

2.5. GHG Emission Mitigation Potential of Improved Cookstoves

Improved cookstoves initially cited as a potential mechanism for reducing the adverse impacts of cooking with traditional open fire. They come into existence started from the 1970s and proceed until now, mainly "designed for increased fuel efficiency, often because of a perceived link between deforestation and household energy" (Ruiz-Mercado et al., 2011). Furthermore, recently the issue of adverse health impacts of indoor air pollution and safety from traditional solid fuel use have given attention in the improved cookstove programs, as well as opportunities to mitigate climate change impacts of stoves (Johnson et al., 2009).

According to Johnson et al. (2009) up to the equivalent of 10 tons of carbon dioxide may also be saved per household per year with an improved stove. This would reduce the GHG emission into the atmosphere and would also help to mitigate global warming and climate change. A study conducted in rural Mexico indicated that households that rely on biomass for a large percentage of their energy demand, adoption of improved biomass stoves can result in a significant reduction of indoor air pollution and emission of greenhouse gases (Pine et al., 2011). Manoa et al. (2017) also found that based on the meals prepared per day by each household the total amount of carbon emission savings for the 1000 local beneficiaries of efficient wood stoves were wide-ranging from 102,200 kg CO_2 (indoor) to 357,700 kg CO_2 (outdoor) per year.

Ethiopia has made a particularly important commitment to improved cookstoves by including them in official strategy document. For example, the climate resilient green economy strategy document targeted to promoting improved cookstoves that will be used by about 20 million households and reduce emission by almost 35Mt of CO_2e by 2030 (FDRE, 2011).

Similarly, a study conducted by Abebe Beyene et al.(2015a) confirms that, on average one improved Mirt stove saves approximately 634kg of fuelwood per year or about 0.94 tons of carbon dioxide equivalents per year. The Ethiopian government is actively promoting the use of improved cookstoves and has planned to distribute 9.4 million improved cookstoves by mid-decade. The CO_2e corresponding to 9.4 million improved cookstoves, assuming that all improved cookstoves distributed perform like the Mirt stove, would then be about 8.8 million tons of CO_2e per year.

Another, study conducted by Dresen et al. (2014) in Kefa, Southern Ethiopia found that Mirt improved cookstove has a capacity of fuelwood savings nearly 40% compared to traditional three-stone fire, leading to a total annual saving of 1.28 tons of fuelwood per household. Considering the approximated share of fuelwood from unsustainable sources, these savings translate to 11,800 tons of CO_2 saved for 11,156 disseminated improved cookstoves. This approves that efficient cooking stoves, if well able to substitute to the local cooking habits, can make a significant contribution to the conservation of forests and carbon emission reduction from forest clearing and degradation.

2.6. Benefits of Improved Cookstove Technology Use

Improved cookstoves initially designed to protect the environment by reducing the amount of biomass energy consumption. It reduces fuel consumption, consequently improves the life of human being through reducing indoor air pollution and has a contribution to climate change mitigation. Furthermore, it reduces the workload and time spent to collect fuelwood and cooking. In general, improved cookstove play a crucial role in the process of ensuring sustainable social, economic and environmental development.

2.6.1. Economic Benefits

Access to improved cookstoves enables to reduce fuelwood demand for household energy consumption. As a result, the rate of deforestation and forest degradation reduces through savings of an ample amount of wood fuel and utilization of animal dung and crop residues which also helps increase land productivity through increasing soil fertility (Amogne Asfaw Eshetu, 2014a). Furthermore, improved stoves also save the household expenditure for fuelwood, shorten cooking and fuelwood collection time and reduce the concentration of smoke and indoor air pollution (Barnes, 1994; Zenebe Gebreegziabher, 2006). The time that would be saved by shortening cooking and fuelwood collection time and workload of women and young girls for collecting fuelwood can be used for other income generating activities and education (Amogne Asfaw Eshetu, 2014a; Lewis and Pattanayak, 2012).

2.6.2. Environmental Benefits

Unsustainable dependence on biomass fuel for household energy consumption is one of the main human causes of deforestation and forest degradation (Lewis and Pattanayak, 2012). The traditional and inefficient ways of using biomass fuels at a rural household level increase the demand for fuelwood. In order to reduce the pressure on forest resource for fuelwood consumption, development and dissemination of improved biomass stoves is among the main measures to be taken (Jan, 2012). A study conducted by Zenebe Gebreegziabher (2006) shows that improved biomass cookstoves have the potential to reduce land degradation through switching to an improved stove and replacing the traditional stoves, leads to less wood and dung is collected as fuel. As a result, deforestation is reduced, thus more wood is available for others, which less dung and crop residues will be used for fuel. Thus, more manure will be available for enhancing soil fertility.

2.6.3. Health Benefits

According to the WHO estimation, indoor smoke from the use of solid fuels (biomass and coal) causes about 36% DALYs (disability-adjusted life years) lost from lower respiratory infections, 22% from chronic obstructive pulmonary disease and about 1.5% from lung cancer which equals 1.6 million premature deaths every year (Ezzati et al., 2004). Household indoor air pollution can also cause pneumonia, tuberculosis, low birth weight, lung cancer, cataracts, possibly asthma, and heart disease and premature mortality (Okuthe and Akotsi, 2014).To reduce all these effects substantially, efficient use of energy to obtain the basic services for economic and social development, use of clean and improved cooking technologies, and switching to clean alternative energy sources are among the solutions for such adverse health impacts of traditional biomass burning (Wilkinson et al., 2007).

Different studies indicate that traditional biomass stoves not only consume more wood fuel for cooking but also emit dangerous gases and particulate matters which have a potential to impact adversely the health of human being, especially women and children. However, improved cookstoves are among the potential solution for such kinds of the problem because "they are designed to be more fuel efficient and reduce smoke emission" (Kazzi, 2016).

2.7. Factors Affecting Improved Cookstove Technology Adoption

Different empirical evidence mainly linked to socio-economic, geographic and cultural characteristics as a cause for unsuccessful improved cookstoves adoption (Mobarak et al., 2012; Molnar, 2017). A study conducted by Jan (2012) using the binary logistic regression model confirms that educational, total monthly income had significant positive impacts in adopting improved stoves at the household level. But, the age of respondents, total land holding, family size, and knowledge towards the risks of burning biomass in the traditional way did not have significant effects on improved stove adoption. Additionally, improved cookstoves have a relative advantage in reducing fuelwood consumption, cost savings for fuel, efficient cooking, reduce emission and low health and environmental risks.

Similarly, Sesan (2012) also found that there is a relationship between household income and adoption of newly improved cookstoves. In contrast, Sehjpal et al. (2014) conducted a study in rural India found that household income did not significantly influenced the adoption of new improved cookstove technologies. Results of a study by Okuthe and Akotsi (2014) related to the adoption of improved cookstoves by households revealed that factors like household education status, gender, leadership status, cultural beliefs, and social norms positively and significantly influenced adoption of the improved cookstove. Furthermore, lack of accessibility, lack of affordability, high initial cost and lack of awareness are among the factors which hinder the adoption of improved cookstoves. Also, the results indicated that young farmers are more active to adopt improved cookstove compared to older farmers.

A study undertaken in urban Ethiopia by Abebe Damte and Koch(2011) focused on the determinants of improved stoves, confirms that education level of household head, income, separate kitchen, and gender of household head were positively and significantly influences the adoption of improved Mirt stove. Other variables such as family size and stove substitution were found insignificant to Mirt stove adoption. Another study on factors affecting urban energy transition and technology adoption in Tigray, Ethiopia by Zenebe Gebreegziabher et al. (2010) mainly focused on household characteristics and price variable revealed that the age of household head, education, family size, and income positively and significantly determines the adoption of improved cooking appliances, electric 'Mitad'[3] and improved cookstoves.

A study conducted on emissions and fuel use performance of improved stoves and determinants of their adoption in Dodola, Southeastern Ethiopia by Fikadu Mamuye et al. (2018) indicated that factors like age of household head, gender, education level, price of stove and income were influenced the adoption of Lakech and Mirchaye improved cookstoves. The finding also revealed that the households that adopt improved cookstoves are younger than the non-adopters.

A study conducted in urban Zanzibar by Sheha and Makame (2017) indicated that 97% of the improved charcoal stove adopters perceive that improved stoves use much better less fuel per meal and save cooking time than the traditional once. They save more than 50% of charcoal compared to the traditional metal charcoal stove. The finding also reveals that durability, the high initial cost of a stove, lack of awareness are among the potential factors that hinder the dissemination and adoption of improved cookstoves to a wider community.

The initial cost of improved cookstoves can be one of the significant factors for its adoption. The findings of Barnes (1994) indicate that rural areas with fuelwood scarcity are more likely to adopt improved cookstoves. In contrast, rural households do not perceive adopting an improved cookstove as a meaningful investment even a scarcity of fuelwood, because fuelwood is often harvested freely. Thus, there is no encouragement to save on fuel costs by adopting new technology (Kazzi, 2016). But, Bensch and Peters (2015) found that even if

[3] 'Mitad' is a circular flat plate used to bake Injera (the local stable food) or bread by putting it upon the stove.

improved stoves emit smoke, women can still acknowledge positive health effects if the stove also promotes “exposure- relevant behavior changes”.

According to Zenebe Gebreegziabher (2006), families that have adopted the improved cookstoves spend less time collecting wood as such stoves are more efficient in their use of wood. Furthermore, savings in cooking frequency, time spent collecting wood and cattle numbers are all statistically significant factors for improved stove adoption.

A number of studies undertaken related to improved cookstove adoption in developing countries. In-depth literature review linked to these studies undertaken by Lewis and Pattanayak (2012) revealed that "the empirical literature bases of ICS adoption remains narrow, thin, and scattered" and failed to deliver systematic evidence to examining the various determinants. Furthermore, most studies examine only a few factors mainly related to household characteristics. However, adoption of ICS can also be affected by other factors such as stove characteristics, awareness and attitude towards stove benefits and institutional factors. Therefore, this research study will endeavor to fill this research gap.

2.8. Theoretical framework of Technology Adoption

This study adopts the theory of diffusion of innovation, which states that new technology diffusion is a process of how new innovations can be disseminated through certain channels over time among members of interlinked socio-economic systems (Rogers, 1995). To disseminate new innovations in successful manner elements such as innovation, communication networks, time, and the social system must be in place. Furthermore, any new technologies should have to pass through an innovation-decision process which includes knowledge, persuasion, decision, implementation, and confirmation (Rogers, 2003).

“An Innovation could be an idea, practice or an object that is perceived as new by an individual or other units of adoption". The degree of adoption or acceptance of new technologies relies on its characteristics such as relative advantage which is the benefits of an innovation to be perceived as compared to the existing once, compatibility – how it is consistent with the existing social norms and beliefs, complexity – comparatively how it is difficult to understand and use, trial ability – to what extent can be experimented with on a limited basis and observability – are the benefits of an innovation are visible to others (Dearing, 2009; Rogers, 2003).

Communication network strategies and ‘opinion leaders' have a crucial role in determining the degree of adoption of an innovation. Opinion leaders can highly influence the behavior of an individual through using different mechanisms, but additional intermediary such as change development agents, extension workers, etc. have also their own role in the diffusion process (Rogers, 1995). The theory of innovation diffusion further considers the adopter classes as an influence on the rate of adoption of new technologies.

2.9. Conceptual Framework

The factors that could likely affect the diffusion of improved stoves divided into five interrelated categories which are technical, economic, infrastructural, cultural and social aspects (Agarwal, 1983; Masera et al., 2000). Accordingly, the conceptual framework shows a diagrammatic representation of the determinant factors for the adoption of improved cookstoves technology in the study. Adoption of improved cookstove technology in this study is the dependent variable defined as to accept or decide to use the improved cookstove technology and is influenced by various explanatory variables that are interconnected. Herein below is the conceptual diagram that illustrates the factors that determine the improved cookstove adoption and helps for data analysis and discussion.

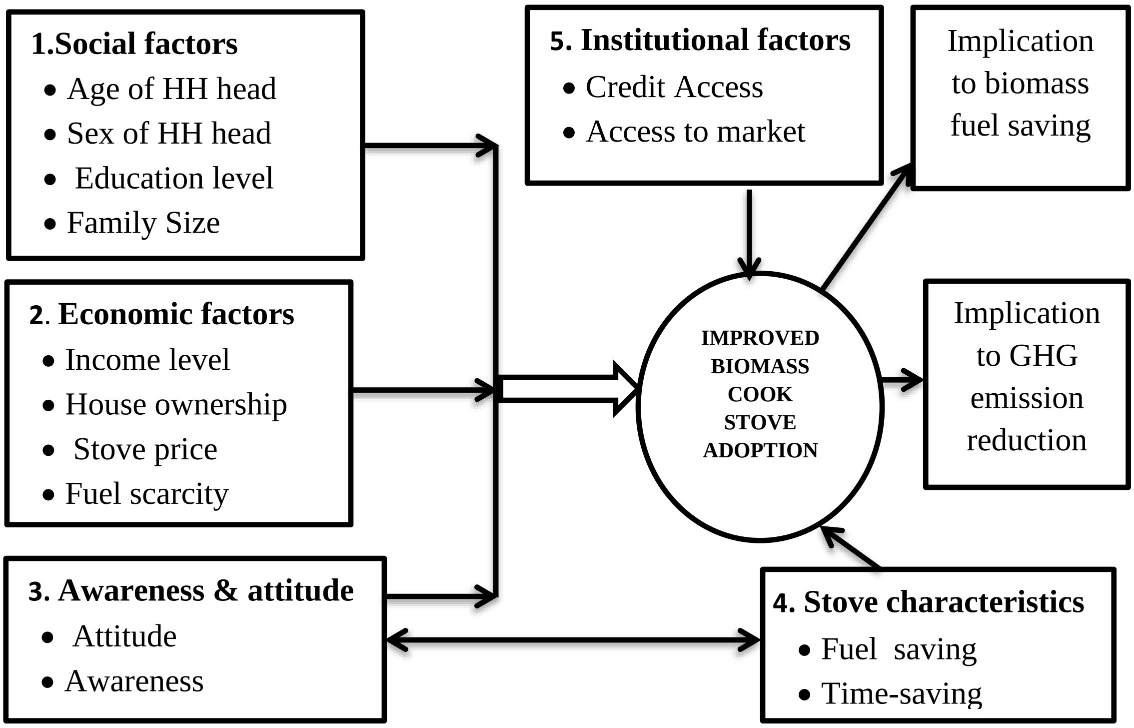

Figure 1: The Conceptual Framework

Source: Developed by my self

The conceptual framework indicates that demographic and social factors such as age of household head, educational level of household head, sex of household head, family size; economic factors such as annual cash income level of household, house ownership, stove price, fuel scarcity; institutional factors such as distance to market, credit access, and stove characteristics include fuel saving and time-saving could influence the decision to adopt improved cookstove technology. Furthermore, knowledge and awareness could also affect the adoption of improved biomass cookstove technology. Adopting and using Mirt ICSs also have a positive implication for a biomass fuel saving and greenhouse gas emission mitigation.

3. MATERIALS AND METHODS

This section describes how the research was carried out in the study area. It includes the description of the study area, sampling techniques, and sample size determination, method of data collection and analysis, and definition of variables and their unit of measurement.

3.1. Description of the Study Area

The study was conducted in Kilte-Awlalo wereda which is geographically found between 39^{o}18$^{'}$- 39^{o} 42$^{'}$E longitude and 13^{o} 36$^{'}$ -13^{o} 58$^{'}$N latitude in the Eastern Zone of Tigray National Regional State, Ethiopia. It is found 45 km far from the regional capital city, Mekelle and 823 km far from Addis Ababa to the north part of the country. Administratively the wereda comprises 19 kebeles and 69 Kushets[4]. Kilte-Awlalo Wereda is bordered with Wereda Atsbi-wonberta to the East; Wereda Enderta to the South; Wereda Sasie-Tsada emba to the North and Wereda Hawuzen to the West (Wereda plan and finance office).

According to the Wereda Agriculture and Rural Development Office (WARDO), the total area of the Wereda is estimated to be 1010.28 square km of which 21% is cultivated land, 4.5% is grazing land, 21% is covered with forest and shrubs while 53.5% is not used for production purpose due to different reasons. The average landholding of a household is 0.64 hectares. Its altitude ranges from 1900-2460 meter above sea level with an annual mean temperature of 17-23^{0}c and annual mean rainfall ranges from 350-450mm.

According to the Wereda plan and finance office (WPFO) (2010) estimation, the Wereda has a total population of 135,501 people. The population of males is about 66,198 (49%) and females are 69,302 (51%). The estimation also showed that the Wereda comprised a total of 30,796 households out of which male-headed household is 21,558 (70%) and the remaining, 9,238 (30%), are female-headed.

[4] kebele/kushet is an equivalent with the lowest administrative units in Ethiopia

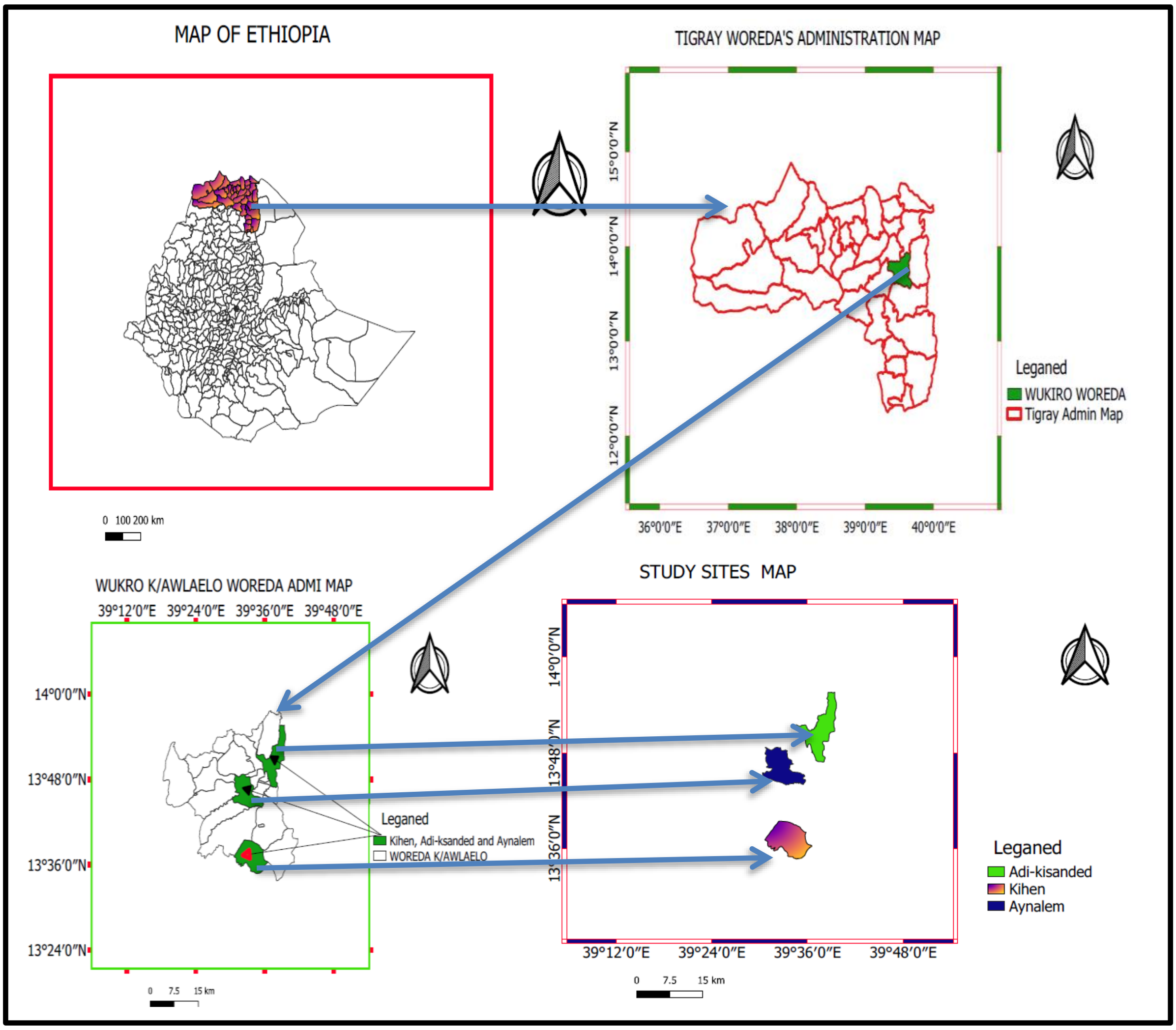

Figure 2: Location map of the study area

3.2. Data Collection Methods

To collect the essential data for this study, a cross-sectional survey method was employed. Both Quantitative and qualitative data were used. As well as primary and secondary data sources were used for the study. The primary data were collected using a structured questionnaire for interview the household head, key informant interviews and focus group discussion. Secondary data were gathered by reviewing different published and unpublished sources including books, journal articles, office reports, magazines and websites which were relevant to this research topic.

The major types of energy sources used in the study area were identified based on the data obtained from the structured questionnaire. The questionnaire also provided quantitative information on the amount of fuel consumption for domestic use at the rural household level for different purposes. To obtain the amount of biomass fuel consumption data in kilograms at rural household level was difficult. Therefore, the amount of biomass fuel consumption was requested in terms of local measurement units such as the number of bundles for wood; a sack for charcoal and dung, and a bundle for crop residue per month. This method of measurement was expected to improve the reliability of information obtained from respondents and was also used by Yohannes Zerihun (2015); Zenebe Gebreegziabher et al. (2007) on other similar studies.

A measurement was made to know the average weight of a bundle of wood, a sack of charcoal, a sack of dung and a bundle of crop residue by taking 10% of the sample households. Accordingly, the average weight of a bundle of wood, a sack of charcoal, a sack of dung and a bundle of crop residue was 20.3kg, 18.2kg, 11.5kg, and 13.2kg, respectively. These average weights were used along with the energy preference and domestic energy consumption pattern of households to estimate the monthly amount of biomass fuel consumption in terms of kilogram per month for domestic use of each sample household. Moreover, the monthly electricity consumption was collected in terms of monthly average payments, and then these monthly payments were converted into equivalent kilowatt hours using the domestic electricity consumption tariffs. Additionally, data on monthly kerosene consumptions were collected in liters. Finally, conversion factors were adopted from different secondary data sources to quantify the energy value of various fuel types used as domestic energy sources.

To identify the major determinants of improved stove technology adoption at the rural household level data was obtained by the structured questionnaire. For this purpose, the data on important socio-economic, stove characteristics and institutional factors related to adoption were collected from both adopter and non-adopter rural households.

To estimate the quantity of greenhouse gas emission reduction due to the adoption of improved cookstove technology at a rural household level, the amount of domestic energy consumption obtained from the structural questionnaire was used. As well as the IPCC default emission factors and global warming potential of different gas types were used to quantify the amount of GHG emission of different biomass fuel types consumed by the adopter and non-adopter households.

A structured questionnaire was the main measurement instrument to collect most of the quantitative information for this study. In the data collection three enumerators were involved, one in each kebele. In order to collect more accurate data from the selected respondents, two days of training was given to the enumerators. The questionnaire was tested as a pilot at some households to strengthen its applicability. After the pilot test, adjustments were made for effective data collection and translated into the local language before the questionnaires were forwarded to the respondents. Questionnaire administration was conducted using face to face interviews with household heads of both the adopter and non-adopter households. The data collection processes were taken four weeks with intensive follow up by the researcher for the enumerators.

3.3. Sampling Techniques and Sample Size Determination

3.3.1.Sampling Techniques

In this study, both purposive sampling and simple random sampling techniques were employed. The study area was selected using a purposive sampling technique because it has high forest degradation and biomass resource scarcity. It has also a relatively better implementation of improved cookstove. It was also used to identify key informants and focus group discussion participants.

A simple random sampling technique was used to select three Kebeles, namely Adi-kisandidd, Aynalem and Kihen were selected randomly from the total of 19 rural Kebeles within the wereda. Moreover, a simple random sampling technique was also used to select the number of household heads who had adopted the improved cookstove technology and the non-adopter households for an interview from each kebele based on the list of households obtained from the kebele administration. Since a simple random sampling is one in which each member in the total population has an equal chance of being selected for the sample and random sampling always produces the smallest possible sampling errors (Renckly, 2002).

3.3.2. Sample Size Determination

The unit of analysis for this study was both the improved cookstove technology adopter and non-adopter households in the study area. To determine a representative sample size for a simple random sampling design Al-Subaihi (2003) formula was adopted. Accordingly, a total sample size of **254** household heads were selected using the equation (1) herein below.

$$n = \frac{N\,Z^2 * p(1-p)}{(N-1)e^2 + Z^2 p(1-p)} \quad \text{.........} \quad (1)$$

Where n = the sample size, N= the population size, z = confidence level at 94% (z =1.96), P= estimated population estimation proportion (0.5), and e = the precision level at 6%. Based on this, the sample size of each kebele was computed as follows.

Table 3: proportional sample size determination

No.	Kebeles	Household number	sample size	percent	Number of adopter	Number of non-adopter
1	Adi-kisandidd	1473	75	29.53	40	35
2	Aynalem	2118	108	42.52	39	69
3	Kihen	1402	71	27.95	30	41
	Total	4993	254	100	109	145

Source: Own computation, 2019

Additionally, the study also collected qualitative data through focus group discussion (FGD) and key informants interview. Key informants were purposely selected based on predetermined role played in the village. Prior to conducting the focus group discussion and key informant interview necessary checklists were prepared. A total of 38 individuals had participated. That is 20 kebele leaders and households, 10 kebele development agents and wereda experts, 6 regional experts and 2 from stove producers. These focus group discussions were comprised of six to eight members per group composed of women, men, and the youth. It was offered general opinions on fuelwood availability, factors influencing improved cookstove adoption, domestic fuel availability, improved stove benefits, emission reduction, awareness, attitude, and suggestions. The qualitative information gained from the FGD and key informant interview were organized based on the specific objectives and were used in the discussion to support the quantitative findings.

3.4. Method of Data Analysis and Model Specification

All the quantitative data collected from different sources were coded and entered into SPSS version 20 statistical tools and excel for statistical analysis. To reduce problems related with incompleteness and other related inappropriate responses the row data was cleaned, edited, coded, grouped, tabulated and summarized with the help of SPSS software version 20 statistical tools. Continuous variables were checked whether their distribution is normal or not using histograms and outliers also checked using box plots. The results of the analysis were interpreted and discussed using descriptive statistics, inferential statistics, and econometric models.

3.4.1. Descriptive Statistics

Descriptive statistics was employed for analysis of data using mean, percentage, frequencies, standard deviation, chi-square test and t-test that give statistical summaries related to variables of concern. Chi-square test, independent and paired samples test were employed to identify variables that vary significantly between adopters and non-adopters. The chi-square test was used to see the association between some categorical variables of adopters and non-adopters. The t-test was used to see if there is a statistically significant difference between the mean of adopters and non-adopters with respect to continuous variables, for example, fuelwood consumption.

3.4.2. Econometric Model Specification for ICS Adoption

To identify the major determinant factors for the household's decision on the adoption of improved cookstove technology, a logistic regression model was employed. Since the outcome of the dependent variable is binary and the explanatory variables are in any form of measurement scale (Peng et al., 2002). The dependent variable in this study is a binary variable with values 1 for adopter and 0 otherwise. The model can be written mathematically as follows.

$$p = E(Y = 1|x) = a + bx \quad \ldots\ldots (1)$$

Where Y= 1 means a given household adopts improved cookstoves, x is the explanatory variable, ‘a' and ‘b’ are parameters to be estimated.

$$P = E(Y = 1|x) = \frac{1}{1+e^{-(a+bx)}} = \frac{e^{a+bx}}{1+e^{a+bx}} \quad \ldots\ldots (2)$$

As P is the probability of adopting improved cookstoves, 1-P is the probability of not adopting the improved cookstoves. Therefore

$$1 - p = (Y = 0|x) = \frac{1}{1+e^{a+bx)}} \quad \ldots\ldots (3)$$

Where Y = 0 is the non-adopter. Therefore, by dividing equation2 to equation3 we can write the model mathematically as follows.

$$\frac{p}{1-p} = e^{a+bx} \quad \ldots\ldots (4)$$

Where $\frac{p}{1-p}$, is the odds ratio of certain events to have occurred which is the ratio of the probability of a given household to adopt improved cookstove to the probability of households that will not adopt it.

By taking the natural logarithm of equation (4) on both sides, one can derive an equation to forecast the odds ratio of certain events to have occurred as follows:

$$Ln\left(\frac{p}{1-\mathrm{p}}\right) = Ln(e^{a+bx}) = a + bx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Therefore, by extending the simple logistic regression into multiple predictors and by considering the residuals, the logit model is written as:

$$logit(Y) = \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon_i \ldots\ldots\ldots\ldots \text{(6)}$$

Where βo is constant term, $x_1, x_2 \ldots x_k$ are explanatory variables that are expected to affect the adoption of improved cookstove technology and $\beta 1, \beta 2, \ldots \beta k$ are the parameter's that is estimated cross ponding to each explanatory variable and ε_i is the error term. Before performing the logistic regression analysis the data was checked for the existence of multicollinearity problem between the independent variables using a correlation matrix and the variance inflation factor (VIF). The variables that have a strong correlation were removed.

3.4.3. Definitions of Variables

Based on different kinds of literature, demographic, economic, institutional, stove characteristics, knowledge and awareness factors that were expected to influence the adoption of improved cookstove selected and some other issues were included in the interview schedule.

Dependent variable: In this study, the dependent variable had a dichotomous nature which denotes the adoption of "Mirt" improved cookstoves. In this case, households using 'Mirt' improved cookstoves for cooking were considered as adopters whereas those who use traditional mud closed stoves were considered as non-adopters. The major independent variables included in the model are defined as following.

Age of household head (AGEHH): with age individuals acquire experience and knowledge related to the benefits of new improved technologies and can accumulate wealth over time which would enable them to adopt new improved technology. In contrast, older people are more conservative and tend to have risk-averse attitude towards accepting a new technology (Jan, 2012; Okuthe and Akotsi, 2014). Thus, the age of the household head was expected to have both positive and negative significant influence in the adoption of improved cookstoves.

Sex of household head (SEXHH): refers to the gender of the household head. Baking and cooking are the responsibilities of women's in the study area. Therefore, female-headed households were expected to adopt improved cookstoves than male-headed households.

Education level of the household head (EDUCA_HH): refers to the level of formal schooling completed by the household head. Education helps to improve human behavior and attitude, creates a favorable mind to make well-informed decisions to adopt new technologies. More educated individuals can be easily understand the overall benefits of improved cookstoves (Molnar, 2017). Therefore, education level was expected to have positive significant influence in the adoption of improved cookstoves.

Family size of household (FAM_SIZE): refers to the number of people living in one house, share and pool resources and eat together in one pot. Large family sizes are assumed as an indicator of labor force available for fuelwood collection and could lead them to low adoption rate of improved cookstove. In contrast, families with labor force availability could also be an opportunity to earn large incomes for the family that can enable them to adopt the improved cookstove. Therefore, family size was expected to have either positive or negative significant influences in the adoption of the improved cookstove.

Income level (INCOME): is defined as the total amount of annual income gained from all sources/activities measured in Birr[5] in last year. Households that have higher income may have a higher probability to adopt new technologies (Lewis and Pattanayak, 2012). Comparatively households with better incomes tend to take risks than poor once. Thus, the income is expected to have a significant positive contribution to adopt improved cookstoves.

House ownership (HOUS_OWN): refers to households that have their own houses. As the households have their own house, they can have enough space for building separate kitchen and to install permanently the improved cookstove. This may make the probability to adopt the improved cookstove is high. Therefore, house ownership is as expected to have a positive significant influence in the adoption of the improved cookstove.

Price of the stove (PRICE_MIRT): the price of improved new stoves can be a significant impediment to adoption. Improved cookstoves are expensive relative to the local traditional stoves. Thus, people may be unable to afford the initial cost of buying the improved stove (Barnes et al., 1993). Therefore, the price of the stove was expected to have a negative significant impact on improved stove adoption.

Fuel saving (FUELSAVING): refers to the amount of biomass fuel saved per month per household. As improved cookstove save fuel, the information on fuel saving positively influences the households to adopt the improved cookstoves. Furthermore, Fuel saving can reduce expenses for purchasing wood fuel, shorten fuelwood collection time and cooking time, and reduce the workload of women and children (Barnes et al., 1993). Thus, fuel saving was expected to have a positive significant effect on improved stove adoption.

Access to credit (CREDIT_ACC): Households who have access to formal credit for improved cookstoves are more likely to adopt improved cookstove technologies than those

[5] Birr is an Ethiopian currency.

who have no access to formal credit. Therefore, credit availability was expected to have both positive and significant impacts on improved cookstove adoption.

Distance to market (DIST_MARKET): refers to the distance to the improved cookstove market. Households who are close to the improved cookstove market have more probability of adopting improved cookstoves. In contrast, households who are far away from the improved cookstove market have less probability to adopt improved cookstoves since improved cookstoves cannot be transport easily for long distance and it requests additional costs for the households to transport it to their residence. Therefore, access to the market was expected to have both positive and negative impacts on the adoption of improved cookstoves.

Fuel scarcity (DIST_FUEL): refers to the deficiency of fuelwood availability. In this case, the fuel scarcity was measured in terms of distance traveled and the time taken to collect the fuel. People in areas which have fuelwood scarcity may have the probability to adopt improved cookstoves. Therefore, fuel scarcity was expected to have a positive impact on the adoption of improved cookstoves.

Awareness (MIRT_AWARE): the degree of awareness of respondents concerning the risks of biomass use in an inefficient way or the benefits of improved cookstoves is obtained from different sources such as TV, radio, newspapers and extension agents working in the area (Jan, 2012). Thus, it was expected that respondents who are more aware of the risks of using biomass in the traditional way or benefit of using improved cookstoves are more likely to adopt the improved cookstove.

3.4.4. Description and Measurements of Variables

Table 4: Description of Explanatory variables and their measurement

variable	Type	Measurement	Expected sign
Age of HH head	continuous	Age in year	+/-
Sex of HH head	categorical	1 male, 0 female	+/-
Education level	continuous	Years of formal schooling	+
Family size	continuous	Number of people in the household	+/-
Income	continuous	Annual total cash income in Birr	+
House ownership	categorical	1 yes, 0 No	+
Stove price	categorical	1 if expensive, 0 otherwise	-
Credit Access	categorical	1 Yes, 0 No	+
Distance to market	continuous	Distance to the market in km	+/-
Fuel saving	continuous	Amount of biomass fuel saved per month in kg	+
Fuel scarcity	continuous	Measured in terms of distance traveled in km and time taken to collect biomass fuel in hours per trip	+
awareness	categorical	1 if aware, 0 otherwise	+

3.4.5. GHG Emission Estimation Equation

The GHG emission from stationary fuel combustion can be calculated by multiplying the amount of fuel consumed by the corresponding emission factor. The fuel consumption data in mass or volume units must be first converted into the energy content of these fuels (IPCC, 2006). In this study only the three important gases such as CO_2, CH_4, N_2O are considered in the GHG emission estimation. The global warming potential (GWP) of these three gases over a 100 years' time horizon is 1, 25, and 298 respectively (IPCC, 2007). To estimate the GHG emission from combustion of a given fuel type 'f' by adopter and non-adopter households were calculated using IPCC guideline for tier one method as follows.

$$\boldsymbol{E_f = \sum_{i=1}^{n}(A_i * EF_i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where E_f = GHG emission in Kg from the burning of fuel type f; n= total number of adopter or non-adopter sample households; A_i= amount of fuel consumed by sample household i; EF_i = default emission factors for gas type i

To estimate the total amount of GHG emissions of the adopter and non-adopter households, first, it must be converted into CO_2e via multiplying by its global warming potential of each gas. The equation is as follows.

$$\boldsymbol{E_{CO2e} = \sum_{i=1}^{n}(A_i * EF_i * GWP_i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where E_{CO2e} = total emission in carbon dioxide equivalent**,** GWP_i= the global warming potential of gas type 'i'.

4. RESULTS AND DISCUSSIONS

This chapter presents all the results of the study based on the identified objectives of this research. It starts with the overall socio-economic characteristics of the sample households and then continues to show the major domestic energy sources, amount of domestic energy consumption, the major determinants of Mirt improved cookstove adoption, carbon emission reduction estimation and the level of awareness and attitude of rural households associated to the improved cookstove. Discussions were made based on the results analyzed. Additionally, the main findings of this research were compared with the findings of other similar studies whether the results supported by or contradicting with and the possible reasons for their difference.

4.1. Socio-Economic Characteristics of Sample Households

4.1.1. Sex of Household Head

As shown in table 5 below, the proportion of female-headed households is two times higher than the male-headed households for the adopter categories, whereas the proportion of male-headed households is five times as much as the female-headed households for the non-adopter category. Moreover, overall about 66.7% of the total females in the sample were found to be adopter which is twice as much as the proportion for male adopters (33.5%). The result clearly indicates that female-headed households are more likely to adopt than male-headed households. Besides males may influence their wives against adopting improved cookstoves whenever they are the decision makers in the house. This finding was similar to the findings of Fikadu Mamuye et al. (2018) who found that female-headed households were more likely to adopt improved cookstoves than the married women of male-headed once. The chi-square test result also indicated that female-headed households had adopted Mirt improved cookstove technology more than male-headed households in the study area and other similar areas ($\chi^2 = 23.143$, degree of freedom = 1 and p-value < 0.001). Therefore, it is better to approach female members and empower them through credit access, training and education etc. if development agents want to improve the adoption rate of the improved cookstoves.

Table 5: Sex distribution of the sample household heads (n = 254)

			Mirt ICS adoption		Total	Chi square	p-value
			non-adopter	Adopter			
Sex of HH head	female	Count	24	48*	72	23.143*	0.000
		% within sex of HHs	33.3%	66.7%	100%		
		% of Total	9.4%	18.9%	28.3%		
	male	Count	121	61*	182		
		% within sex of HHs	66.5%	33.5%	100%		
		% of Total	47.6%	24.0%	71.7%		
Total		Count	145	109	254		
		% of Total	57.1%	42.9%	100.0%		

Sources: Own Survey, 2019

4.1.2. Age and Education level of the Sample Households

As table 6 shows, the mean age of the total sample households was 45.02 years, with a range of 26 to 75 years old. This finding is similar to Birhane et al. (2017) who found that the mean age of the respondents from the eastern zone of Tigray, Ethiopia was 45.5 years. The mean age of Mirt improved cookstove adopter and non-adopter sample household heads were 44.65 and 45.30 years, respectively. The findings of Fikadu Mamuye et al. (2018); Okuthe and Akotsi, (2014) also revealed that the households that adopt the improved cookstoves were younger than the non-adopter households. However, the independent samples test indicated that there was a statistically insignificant mean age difference between adopter and non-adopter households. Therefore, age of the household heads could not have an influence on the adoption of improved cookstove technology in the study area.

The mean educational level of the sample household heads in years of formal schooling was 3.35 years, with a range of zero to thirteen years of schooling. The result also shows that the mean educational level of the sample household heads of Mirt improved cookstove adopter categories was two third times higher than the non-adopter household head categories (Table 6). This result clearly indicates that as individuals become more educated their knowledge and awareness of the merits and demerits of newly produced technologies also become increased which helps them in decision making to adopt the newly produced technologies. Similarly, the results of the independent samples test show that there is a significant mean difference in educational level between the sample Mirt improved cookstove adopter and non-adopter households ($p < 0.001$). A similar finding was found by Okuthe and Akotsi (2014); education had a significant and positive influence on the adoption decision. Thus, it is better to strengthen the rural household heads through education and educational extension services that could help to large scale uptake of improved cookstove technologies by the wider community.

4.1.3. Family Size of the Sample Households

The mean family size of the total sample households were 5.23 persons with a range of one to eleven persons. This result is relatively similar to the findings of Melaku Berhe et al. (2017) who conducted a study in two districts of Tigray and found that the average family size was 5.4 persons. The mean family size of the sample Mirt improved cookstove adopter and non-adopter household categories were 4.99 and 5.41 persons, respectively. The independent samples test showed that there was an insignificant mean difference in family size between the improved cookstove adopter and non-adopter sample households at $p > 0.05$ (Table 6). This implies that family size had no influence on the decision to adopt improved cookstoves. A study conducted by Dresen et al. (2014) in Kefa region of south Ethiopia also found that the family size of the non-user of improved cookstove was slightly higher than the improved cookstove user households, but the difference is not statistically significant.

Table 6: Age, Education level, Family size, Income and land holding of the sample households

Variable	Mirt improved biomass cookstove adoption						mean difference	p-value
	Adopter (n= 109)			Non-adopter (n= 145)				
	mean	S.D	S.E	Mean	S.D	S.E		
Age of HH (yr.)	44.65	10.08	0.965	45.30	12.389	1.029	-0.645	0.657
Education level (yr.)	4.32	3.687	0.353	2.62	3.245	0.269	1.700	0.000
Family size	4.99	2.263	0.217	5.41	2.09	0.174	-0.416	0.131
Income level (Birr)	13888	6877.75	658.77	9729.9	5259.75	436.79	4158.1	0.000
Landholding (ha.)	0.484	0.36	0.034	0.728	0.526	0.0436	-0.244	0.000

Sources: Own Survey, 2019

4.1.4. Mean Annual cash Income of the Sample Households

As shown in table 6 above, the mean annual cash income of the sample household heads were 11,514.28 Birr. There was a difference in the annual total cash income of the household head from a minimum 3250 Birr to a maximum 31,600 Birr. The mean annual total cash income of the sample Mirt improved cookstove adopter household categories were almost 30% higher than the non-adopter household categories. Results of the independent samples test indicated that there was a significant mean annual cash income difference between the Mirt improved cookstove adopter and non-adopter sample household heads at p-value > 0.001. This result clearly implies that as the annual total cash income level of the rural households increase the willingness to pay for improved cookstove increases. A study conducted in urban Ethiopia by Abebe Beyene and Koch (2013) found similar finding that households in the lowest income bracket are less likely and slowest to adopt ICS than the households that are in the highest income bracket.

4.1.5. Average Landholding of the Sample Households

The average landholding size of each sample household in the study area was found to be 0.623 hectares. This result is not similar to both the national level average landholding size of 1.37 hectare and Tigray regional national state landholding size of 0.8 hectares (CSA and WB, 2013). But, the result is relatively similar to the woreda administrative landholding size, which is 0.64 hectare. The result also shows that the mean landholding size of the non-adopter household categories was higher almost by 34% than the adopter household categories. Similarly, the independent samples test results indicated that there was a significant mean landholding size difference between the adopter and non-adopter household head categories (Table 6). This result implies that landholding size has no influence on improved cookstove adoption in the study area. The main reason could be that the landholding size may not be enough to produce surplus products to sale and gain cash earnings to purchase improved cookstove and other newly produced technologies that can improve the lives of the rural households.

4.2. Major Types of Domestic Energy Sources

In the study area, biomass energy is mainly used for cooking and baking purposes which are the two main activities more frequently undertaken on a daily bases at the rural households in the study area. These two types of main activities consume the majority of the biomass energy demand. This section presents the main energy sources by type of activities as well as the main source of biomass energy; domestic energy consumption patterns of the total sample households and the adopter and non-adopter households in the study areas.

4.2.1. The Main Types of Energy Source for Baking and Cooking

As shown in figure 3A below, rural households mainly used two types of energy sources for baking[6] in the study area while dung is the most important energy source which is often used

[6] Baking refers to the process of making food such as Injera, bread from a dough, batter, etc.

by more than 88% of the sample households. Furthermore, the study identified the proportion of the main types of energy source often used for cooking[7] in the study area by the total sample households were as shown in figure 3B below, dung fuel and fuelwood were reported by 53.54% and 41.34% of the respondents respectively. The uses of other sources like charcoal and crop residue were reported by 4.33% and 0.79% of the sample households respectively.

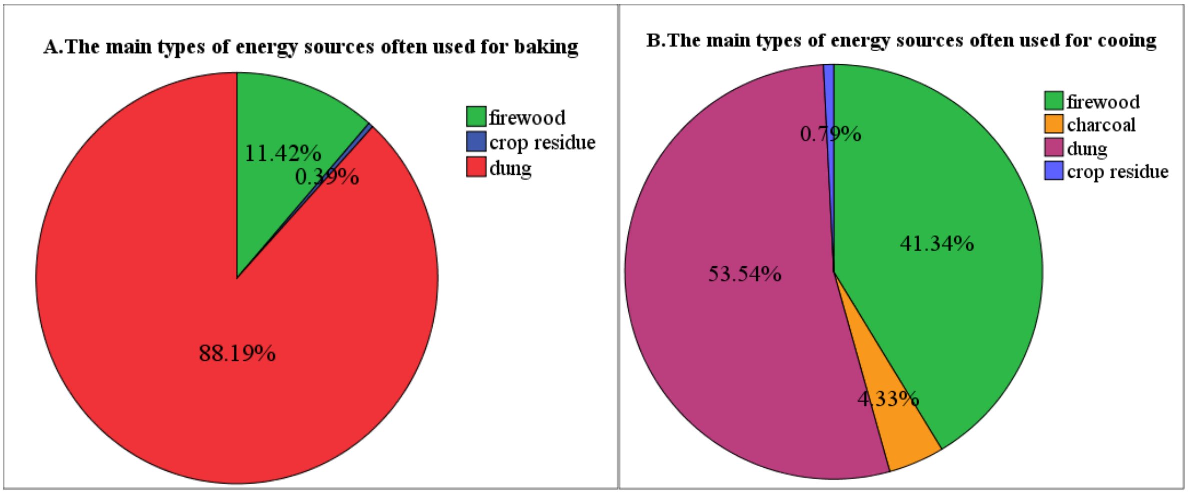

Figure 3: The main types of energy sources often used for baking and cooking by the sample household

The result in figure 3 above implies that animal dung was the dominant energy source often used for baking purpose in the study area almost eight times higher than firewood, but the proportion of crop residue was almost negligible. This clearly implies that the sample households are mostly dependent on dung than fuelwood to gain their daily energy demand for baking purposes in the study area. Because firewood availability is very limited and dung fuel is also freely available the whole year. Similarly, the result also indicates that still, dung fuel was also the dominant energy source often used for cooking more than one times of fuelwood. However, firewood was the dominant energy source most commonly used for

7 Cooking refers to the process of preparing stew (wet), soup, boiling water and boiling tea and coffee, etc.

cooking and baking purposes by the majority of the rural households in Ethiopia as a country (CSA and WB, 2013). This difference is due to the fact that in the study area fuelwood is very scarce and cutting trees for fuelwood use is not allowed by law. This could also have an effect in reducing firewood consumption. The result also indicates that fuelwood was often used for cooking purposes rather than for baking purposes in the study area. The main reason is that the rural households in the study area prefer fuelwood for cooking rather than for baking purposes. The findings of Alemu Mekonnen and Kohlin (2008) has also shown that particularly in the northern half of the Ethiopian high lands, the use of dung as manure is limited because a significant amount of dung is consumed as a source of household fuel. Additionally, Amogne Asfaw Eshetu (2014b) conducted a study in rural households of South Wollo, Amhara region, Ethiopia and found that the use of dung as a fuel is a common practice due to the shortage of fuelwood. Therefore, the major energy sources often used for baking and cooking are dung and firewood in the study area and other similar areas.

4.2.2. The Main Types of Energy Source for Lighting

The type of energy source for lighting by rural households partly determines the quality of life and the environment. As indicated in figure 4 below, the main type of energy source used by the total sample households for lighting purposes was 92.9% solar lantern, 5.1% electricity, 0.8% kerosene, 0.8% dry cell, 0.4% candle, respectively. The result implies that the use of solar energy sources for lighting in the study area was very common with some sort of access to electricity whereas the use of kerosene, dry cell and candle as an energy source for lighting in the study area was almost negligible because all these energy sources substituted by solar energy. In the study area, electricity was used only for lighting. The FGD Participants were mentioned that the main reason for not using electricity for baking is that electric power in the study area has not capacity to run the baking technology. In sum, the main energy source for lighting in the study area is solar energy. Using clean alternative energy sources like solar energy for lighting has a significant role in improving the health of the families as well as to protect the environment as it is a green source of energy.

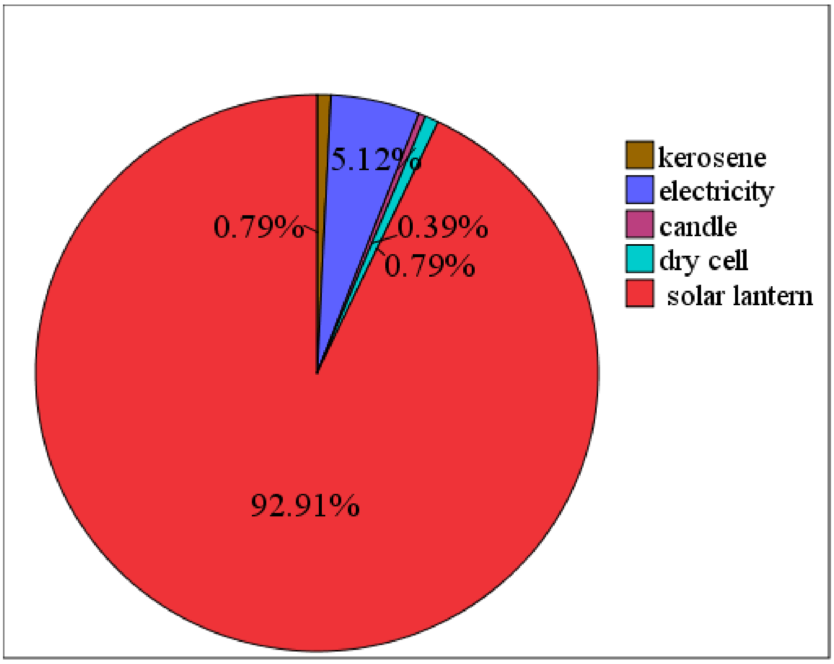

Figure 4: The main types of energy source often used for lighting by the sample household

4.3. Main Source of Biomass Energy

4.3.1. Source of Wood Fuel

Rural households in the study area obtain traditional biomass energy for domestic energy use from various sources. As shown in figure 5 below, the result reveals that 31.89% of the sample households obtain their fuelwood demand for household energy use from their own plantation, and 40.94% excessively depends on community forest, 8.66% purchasing, while the rest 18.11% combine own plantation and community forest. The households who do not have fuelwood source were negligible. This finding is consistent with the findings of Abebe Damte et al. (2011) who was found that rural households in Ethiopia, their biomass energy sources are obtained from their own field, natural forest and state or government forests, only very few households (4.5%) purchase fuelwood. Similarly, a study conducted in Tanzania by Lp (2016) also found a similar finding, a number of households collected firewood from natural forest, plantation forest and own farm and other places. The result clearly implies that the dominant fuelwood source for the majority of the households for domestic energy use in the study area was the community forest. Collecting fuelwood from the forest in an unsustainable way exacerbates the deforestation and forest degradation. Furthermore, especially women's and children's lost an ample amount of time for fuelwood collection that can be used for other productive activities. Janssen and Rutz (2012) stated that the collection and use of biomass for traditional bioenergy systems can contribute to the overexploitation and degradation of ecosystems example, forest degradation or deforestation, loss of soil fertility and biodiversity. However, There is an inspire finding that is a significant number of households also had their own plantation for fuelwood sources. This practice should be encouraged to solve the problem of fuelwood scarcity and to ensure the sustainable fuelwood harvest in the study area and other similar areas.

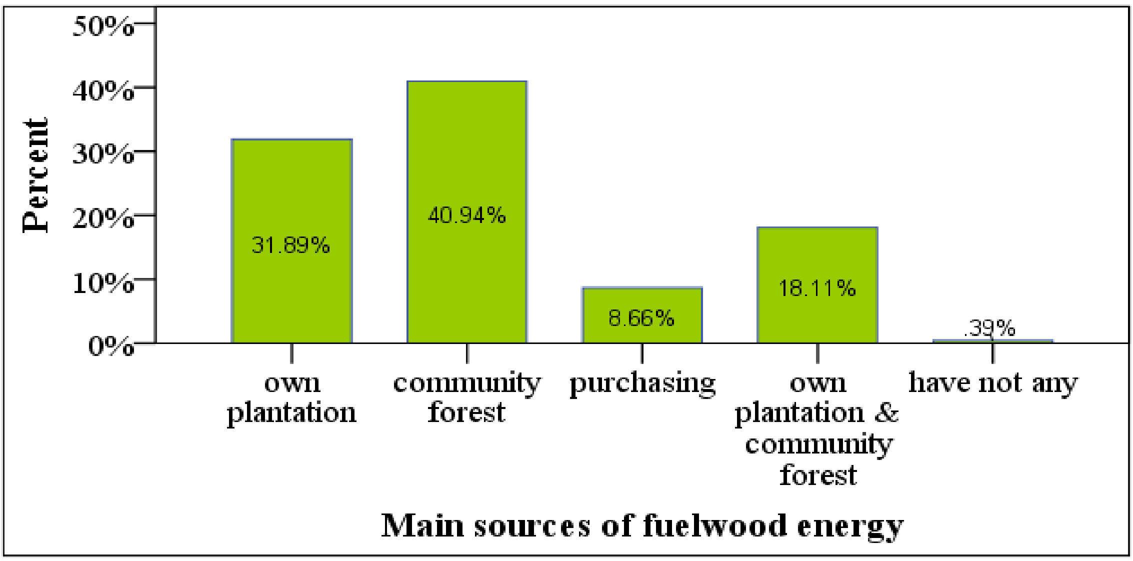

Figure 5: The main sources of fuelwood for domestic energy use in the study area

4.3.2. Source of Dung Fuel

Dung fuel is one of the traditional biomass energy sources for a number of rural households in many rural areas in Tigray, Ethiopia. The results presented in figure 6 below indicate that the main sources of dung fuel for household energy use in the study area are own cattle

57.87%, collecting from field 27.56%, both own cattle and collecting from field 14.57%, respectively. This result showed that the majority of the rural households in the study area obtain their daily dung fuel demand for household energy use from their own cattle, although a significant number of rural households collect dung fuel from the field, indicating that wood fuel is not much available in the study area. Collecting dung for household fuel use has an impact on reducing soil fertility in the study area, as well as burning dung for energy use, which also impacts the health of the family. Zenebe Gebreegziabher et al. (2007) and Legesse Abate (2016), stated that collecting dung and crop residue for household energy use impacts land quality and agricultural productivity through reducing the soil fertility because dung and crop residues are important for soil humus and soil fertility improvements.

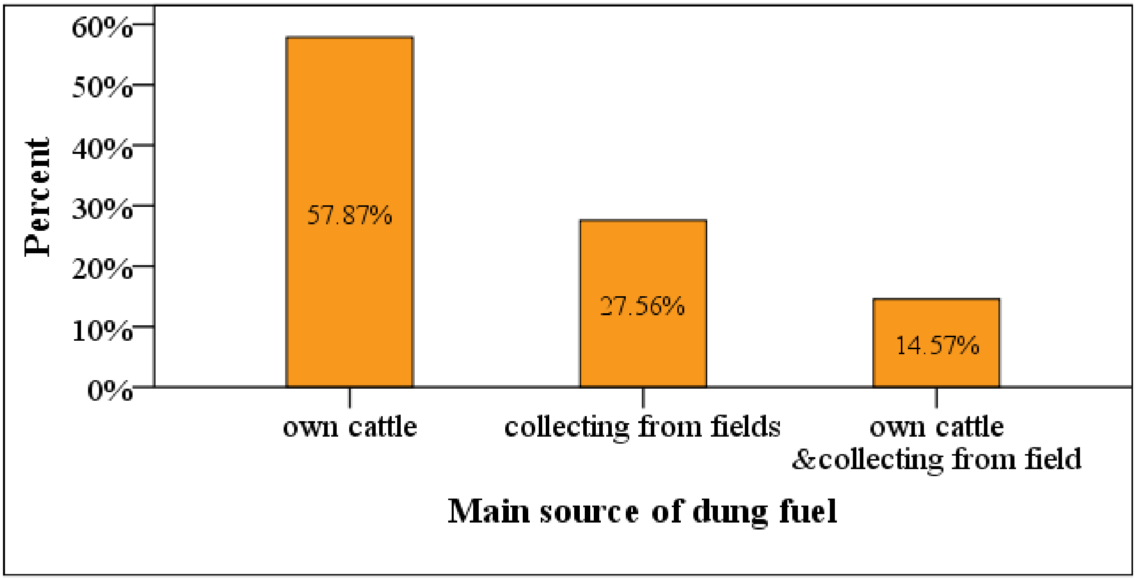

Figure 6: The main source of dung fuel for domestic energy use in the study area

4.3.3. Source of Charcoal

Charcoal is among the traditional biomass energy sources that commonly used for cooking purposes in most developing countries. As shown in figure 7 below, the main sources of charcoal in the study area for household energy use were purchasing 14.57% and preparing by themselves 12.99%, respectively. However, 72.44% of the sample households did not use charcoal as an energy source. Almost 27.56% of the sample households used charcoal as an energy source in the study area. However, the results in Table 6 below shows that the proportion of charcoal used for cooking by the sample households were 6.33% only which is very small compared to firewood and dung fuel consumption. Even though, to produce charcoal so much wood biomass is demanded that can lead to deforestation and forest degradation. Furthermore, burning of wood fuel to produce charcoal using traditional Kline emits so much greenhouse gases into the environment which can cause climate change and can also impact the health of human beings.

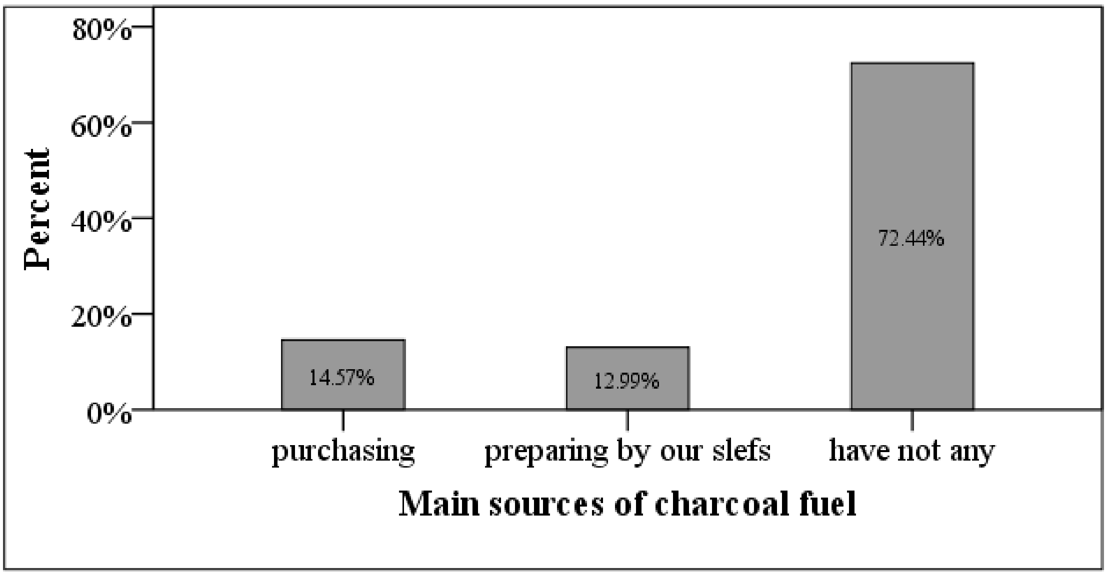

Figure 7: The main source of charcoal for domestic energy use in the study area

4.4. The status of Improved Cookstove Adoption

This study mainly focused on the determinants of improved cookstove adoption and their potential contribution to biomass fuel saving and greenhouse gas emission reduction. To understand the status of adoption of improved cookstoves in the study area the sample rural households were asked the types of stoves currently used for cooking and baking purposes in their home. Figure 8A below indicates that out of the 254 respondents 109 (42.91%) had adopted and currently used Mirt improved cookstove while the remaining 145 (57.09%) were used the traditiona closed mud stove for baking (Injera and Bread) purposes. Furthermore, figure 8B below also shows the types of stoves used currently for cooking purpose that

45.28% were traditional mud stove, 14.96% both Lakech improved charcoal stove and traditional mud stove, 11.42% both traditional metal charcoal stove and traditional mud stove, 18.11% Lakech charcoal stove, 8.66% traditional metal charcoal stove, and 1.57% Mirchaye improved charcoal stove, respectively. The result suggests that the majority of rural households used traditional stoves for baking and cooking purposes. It also indicates that the level of adoption of improved cooking and baking technologies in the study area is until now low.

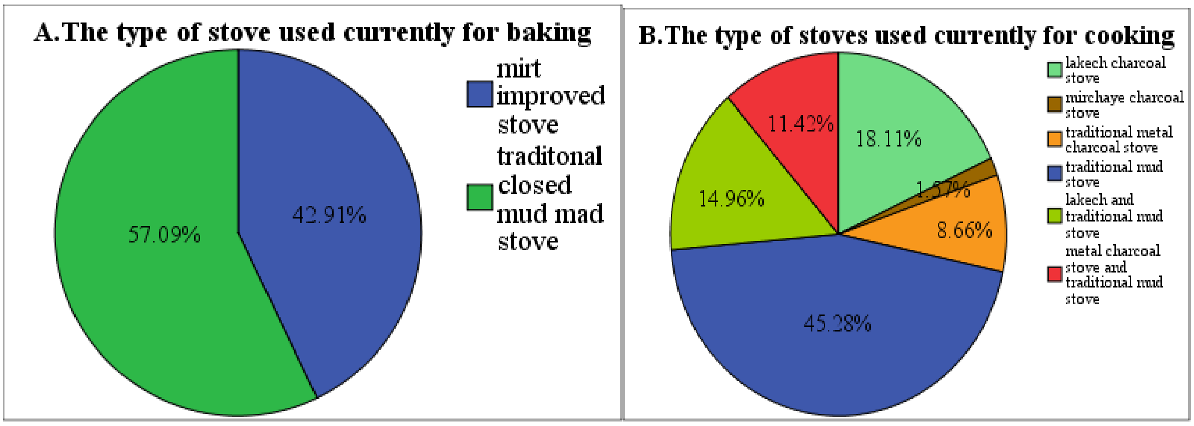

Figure 8: The types of stoves currently used for baking and cooking in the study area

Different findings have shown that the adoption rate of improved cookstove widely vary from 40% in rural Mexico (Ruiz-Mercado et al., 2011), 60% in Kenya (Silk et al., 2012) and almost 100% in Senegal (Bensch and Peters, 2012). A study conducted by Legesse Abate, (2016) in rural Enderta district, Tigray, Ethiopia, also found that 43.40% of the households have access to improved cookstoves while 56.60% have not. The low adoption rate of improved cookstoves could be attributed to different reasons. The results in Table 12 shows that the main reasons for not adopting the improved cookstove are lack of awareness, the price of the stove is expensive, lack of credit facility and the stoves produced and disseminated have low quality are among the many reasons. Furthermore, the participants of FGD also stated that the main reasons for the low adoption of the improved cookstoves were one, inadequate information about the particular innovation. Second, Mirt improved cookstove is not affordable in terms of its design i.e. its height is short and its wood inlet is also too narrow to insert big wood logs and thirdly, the stove produced and disseminated has a low quality. The picture below shows some of the types of stoves used for baking and cooking in the study area i.e. Mirt improved cookstove and traditional mud closed stove.

Figure 9: Mirt improved (left) and traditional mud closed (right) baking stoves

Figure 10: Traditional mud closed cooking stoves in the study area

4.5. Domestic Energy Consumption

4.5.1. Domestic Energy Consumption of the Sample Households

As shown in table7, the average monthly various fuel types for household energy use had been computed. Accordingly, the monthly average total energy consumption of sample household was about 2299.904MJ, excluding biogas, solar energy, candle, and battery. Out of this, the traditional biomass fuels had a share of 2250.32 MJ (97.84%) of the total energy consumption per month per household. Fuelwood and Dung fuel alone had a share of 2063.9MJ (89.74%) of the total household energy consumption per month per household. Fuelwood alone had a share of 916.45MJ (39.85%), While dung fuel constituted 1147.45MJ (49.89%) of the total energy consumption of each sample households. The consumption of kerosene and electricity was found almost 2.16% which is negligible.

The result clearly indicates that firewood and dung fuel are the main energy sources for rural household use in the study area. A study conducted in rural Tigray, Ethiopia by Melaku Berhe et al. (2017) found a similar finding, the consumption of firewood and animal dung was 14.6 kg (226.3MJ) and 19.3kg (266.34MJ) per week per household. Consumption of kerosene was also found negligible. Similarly, Zenebe Gebreegziabher et al. (2007) has also found the consumption of dung to be 28.43kg and wood fuel 13 kg per week per household. Furthermore, Legesse Abate (2016) conducted a study on rural areas of Enderta wereda, Tigray, Ethiopia was found that large proportion of households are dependent on firewood and dung source of energy for household use while the consumption of crop residue and kerosene were found to be the lowest energy sources consumed in the study area. The results indicated that animal dung was the dominant energy source for household energy use. The ideas raised in the focus group discussion also supported the result they concluded all that dung as their main fuel source. The main reasons rose in the discussions were one, dung is freely available the whole year. Second, since the area has higher deforestation and forest degradation due to different reasons such as cutting trees for fuelwood use is not allowed by law in the study area. They also mention that for solving the fuelwood problem in the study area the government is taking a measurement through distributing seedlings and giving technical support to plant 50 Eucalyptus seedlings each household every year on their backyard or on other marginal lands around their settlements.

Table 7: Mean domestic energy consumption of the total sample households (n = 254)

Fuel type	Mean consumption per month per household in MJ			95% confidence interval		% share
	Mean	S.D	S.E	Lower	Upper	
Fuelwood	916.45	389.80	24.458	868.284	964.6213	39.85
Charcoal	145.491	240.677	15.101	115.751	175.231	6.33
Crop residue	40.925	134.012	8.408	24.365	57.485	1.78
Dung fuel	1147.451	472.351	29.638	1089.083	1205.819	49.89
Kerosene	0.638	6.061	0.380	-0.111	1.387	0.028
Electricity	48.946	95.998	6.024	37.083	60.808	2.128
Total	2299.904	809.255	50.777	2199.904	2399.903	100

Source: Own Survey, 2019

4.5.2. Domestic Energy Consumption of Mirt ICS Adopter Households

The domestic energy consumptions of the adopter sample households have also relied on traditional biomass energy. The average monthly fuelwood, dung fuel, charcoal, and crop residue consumption of each Mirt improved cookstove adopter sample households before adopting the Mirt improved cookstove technology was 83.14kg, 102.76kg, 5.84kg, and 3.27 kg, respectively. While the average monthly consumption of each household after adopting the Mirt improved cookstove technology was 46.43kg, 58.185kg, 4.10kg, and 2.42kg, respectively in the same order. The reduction in fuelwood, dung fuel, charcoal and crop residue consumption was 44.15%, 43.38%, 29.97%, and 25.91%, respectively. The independent samples test results indicate that there is a significant mean difference in both the fuelwood and dung fuel energy consumption before and after Mirt improved cookstove adoption, p-value < 0.001. In the same way, there was also a significant mean difference in charcoal consumption before and after Mirt improved cookstove adoption at p-value = 0.002, but crop residue is not significant (Table 8).

Table 8: Mean domestic biomass energy consumption of Mirt stove adopter households (n =109)

Fuel type	Mean consumption per month per HH in kg						mean difference	p-value
	Before	S.D	S.E	After	S.D	S.E		
Fuelwood	83.139	28.390	2.719	46.429	18.178	1.741	36.71	0.000
Charcoal	5.844	9.713	0.930	4.091	6.809	0.652	1.753	0.002
Crop residue	3.269	7.913	0.758	2.422	6.700	0.642	0.847	0.052
Dung fuel	102.76	28.836	2.762	58.185	20.475	1.961	44.575	0.000
Total	195.02	51.323	4.916	111.128	32.994	3.160	83.887	0.000

Source: Own survey, 2019

In sum as table 8 above shows, the overall average traditional biomass energy consumption of the sample Mirt improved cookstove adopter households before and after adopting the Mirt improved cookstove technology was 195.0kg and 111.13kg per month per household, respectively. The mean difference in biomass energy consumption due to Mirt improved cookstove adoption and other factors was 83.89kg (43.02%) per month per household, fuel savings. The paired samples test indicates that there was also a significant average monthly traditional biomass energy consumption difference before and after adopting Mirt improved cookstove, p-value < 0.001. According to the Mines and Energy Agency of Tigray region official report of 2016 up to 2018, around 100,005 Mirt improved cookstoves were distributed to the rural households. If all these distributed improved cookstoves perform effectively and used sustainably, it would then be enabled to save approximately about 100,673 tons of biomass fuel from burning per annum. This implies improved cookstoves have a significant contribution to achieving the climate resilient green economy strategy as one of the mechanisms to abate GHG emissions due to burning of biomass fuels for household energy use. A study conducted in rural India by Hazra (2014) had found that households that had improved cookstoves were used significantly less firewood than households with only traditional stoves. The result is also consistent with the findings of

USAID (2017); improved cookstoves can reduce fuel use by 30-60% as compared to the traditional cookstoves. A similar finding was also found by Bensch and Peters (2012) that for all meals and dish types the improved cookstove consumes substantially less firewood than the traditional open fire stoves, the savings ranged between 39% and 46%. Therefore, Mirt improved cookstoves have an important contribution for reducing traditional biomass energy consumption and thus, reducing deforestation and forest degradation due to the reduction of biomass fuel consumption in the study area and other similar areas.

4.5.3. Domestic Energy consumption of ICS Non-adopter Households

The non-adopter sample households used traditional biomass energy sources to gain their daily energy demand. The average monthly fuelwood, dung fuel, charcoal, and crop residue consumption of each Mirt improved cookstove non-adopter sample households before five years' time was 79.31kg, 106.67kg, 6.65kg, and 2.78kg, respectively. While the average monthly consumption of each Mirt improved cookstove non-adopter sample households after five years' time was 68.67kg, 101.914kg, 5.71kg, and 2.96kg, respectively. The paired samples test results indicate that there was a significant mean difference in fuelwood consumption before and after five years' time at 95% confidence interval, p-value < 0.001. Similarly, there was also a significant mean difference in dung fuel consumption. But, the mean difference in monthly consumptions of both charcoal and crop residue before and after five years' time was found insignificant at p-value > 0.05 (Table 9).

In general, the overall average traditional biomass energy consumption of the non-adopter sample households before and after five years' time was 195.41kg and 179.26kg per month per household, respectively. The mean difference due to different other factors was 16.16kg (8.27%) per month per household. While the average total reduction in traditional biomass energy consumption of the Mirt improved cookstove adopter sample households after adopting the Mirt improved cookstove technology was 83.89kg (43.02%) per month per household (Table 8). Therefore, the reduction in traditional biomass energy consumption due to adopting the Mirt improved cookstove was 67.73kg (34.75%) per month per household. Relatively a similar finding was found by Dagninet Amare et al. (2015) that Mirt improved cookstove user households can save more than 33% of the average annual wood fuel energy consumption than those households who use the traditional open fire.

Furthermore; when we compared the current total average traditional biomass energy consumption of the Mirt improved cookstove non-adopter and adopter sample households was 179.26 kg and 111.128 kg per month per household, respectively. The average reduction in traditional biomass energy consumption due to Mirt improved cookstove adoption was 68.132 kg (38.01%) per month per household or 0.82 tons per year per household of biomass energy consumption saved. This result implies that large scale dissemination of improved cookstoves has an important contribution in reducing biomass energy consumption, thus enables to reduce deforestation and forest degradation since biomass energy demand for household use is one of among the main reasons in the context of Ethiopia for deforestation and forest degradation. This finding was more or less similar to the findings of (FDRE, 2011); introducing efficient stoves reduce forest degradation by saving 0.9 tons of biomass per year per household. The result is also consistent with the findings of Amogne Asfaw Eshetu, (2014b), improved cookstoves enable to reduce fuelwood demand for household energy consumption, as a result, the rate of deforestation and forest degradation reduces through savings of an ample amount of wood fuel, animal dung and crop residue utilization which also helps to increase land productivity through increasing soil fertility. As mentioned in the CRGE document of Ethiopia, improved cookstoves have the potential to save fuelwood on average by 50 percent as compared to the traditional once (FDRE, 2011). The main reason for this difference might be that in this study, the Mirt improved cookstove was compared with the mud closed traditional stove. Therefore; development and dissemination of the Mirt improved cookstoves at large scale have a vital role in saving the traditional biomass energy consumption at the rural household level. And consequently, it reduces deforestation and forest degradation due to fuelwood collection for household energy consumption.

Table 9: Mean domestic biomass energy consumption of non-adopter households before and after five years (n = 145)

Fuel type	Mean consumption per month per HH in kg						mean difference	p-value
	Before	S.D	S.E	After	S.D	S.E		
Fuel Wood	79.31	26.801	2.226	68.67	25.488	2.117	10.640	0.000
Charcoal	6.652	11.261	0.935	5.713	9.225	0.766	0.939	0.218
Crop residue	2.776	7.804	0.648	2.958	10.317	0.857	-0.182	0.691
Dung fuel	106.67	23.804	1.977	101.91	30.294	3.818	4.758	0.006
Total	195.41	44.343	3.682	179.26	45.980	3.818	16.156	0.000

Source: Own survey, 2019

4.6. Determinants of Mirt Improved Cookstove Adoption

To identify the major determinants of Mirt improved cookstove adoption, the binary logistic regression analysis was performed and the findings were presented in table 10 below. The results indicated that among the independent variables fitted into the model, eight variables i.e. sex of household head, education level of household head, annual cash income of the household head, price of Mirt improved cookstove, access to credit facility, distance to market, fuel saving and awareness were found statistically significant at p-value < 0.05. Moreover, among all the variables included in the model, the age of household head, education level, annual cash income, house ownership, access to the credit facility, fuel scarcity, and fuel-saving were found positively correlated with Mirt improved cookstove adoption. While, sex of household head, family size, the price of Mirt improved cookstove and distance to market were found negatively correlated with Mirt improved cookstove adoption (Table 10). This implicates that socio-economic, institutional, stove characteristics and knowledge and awareness are important factors for the dissemination and use of Mirt improved cookstoves to the wider community.

The binary logistic regression analysis results also revealed that the model performance or omnibus tests of the model coefficients for all the explanatory variables fitted into the model was found statistically significant (chi-Squared=286.766, degree of freedom= 12 and p < 0.001). Hence, the Hosmer and Lemeshow test of the goodness of fit of the logistic regression model indicated that the model fits the data well (chi-Squared=0.564, degree of freedom=8 and p > 0.05). Furthermore, the descriptive measures of the full model summary goodness of fit also support that the model fits the data well (-2LL= 60.211, Cox and Snell R-squared=67.7% and Nagelkerke R-Squared= 90.8%). The overall correct classification of cases had increased from 57.1% to 94.9%. Therefore, all these results of the tests of the goodness of fit of the model support the quality of the model.

Table10: Binary logistic regression estimation of the major factors influencing Mirt ICS adoption

Variables	β	S.E	Wald	Sig.	Odds ratio	95% Confidence interval	
Sex of HHH (1=male)	-3.351	0.98	11.693	0.001***	0.035	0.005	0.239
Age of HHH	0.056	0.038	2.150	0.143	1.058	0.981	1.141
Education level	0.286	0.120	5.649	0.017**	1.331	1.051	1.686
Income level (ln)	1.828	0.927	3.892	0.049**	6.224	1.012	38.282
Family size	-0.100	0.216	0.215	0.643	0.905	0.593	1.381
House ownership(1)	0.558	1.280	0.190	0.663	1.747	0.142	21.454
Price of Mirt ICS(1)	-1.668	0.830	4.043	0.044**	0.189	0.037	0.959
Access to credit(1)	2.166	0.838	6.688	0.010***	8.726	1.690	45.067
Distance to market	-0.409	0.166	6.097	0.014**	0.664	0.480	0.919
Fuel scarcity	0.162	0.263	0.378	0.539	1.176	0.702	1.970
Fuel saving	0.005	0.001	22.401	0.000***	1.005	1.003	1.008
Awareness(1=yes)	1.990	0.928	4.598	0.032**	7.314	1.186	45.087
Constant	-23.616	8.934	6.988	0.008	0.000		
Observation		*254*					
Omnibus Tests of coefficient		*Chi-square* *p-value*				*286.788* *0.000*	
Model Summary		*-2log likelihood* *Cox and Snell R square* *Nagelkerke R square*				*60.11* *0.677* *0.908*	
Hosmer and Lemeshow Tests		*Chi-square* *p-value*				*0.567* *1.00*	
Classification		*Overall percentage (cut value=0.5)*				*94.9%*	

****and** represent significance at 1% and 5% confidence level respectively.*

a) *variables entered on step1: SEXHH, AGEHH, EDUCA_HH, FAM_SIZE, INCOME (Ln), HOUS_OWN, PRICE_MIRT, DIST_FUEL, CREDIT_ACCESS, DIST_MARKET, MIRT_AWARE, FUELSAVING*

As shown in table 10 above, the association between sex of household head and Mirt improved cookstove adoption was found negative and significant (p<0.01), as expected. This negative association indicates that male headed households were less likely by an odds ratio of 0.035 times to adopt the Mirt improved cookstove compared to the female-headed households. This implies that female-headed household's priory decided to adopt the Mirt improved cookstove since in the context of Ethiopia the cooking and baking activities are primarily the responsibility of women’s and they are also the victims of the adverse effects of preparing food and collecting fuelwood as compared to their male counterparts. Kazzi (2016) stated that improved cookstoves have a positive advantage to women's because improved cookstoves reduce workloads of women's through reducing the cooking and fuel collection time. Jeuland et al. (2015) in rural India were also found a similar finding that female-headed households were more likely to adopt and use clean cookstoves.

As expected, the age of the household head had a positive association with Mirt improved cookstove adoption. The odds of adopting the Mirt improved cookstove were more likely by an odds ratio of 1.058 times as a unit increment in the age of household head, holding other variables constant but which is not statistically significant (p= 0.143) (Table 10). As individuals become older, they acquire experience and knowledge related to the benefits of new technologies and can accumulate wealth over time which would enable them to adopt new technology. In contrast, older people are more conservative and have a risk-averse attitude towards accepting a new technology (Okuthe and Akotsi, 2014). The result is consistent with the findings of Jan (2012); the age of household heads did not have significant effects on the improved stove adoption. In contrast, Fikadu Mamuye et al. (2018); found that the age of household head was found significant in the adoption of Lakech and Mirchaye improved cookstoves.

The results of the analysis also showed that the education level of the household head had a positive and significant correlation with Mirt improved cookstove adoption at p-value = 0.017, as expected. Controlled other factors, the odds of adopting the Mirt improved cookstove was more likely by an odds ratio of 1.331times as the education level of the household head increases by a unit more years of formal schooling (Table 10). This result supports to the idea of Erick and Kirubi (2018), education helps to improve human behavior and attitude, creates a favorable mind to make well-informed decisions to adopt new technologies. It is also similar with the findings of Abebe Beyene and Koch (2013); and Fikadu Mamuye et al. (2018) who obtained a positive and significant association between education level and adoption of the improved cookstove.

To overcome the linearity issues of the variable (Jan, 2012) a natural log of the total annual income was used as a predictor variable. The finding reveals the association between the total annual income of the household head and Mirt improved cookstove adoption was positive and significant at p-value = 0.049, as expected. If the total annual income of the household head increased by one Birr, the odds of adopting the Mirt improved cookstove was more likely by an odds ratio of 6.224 times (Table 10). Lewis and Pattanayak (2012), households that have higher income may have a higher probability to adopt new technologies. Earlier studies by Abebe Damte and Koch (2011); Jan (2012); Sesan (2012); And Fikadu Mamuye et al. (2018) indicated that income level had a positive and significant effect on the improved cookstove adoption. However; Sehjpal et al. (2014) conducted a study on rural India found that household income has not significantly influenced the adoption of new improved cookstove technologies. Therefore, the income level of the rural household is an essential factor for the dissemination of improved cookstoves at large scale to the wider community.

The results in table 10 indicate that family size was negatively correlated with Mirt improved cookstove adoption and was not statistically significant (p = 0.643). The result in table 6 also shows that the non-adopter sample households had higher family size than the adopter sample households. A unit increment in family size, the log odds of adopting the Mirt improved cookstove was less likely by the odds ratio of 0.905 times. The result is similar to the findings of Abebe Beyene and Koch (2013), they obtain family size was an insignificant factor in the adoption of Mirt improved cookstove. Jan (2012) was also found a similar finding. Jagger and Jumbe (2016) was conducted a study in rural Malawi and found that households with a large force for fuel collection were less likely to adopt improved cookstoves. But contrarily, a study on factor affecting urban energy transition and technology adoption by Zenebe Gebreegziabher et al., (2010) family size was obtained as a positive and significant determinant of the adoption of improved cooking appliances, electric “Mitad” and improved cookstoves.

House ownership of the sample households had a positive insignificant association with the Mirt improved cookstove adoption. Households who have their own house were more likely to adopt the Mirt improved cookstove by an odds ratio of 1.747 times compared to the households who have not their own house, but this was not significant ($p = 0.663$) (Table 10). A similar finding was found by Abebe Damte and Koch (2011).

The price of the Mirt improved cookstove had a negative and significant effect on adoption of the Mirt improved cookstove at $p = 0.044$, as expected. When there is a unit increment in the price of the Mirt improved cookstove, the likelihood of adopting the Mirt improved cookstove would be less likely by an odds ratio of 0.189 times, other factors kept constant (Table 10). Lewis et al. (2015), identify price as a significant barrier to adoption. Barnes et al. (1993), improved cookstoves are expensive relative to the local traditional stoves. Thus, people may be unable to afford the initial cost for buying the improved stove. The result is consistent with the findings of Sheha and Makame (2017), the initial cost of stoves was among the potential factors that influence the adoption of improved cookstoves by a wider community. It is also similar to the findings of Brooks et al. (2016), the price had a negative and significant association with improved stove use.

The result also indicated that access to credit facilities had a positive and significant association with Mirt improved cookstove adoption at p-value = 0.01, as expected. Households who have access to credit facilities for Mirt improved cookstoves were more likely for adopting the Mirt improved cookstove by an odds ratio of 8.726 times compared to the households who have not access to credit (Table 10). A review conducted by Lewis and

Pattanayak, (2012) also found a similar finding that access to credit facility had a positive and significant influence on the adoption of improved cookstoves. Melaku Berhe et al. (2017) also reported that access to credit positively and significantly influence the adoption of biogas technology. Therefore, the availability of credit facilities can have a positive implication in solving the financial constraints of rural poor households in order to adopt clean energy technology.

The variable distance to market had a negative and significant correlation with the adoption of Mirt improved cookstove at 5% level of significance (p-value = 0.014). If distance to the Mirt improved cookstove market increased by one kilometer, the odds of adopting the Mirt improved cookstove were less likely by an odds ratio of 0.664 times, holding other variables constant (Table 10). This implies that households who are far away from the Mirt improved cookstove market or production center are less likely to adopt the Mirt improved cookstove than households who are near to the market. The finding by Hadush Hagos et al. (2018) was consistent with this result, that shows the distance from market affects negatively and significantly the adoption of improved agricultural technologies.

In this study, fuel scarcity was measured in terms of distance traveled and time taken to collect biomass fuel sources per trip. Since there was a multicollinearity problem between distance traveled and time is taken to collect biomass fuel sources, only distance traveled per trip to collect biomass fuel sources was incorporated into the Model analysis. Accordingly, the result indicated in table 10 show that there is a positive and insignificant association between fuel scarcity and Mirt improved cookstove adoption. If fuel scarcity increased by one unit, the likelihood of adopting Mirt improved cookstove was 1.776 times more likely but this was not significant (p= 0.539). This result is in line with the findings of Kazzi (2016) rural households do not perceive adopting an improved cookstove as a meaning full investment even scarcity of fuelwood have because fuelwood is often harvested freely. In contrast, Barnes (1994) was revealed that rural areas with fuelwood scarcity are more likely to adopt improved cookstoves.

The finding also showed that there is a positive and significant association between fuel saving and the adoption of Mirt improved cookstoves at p-value < 0.001, as expected. If there is a one kilogram increment in fuel consumption saving per month in the rural households, the odds of adopting the Mirt improved cookstove were more likely by an odds ratio of 1.005 times (Table 10). Zenebe Gebreegziabher (2006) households that have adopted the improved cookstove spent less time collecting wood and more efficient in their use of wood and they were statistically significant factors for improved cookstove adoption. Similarly, Debbi et al. (2014) and Kanangire et al. (2016), also found that significant fuel savings were considered as a motivation for adoption of the improved cookstove.

Results of the analysis in table 10 also show that awareness had a positive and significant association with the adoption of Mirt improved cookstove at p-value = 0.032, as expected. This indicates that, as individuals become more aware of the benefits of new improved technologies, the probability of adopting that technology increases. Similarly, the result indicates that those households who are aware of the benefits of the Mirt improved cookstove are more likely 7.314 times to adopt the Mirt improved cookstove than those households who were not aware of the benefits of the Mirt improved cookstove technology. A similar finding was found by Sheha and Makame (2017), lack of awareness was among the potential factors that hinder the adoption of improved cookstoves to the wider community. Chepkurui and Moronge (2016) also found that the level of awareness had a positive and significant influence on the utilization of improved energy saving cookstoves. Therefore, raising the awareness level of the rural households would help them to decide for adoption and sustained use of the more energy efficient improved biomass cookstoves.

4.7. Reasons to Adopt Mirt Improved Cookstove

Among the many reasons influencing the individuals to adopt the new improved innovation is its relative advantage in comparison to the old one to be expected to replace (Massawe et al., 2015). Out of the many reasons some of them were analyzed using descriptive statistics in this research study. Adopter sample households were asked to rank the top most important reasons for adopting the Mirt improved cookstoves. Accordingly the results in table 11 indicates that, 29.36% respondents reported own interest, 26.6% respondents identified fuel problem for domestic use, 25.69% of the respondents encouraged by the extension officer, 14.68% respondents influenced by friends/neighbors who had adopted Mirt improved cookstove and the rest 3.67% the respondents reported high cost of energy resource respectively. In the study area, fuelwood availability is very limited, to solve this problem extension services given by the government and previously distributed improved cookstoves also play a crucial role to influence positively individuals to adopt the improved cookstoves. The female participants of FGD also stated that the main reasons for the adoption of improved cookstoves are "enable us to prepare our foods with few fuelwoods, reduce deforestation, and enable us to cook quickly if once heated".

Table 11: The main reasons to adopt Mirt improved cookstove (n=109)

	Main reason	Frequency	Valid percent	Cumulative Percent	Rank
valid	Own interest	32	29.36	29.36	1
	Fuel problem for domestic use	29	26.6	55.96	2
	Encouraged by the extension officer	28	25.69	81.65	3
	Influenced by friends/neighbor's	16	14.68	96.33	4
	The high cost of energy resource	4	3.67	100	5
	Total	109	100		

Source: Own Survey, 2019

4.8. Reasons not to Adopt Mirt Improved Cookstove

The rural households could have so many reasons for not adopting the improved cookstoves. To examine the main reasons for not adopting the Mirt improved cookstove in the study area, the non-adopter sample households were asked to rank the main reasons for not adopting the Mirt improved cookstoves. The results in Table 12 below shows that out of the 145 respondents who give their response, 55.17% of the respondents reported a lack of awareness, 12.41% price of the stove is expensive, 9.66% lack of credit access, 8.97% lack of stove quality, 7.69% not accessible, 4.14% not affordable and 2.07% the stove has a higher smoke. The result implies that lack of awareness is the main challenge not to disseminate the improved cookstove at large scale. Price of the stove, lack of credit access, low stove quality and low availability stoves in the market are also the impediments to the adoption of improved cookstoves. This result is also consistent with the results of logistic regression analysis in table 10. The development agent, wereda and regional experts who participated in the FGD also mentioned that the main reasons for not adopting the Mirt improved cookstoves are lack of awareness, low attitude towards the benefits of improved cookstoves, design of the stove not afforded by majority of the individuals and low participation and integration of stakeholders are among the main challenges.

The government and other development partners also practically consider these constraints as the main impediments to improved stove dissemination and try to solve them through giving capacity building trainings to enhance the level of awareness of the rural households and the capacity of stove producers in order to improve stove quality and accessibility of stoves for rural households. Additionally, the government is working in cooperation with other development agents and research centers to improve the design of the stoves and produce new generations which are affordable to the user households.

Table 12: The main reasons for not adopting the Mirt improved cookstove (n= 145)

Response		Frequency	Valid percent	Cumulative Percent	Rank
Valid	Lack of awareness	80	55.17	55.17	1
	It is expensive	18	12.41	67.58	2
	Lack of credit access	14	9.66	77.24	3
	Lack of stove quality	13	8.96	86.20	4
	Not accessible	11	7.59	93.79	5
	Not affordable	6	4.14	97.93	6
	High smoke	3	2.07	100	7
	Total	145	100		

Source: Own Survey, 2019

4.9. Awareness and Attitude of the Sample Households

This section of the study assesses the level of awareness and attitude level of the sample households about the benefits of using Mirt improved cookstove, perception of the rural sample households of using improved cookstoves. Furthermore, it assesses the awareness level of the rural households in the study area about the adverse impacts of traditional biomass energy for households use using rudimentary stoves.

4.9.1. Awareness about the Benefits of Using Mirt Improved Cookstove

The Mirt improved cookstove adopter sample households were asked to rank the top most important benefits of using improved cookstoves to assess their level of awareness about the benefits of using improved cookstoves in the study area. As shown in table 13, the sample households were responded 64.2% reduce fuelwood consumption. The next most valued attributes are the ability to minimize forest degradation (15.6%) and improve health (11.9%). Only 5.5% and 2.8% of the respondents stated that they save both cooking and firewood collection time, and minimize fire-related accidents respectively. From this finding, one can easily understand that the adopter households in the study area are aware of more about the fuel saving capacity of improved cookstoves and their contribution to reducing forest degradation as well as their implications to heath. Governmental and non-governmental organizations promoted improved cookstoves to same extent using different promotion mechanisms in order to enhance the level of knowledge and awareness of the rural households about the multidimensional benefits of improved cookstoves, especially related to their potential for fuel saving and their contributions to protect deforestation and forest degradation because these problems are the prior issues in the study area.

Table 13: Awareness about the benefits of using Mirt improved cookstove (n = 109)

	Responses	Frequency	Valid percent	Cumulative percent	Rank
Valid	Reduce fuel wood consumption	70	64.2	64.2	1
	Minimize forest degradation	17	15.6	79.8	2
	Improve health	13	11.9	91.7	3
	Save cooking and firewood collection time	6	5.5	97.20	4
	Minimize fire related accident	3	2.8	100	5
	Total	109	100		

Source: Own Survey, 2019

4.9.2. Perception on Mirt Improved Cookstove

To assess the perception of the sample households about that whether improved cookstoves are compatible with the existing culture of the community, 254 sample households were asked to put their perception. The results in figure 11 below indicate that 1.57% strongly disagrees, 7.09% disagree, 9.84% neither (can't say) since they have little or have not information about the technology, 60.63% agree that improved cookstoves are compatible with our cultures and 20.87% the respondents also strongly agree. Those who agree and strongly agree were well aware of the benefits of the technology and adopted it or get an experience about the benefits of the technology from others. While these who strongly disagree and disagree about the compatibility of the technology with the existing culture had some doubts or had never heard of the technology before and also have the interests to use big logs of wood for cooking since the improved cookstoves are not appropriate for burning of large logs of wood. Kanangire et al. (2016) also found that beliefs and culture had a very negligible impact on the use of improved stoves. Therefore, majority of the rural households in the study area have a positive perception on improved biomass cookstove that is an advantage to improve the ICS adoption rate.

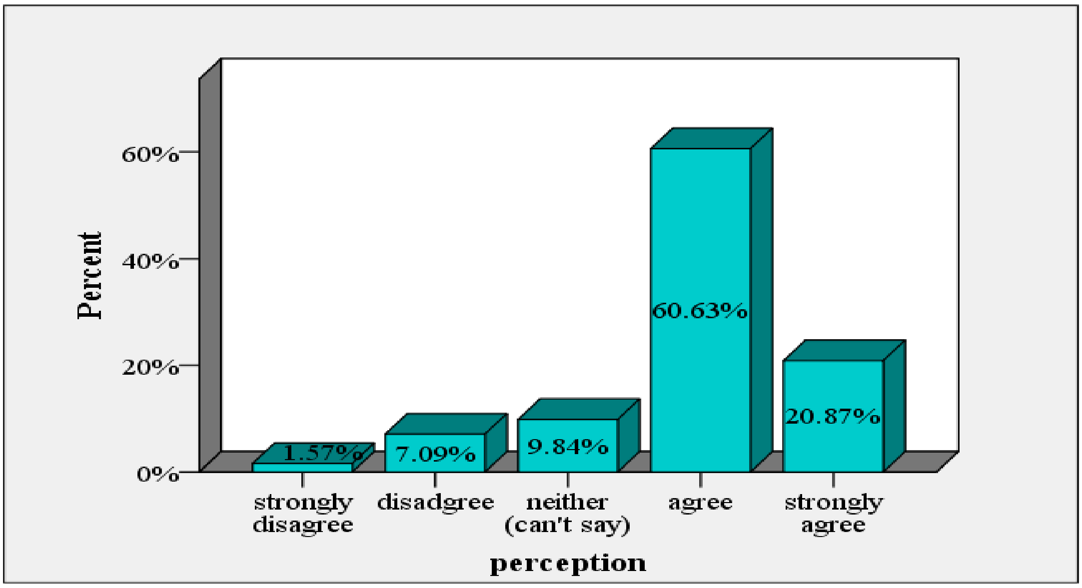

Figure 11: Perception on the compatibility of Mirt improved cookstove with the existing culture

4.9.3. Awareness about Traditional Biomass Energy

Using biomass energy source in traditional ways in inefficient cookstoves have many direct and indirect adverse influences on human life and their environment. Emission from solid fuel burning in traditional stoves impacts the local, regional and global environment as well as the household's health (Jeuland et al., 2014). To assess the level of awareness of rural households in the study area the sample households were asked to rank the top important problems related to health, physical discomfort or injures associated with the use of traditional biomass energy using traditional cookstoves. The findings in table 14 show that, 7.5% headache, 55.5% eye irritation, 9.8% coughing, 13% difficulty of breathing, and 3.9% burning accident, 10.2% injury or violence during fuel collection respectively. Barnes et al.,

(2012) states that households used traditional biomass energy using rudimentary stoves, over the years they become accustomed to persistent coughing and watering of the eyes, which are symptomatic of overexposure into indoor air cooking smoke. Furthermore, exposure to smoke due to the burning of biomass energy sources contributes significantly to numerous respiratory illnesses and diseases, including acute respiratory infection, chronic obstructive lung disease, and lung cancer.

The ideas raised on the focus group discussion in all groups also support the result. They concluded all that cooking with dung and firewood using traditional stoves have high smoke and this smoke affects our health, especially women's and children's suffering with the health problem of eyes and respiratory organs since mothers spent more time holding their children's on their back to prepare food for their families.

Table 14: Awareness about health impacts of using traditional biomass energy with traditional stoves

	Problems	Frequency	Valid percent	Cumulative Percent	Rank
Valid	Headache	19	7.5	7.5	4
	Eye irritation	141	55.5	63	1
	Coughing	25	9.8	72.8	5
	Difficulty of breathing	33	13	85.8	2
	Burning accident	10	3.9	89.9	6
	Injury/violence in fuel collection	26	10.2	100	3
	Total	254	100		

Source: Own Survey, 2019

4.10. Greenhouse Gas Emission Estimation at Rural Household Level

4.10.1. GHG Emission of Mirt Improved Cookstove Adopter Households

Solid biomass burning is one of the major contributors to carbon dioxide emission, a principal gas in global warming and climate change (Manoa et al., 2017). To estimate the contributions of improved cookstoves intervention on total greenhouse gas emissions require the quantification of the amount of fuelwood savings due to the use of improved cookstoves

(Abebe Beyene et al., 2015a). The results in Table 15 below shows that the average annual greenhouse gas emission of the Mirt improved cookstove adopter sample households before adopting the Mirt improved cookstove technology was 4025.39 kg of CO_2 equivalent per household per year emitted into the environment due to burning of biomass energy source to gain their daily energy demand using the traditional made up of mud closed stove in the study area. Combustion of the traditional biomass fuels on an open fire or traditional stoves for household energy use has adverse effects on human health, environment and socio-economic development (Jagger and Jumbe, 2016; Puzzolo et al., 2013).

Table 15: Average GHG emission before Mirt improved cookstove adoption

Fuel type	consumption in kg or MJ per month per HH		Emission in kg of CO_2e /month/HH			Total Emission in kg of CO_2e /month/HH	Total Emission in kg of CO_2e/ year/HH
	kg	MJ	CO_2	CH_4	N_2O		
Fuelwood	83.139	1288.65	144.33	9.66	1.54	155.53	1866.36
Charcoal	5.844	169.48	18.98	1.27	0.20	20.45	245.45
Crop residue	3.269	49.04	4.90	0.37	0.06	5.33	63.96
Dung	102.76	1418.09	141.81	10.64	1.69	154.13	1849.62
Total	195.012	2925.25	310.02	21.94	3.49	335.45	4025.39

Source: Own survey, 2019

As the result indicates in table 16 below, the average annual greenhouse gas emissions of the sample households after Mirt improved cookstove adoption were 2308.78 kg of CO_2 equivalent per household per year. There is a substantial reduction in greenhouse gas emissions after adopting the Mirt improved cookstove compared with before adopting the Mirt improved cookstove technology. The reduction in greenhouse gas emissions after adopting the Mirt improved cookstoves were 1716.61 kg (42.64%) or 1.72 tons of CO_2 equivalent per household per year. If we consider the fraction of non-renewable biomass 0.88, which is the CDM default value for Ethiopia (UNFCCC,2012) as cited by Abebe

Beyene et al. (2015b), the estimated GHG emission reduction potential was 1.51 tons of CO_2 equivalent per household per year. According to CSA (2007) population and housing census of Ethiopia, 12,525,016 numbers of rural households have existed. Assume the dependence of rural households on biomass energy and the adoption rate of improved cookstove is the same as that of the study area (i.e. 42%), around 5.2 Million rural households could adopt the improved cookstove technology, which leads to GHG emission savings of about 7.9 Mt CO_2e per year, if they used sustainably. Assume the price reference of $5 to $15 per ton of CO_2e abate (CRGE, 2011), could be worth between $39.5 million and $118.5 million per annum. A study conducted by Vahlne and Ahlgren (2014) conclude that dissemination and sustained use of improved cookstoves have significant potential to reduce the amount of fuelwood consumed which leads to reducing the pressure on natural resource, substantial smoke emission reduction and have also a contribution to global warming mitigation. Therefore; improved cookstoves have a significant contribution in reducing the greenhouse gas emission due to the burning of traditional biomass fuels using inefficient stoves for household energy use at the rural household level in the study area and all other similar areas.

Table 16: The Average GHG emission after Mirt improved cookstove adoption

Fuel type	consumption in kg or MJ per month per HH		Emission in kg CO2e /month/HH			Total Emission in kg of CO_2e /month/HH	Total Emission in kg of CO_2e/ year/HH
	kg	MJ	CO_2	CH_4	N_2O		
Fuelwood	46.429	719.65	80.60	5.40	0.86	86.86	1042.27
Charcoal	4.091	118.64	13.29	0.89	0.14	14.32	171.83
Crop residue	2.422	36.33	3.63	0.27	0.04	3.95	47.39
Dung	58.185	802.95	80.30	6.02	0.96	87.27	1047.29
Total	111.128	1677.57	177.82	12.58	2.00	192.4	2308.78

Source: Own survey, 2019

4.10.2. GHG Emission of Mirt Improved Cookstove Non-adopter Households

As the results indicated in Table 9 above, rural households that were not using the improved cookstove for burning the biomass energy sources to meet their daily energy need had consumed more biomass fuel. Furthermore; the results in Table 17 below indicate that the average annual greenhouse gas emissions of the Mirt improved cookstove non-adopter sample households due to the burning of biomass energy for their daily needs were 3661.99 kg of CO_2 equivalent per household per year. When we compared this with GHG emissions of the Mirt improved cookstove adopter sample households, the non-adopter sample households were emitting 1353.21kg (36.95%) of CO_2 equivalent per household per year more. This result also supports to the result in table 15 above i.e. the adopter sample households were similarly emitted more GHG emission before adopting the Mirt improved cookstove.

Table 17: The Average GHG emission of Mirt improved cookstove non-adopter households

Fuel type	consumption in kg per month per HH		Emission in kg of CO_2e /month/HH			Total Emission in kg of CO_2e /month/HH	Total Emission in kg of CO_2e/ year/HH
	kg	MJ	CO_2	CH_4	N_2O		
Fuelwood	68.67	1064.39	119.21	7.98	1.27	128.46	1541.55
Charcoal	5.713	165.68	18.56	1.24	0.20	20.00	239.95
Crop residue	2.958	44.37	4.44	0.33	0.05	4.82	57.87
Dung	101.26	1397.39	139.74	10.48	1.67	151.88	1822.62
Total	178.60	2671.82	281.94	20.04	3.18	305.17	3661.99

Source: Own survey, 2019

4.10.3. GHG Emission Comparison between Adopter and Non-adopter Households

The average annual greenhouse gas emissions of the Mirt improved biomass cookstove adopter and non-adopter sample households were 2308.78kg and 3661.99kg of CO_2 equivalent per household per year respectively (Table 18). The mean annual greenhouse gas emission difference between the Mirt improved cookstove adopter and non-adopter sample households were 1353.21kg or 1.35 tons of CO_2 equivalents per household per year. Considering the fraction of non-renewable biomass 0.88, which is the CDM default value for Ethiopia, the estimated GHG emission reduction was 1.19 tons of CO_2 equivalents per household per year. This result indicates that as the rural households adopting the Mirt improved cookstove technology, it can enable them to reduce their greenhouse gas emissions into the environment by almost 37% of their emissions per year per household. The Ethiopian government had targeted to distribute 9.4 million improved cookstoves over the mid-decade. Assume that half of the stoves distributed would be Mirt improved cookstove and perform effectively and sustainably, this would then be enabled to save approximately 5.59Mt of CO_2e per year. This finding was also consistent with USAID (2017), clean and efficient stoves can save anywhere from 1-3 tons of CO_2e/stove/year, with 1-2 tons being most common. Kanangire et al. (2016) also concluded that the dissemination of improved cookstove technologies was among the mechanisms to minimize indoor air pollution as well as to mitigate climate change. Therefore; dissemination of Mirt improved cookstove to the wider community have a significant influence in mitigating climate change through reducing greenhouse gas emission into the environment and also have an essential contribution in reducing indoor air pollution which is one of the leading reasons for the death of human being, especially women’s and children’s in developing countries like Ethiopia.

Table 18: Comparison of average annual GHG emission of the adopter and non-adopter sample households

Fuel type	Total emission in kg CO_2e/year/HH		Emission reduction in kg/year/HH (a-b)	Percent of GHG reduction
	Non-adopter (a)	Adopter (b)		
Fuelwood	1541.55	1042.27	499.28	32.39
Charcoal	239.95	171.83	68.12	28.39
Crop residue	57.87	47.39	10.48	18.11
Dung	1822.62	1047.29	775.33	42.54
Total	3661.99	2308.78	1353.21	36.95

Source: Own Survey, 2019

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The major energy sources often used for baking and cooking purposes are animal dung and fuelwood at rural household in the study area. While the use of crop residue and other fuel sources for baking purposes are almost negligible. The majority of rural households in the study area use solar energy for lighting, but the use of kerosene, dry cell and candle for lighting are insignificant.

The average biomass energy consumption of rural households in the study area is significantly reduced after improved cookstove adoption. Similarly, the improved cookstove adopter rural households significantly consume less biomass energy compared to the non-adopter rural households in the study area. Therefore, development and dissemination of improved cookstove at a large scale have a positive significant effect to reduce the biomass energy consumption of the rural household.

The adoption status of the improved cookstove technology has been found low among rural households. The binary logistic regression model analysis results indicated that the education level of the household head, annual income level, access to credit facilities, fuel saving and awareness had a positive and significant influence on improved cookstove adoption. Furthermore, the sex of household head, the price of the improved cookstove, and the distance to improved cookstove market influences Mirt improved cookstove technology adoption negatively and significantly.

The adopter households had more awareness about the benefits of improved cookstoves mostly related to fuel saving, contribution to reduce forest degradation, and their implication to health improvement. Furthermore, majority of the rural households in the study area have a positive perception on improved cookstoves in relation to their beliefs and cultures.

The estimated average greenhouse gas emission of the rural households who adopt and use the improved cookstove technology is significantly reduced compared to the non-adopter rural households in the study area and other similar areas. This implies that improved cookstove technologies have a potential contribution to mitigate the greenhouse gas emission into the environment due to the burning of biomass fuel for household energy use.

5.2. Recommendations

Based on the study findings the following policy recommendations have been proposed.

- ❖ Development and dissemination of Mirt improve cookstove technologies should be encouraged to reduce the biomass fuel consumption for household use that could adversely impact the forest resource.
- ❖ The government and all other development agents should give due attention to improve education level, enhance access to credit facilities, raise awareness level of rural households, increase income level of rural households, make price of improved cookstoves affordable to the user to improve the adoption rate of Mirt improved cookstov.
- ❖ It is better to approach female members and empower them through credit access, training and education, if development agents want to improve the adoption rate of the improved cookstoves.
- ❖ To mitigate the GHG emission due to burning of biomass fuel for household use, large scale dissemination of Mirt improved cookstove should be targeted.
- ❖ Further research should be carried out by the researchers and scientific communities on improved cookstoves to measure more precisely their implications to reduce biomass energy consumption as well as their contribution for social, economic and environmental benefits. Furthermore, if anyone wants to conduct more precise researches on this area, the researcher should consider into account fuel type, fuel property, operating condition, quality of stove maintenance and age of the stove used to burn the fuel etc.

REFERENCES

Abebe Beyene, Koch, S.F., 2013. Clean fuel-saving technology adoption in urban Ethiopia. Energy Economics 36, 605–613.

Abebe Beyene, Bluffstone, R., Zenebe Gebreegzhiaber, Martinsson, P., Alemu Mekonnen, Vieider, F., 2015a. Do Improved Biomass Cookstoves Reduce Fuelwood Consumption and Carbon Emissions? Evidence from Rural Ethiopia Using a Randomized Treatment Trial with Electronic Monitoring, Policy Research Working Papers. The World Bank.

Abebe Damte, Koch, S.F., 2011. Covariates of Fuel Saving Technologies in Urban Ethiopia. Presented at the World Renewable Energy Congress, Linköping, Sweden, pp. 1046–1053.

Abebe Damte, Koch, S.F., Alemu Mekonnen, 2011. Coping with Fuel Wood Scarcity: Household Responses in Rural Ethiopia 36.

Agarwal, B., 1983. Diffusion of rural innovations: Some analytical issues and the case of wood-burning stoves. World Development 11, 359–376.

Alemu Mekonnen, Kohlin, G., 2008. Biomass Fuel Consumption and Dung Use as Manure: Evidence from Rural Households in the Amhara Region of Ethiopia. Environment for Development 23.

Al-Subaihi, A.A., 2003. Sample size determination, Influencing factors and calculation strategies for survey research. Neurosciences 8, 79–86.

Amogne Asfaw Eshetu, 2014a. Role of fuel efficient stoves in achieving the millennium development goals: case of Ethiopia. E3 Journal of Environmental Research and Management 5, 0156–0168.

Amogne Asfaw Eshetu, 2014b. Factors Affecting the Adoption of Fuel Efficient Stoves among Rural Households in Borena Woreda: North central Ethiopia. International Journal of Energy Science 4, 141.

Bailis, R., Drigo, R., Ghilardi, A., Masera, O., 2015. The carbon footprint of traditional woodfuels. Nature Climate Change 5, 266–272.

Balakrishnan, K., Ramaswamy, P., Sambandam, S., Thangavel, G., Ghosh, S., Johnson, P., Mukhopadhyay, K., Venugopal, V., Thanasekaraan, V., 2011. Air pollution from household solid fuel combustion in India: an overview of exposure and health related information to inform health research priorities. Global Health Action 4, 5638.

Barnes, D.F. (Ed.), 1994. What makes people cook with improved biomass stoves? A comparative international review of stove programs, World Bank technical paper, Energy series. World Bank, Washington, D.C.

Barnes, D.F., Kumar, P., Openshaw, K., 2012. Cleaner Hearths, Better Homes New Stoves for India and the Developing World. World Bank, New Delhi.

Barnes, D.F., Openshaw, K., Smith, K.R., Plas, R. van der, 1993. The Design and Diffusion of Improved Cooking Stoves. The World Bank Research Observer 8, 119–141.

Bensch, G., Peters, J., 2015. The intensive margin of technology adoption – Experimental evidence on improved cooking stoves in rural Senegal. Journal of Health Economics 42, 44–63.

Bensch, G., Peters, J., 2012. A Recipe for Success? Randomized Free Distribution of Improved Cooking Stoves in Senegal. SSRN Electronic Journal.

Birhane, E., Mengistu, T., Seyoum, Y., Hagazi, N., Putzel, L., Rannestad, M.M., Kassa, H., 2017. Exclosures as forest and landscape restoration tools: lessons from Tigray Region, Ethiopia. International Forestry Review 19, 37–50.

Brooks, N., Bhojvaid, V., Jeuland, M.A., Lewis, J.J., Patange, O., Pattanayak, S.K., 2016. How much do alternative cookstoves reduce biomass fuel use? Evidence from North India. Resource and Energy Economics 43, 153–171.

Chepkurui, L., Moronge, D.M., 2016. Drivers of Utilization of Improved Energy Saving Cookstoves Project in Kenya: A Case of Bomet country. Business and change management 3, 299–327.

Centeral Statistics Agency, World bank, 2013. Ethiopia Rural Socioeconomic Survey (ERSS), Survey Report, Adiss Ababa

Dagninet Amare, Asmamaw Endeblhatu,, Awole Muhabaw, 2015. Enhancing Biomass Energy Efficiency in Rural Households of Ethiopia. Journal of Energy and Natural Resources 4, 27–33.

Dawit Guta, 2016. Bio-Based Energy, Rural Livelihoods and Energy Security in Ethiopia. Peter Lang D. https://doi.org/10.3726/978-3-653-06173-4

Dawit Guta, 2012. Assessment of Biomass Fuel Resource Potential And Utilization in Ethiopia: Sourcing Strategies for Renewable Energies. International Journal of Renewable Energy Research 2, 9.

Dearing, J.W., 2009. Applying Diffusion of Innovation Theory to Intervention Development. Research on Social Work Practice 19, 503–518.

Debbi, S., Elisa, P., Nigel, B., Dan, P., Eva, R., 2014. Factors Influencing Household Uptake of Improved Solid Fuel Stoves in Low- and Middle-Income Countries: A Qualitative Systematic Review. International Journal of Environmental Research and Public Health 11, 8228–8250.

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, 1137–1157.

Erick, M.K., Kirubi, G., 2018. Key Factors Influencing Adoption of Biogas Technology in Meru County, Kenya. 12, 57–67.

Ezzati, M., Lopez, A., Rodgers, A., Murray, C., eds, 2004. Comparative quantification of health risks. Global and regional burden of disease attributable to selected major risk factors. Geneva: World Health Organization, 1435–94.

Federal Democratica Republic of Ethiopia, 2011. Ethiopia's Climate-Resilient Green economy strategy, Addis Ababa.

Fikadu Mamuye, Bekele Lemma, Teshale Woldeamanuel, 2018. Emissions and fuel use performance of two improved stoves and determinants of their adoption in Dodola, southeastern Ethiopia. Sustainable Environment Research 28, 32–38.

Geissler, S., Hagauer, D., Horst, A., Krause, M., Sutcliffe, P., 2013. Biomass Energy Strategy Ethiopia.

Gillenwater, M., 2005.Calculation Tool for Direct Emissions from Stationary Combustion 94.

Hadush Hagos, Ndemo, E., Jemal Yosuf, 2018. Factors affecting adoption of upland rice in Tselemti district, northern Ethiopia. Agriculture & Food Security 7.

Hazra, S., 2014. Adoption and use of improved stoves and biogas plants in rural India, SANDEE working papers. South Asian Network for Development and Environmental Economics, Kathmandu.

IEA, 2014. Africa Energy Outlook, A Focus on Energy Prospects in Sub-Saharan Africa, World Energy Outlook Special Report.

IPCC, 2007. The Physical Science basis. Contribution of Working Group I to the Fourth Assessment Report of IPCC. Cambridge: Cambridge University Press.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. 319.

Jagger, P., Jumbe, C., 2016. Stoves or sugar? Willingness to adopt improved cookstoves in Malawi. Energy Policy 92, 409–419.

Jan, I., 2012. What makes people adopt improved cookstoves? Empirical evidence from rural northwest Pakistan. Renewable and Sustainable Energy Reviews 16, 3200–3205.

Janssen, R., Rutz, D. (Eds.), 2012. Bioenergy for Sustainable Development in Africa. Springer, Dordrecht.

Jeuland, M.A., Bhojvaid, V., Kar, A., Lewis, J.J., Patange, O., Pattanayak, S.K., Ramanathan, N., Rehman, I.H., Tan Soo, J.S., Ramanathan, V., 2015. Preferences for improved cook stoves: Evidence from rural villages in north India. Energy Economics 52, 287–

Johnson, M., Edwards, R., Ghilardi, A., Berrueta, V., Gillen, D., Frenk, C.A., Masera, O., 2009. Quantification of Carbon Savings from Improved Biomass Cookstove Projects. Environmental Science & Technology 43, 2456–2462.

Kanangire, R.R., Mbabazize, D.M., Shukla, Dr.J., 2016. Determinants of Adoption of Improved Biomass Stove in Rural Households of Muhazi Sector in Rwamagana District. European Journal of Business and Social Sciences 5, P.P. 201-223.

Kazzi, M., 2016. A Case Study of the Performance, Adoption, and Dissemination of Improved Clay Cook Stoves in Rural Senegal 66.

Lambe, F., Jürisoo, M., Wanjiru, H., Senyagwa, J., 2015. Bringing clean, safe, affordable cooking energy to households across Africa: an agenda for action. Prepared by the Stockholm Environment Institute, Stockholm and Nairobi, for the New Climate Economy. 32.

Legesse Abate, 2016. Determinants of Rural Household Source of Energy Consumption in Enderta District, Tigray, Ethiopia. Journal of Energy Technologies and Policy 6, 16.

Lewis, J.J., Bhojvaid, V., Brooks, N., Das, I., Jeuland, M.A., Patange, O., Pattanayak, S.K., 2015. Piloting Improved Cookstoves in India. Journal of Health Communication 20, 28–42.

Lewis, J.J., Pattanayak, S.K., 2012. Who Adopts Improved Fuels and Cookstoves? A Systematic Review. Environmental Health Perspectives 120, 637–645.

Lp, L., 2016. Household Energy Consumption Patterns in Tanzania. Journal of Ecosystem & Ecography 01. https://doi.org/10.4172/2157-7625.S5-007

Manoa, D.O., Oloo, T., Kasaine, S., 2017. The Efficiency of the Energy Saving Stoves in Amboseli Ecosystem-Analysis of Time, Energy and Carbon Emissions Savings. Open Journal of Energy Efficiency 06, 87–96.

Masera, O.R., Saatkamp, B.D., Kammen, D.M., 2000. From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. World Development 28, 2083–2103.

Massawe, F.A., Bengesi, K.M.K., Kweka, A.E., 2015. Patterns of Household Cooking Energy and Associated Factors: Experience from Kilimanjaro Region, Tanzania 8, 26.

Melaku Berhe, Hoag, D., Girmay Tesfay, Keske, C., 2017. Factors influencing the adoption of biogas digesters in rural Ethiopia. Energy, Sustainability and Society 7.

Mobarak, A.M., Dwivedi, P., Bailis, R., Hildemann, L., Miller, G., 2012. Low demand for nontraditional cookstove technologies. Proceedings of the National Academy of Sciences 109, 10815–10820.

Molnar, T.I., 2017. "Variation in Cookstove Demand: Age and Education Effects in Northern Ghana". Environmental Studies Graduate Theses & Dissertations. 46. 65.

Okuthe, I.K., Akotsi, E.N., 2014. Adoptions of Improved Biomass Cook Stoves by Households: an Example from Homabay County. International Journal of Humanities and Social Science 4, 16.

Peng, C.-Y.J., Lee, K.L., Ingersoll, G.M., 2002. An Introduction to Logistic Regression Analysis and Reporting. The Journal of Educational Research 96, 3–14.

Pine, K., Edwards, R., Masera, O., Schilmann, A., Marrón-Mares, A., Riojas-Rodríguez, H., 2011. Adoption and use of improved biomass stoves in Rural Mexico. Energy for Sustainable Development 15, 176–183.

Puzzolo, E., Stanistreet, D., Pope, D., Bruce, N., Rehfuess, E., 2013. Factors influencing the large-scale uptake by households of cleaner and more efficient household energy technologies. London: EPPI-Centre, Social Science Research Unit, Institute of Education, University of London.

Renckly, T.R., 2002. Air University Sampling and Surveying Hand book,Guidelines for planning, organizing, and conducting surveys 102.

Rogers, E.M., 2003. Diffusion of innovations, 5th ed. ed. Free Press, New York.

Rogers, E.M., 1995. Diffusion of innovations, 4th ed. ed. Free Press, New York.

Ruiz-Mercado, I., Masera, O., Zamora, H., Smith, K.R., 2011. Adoption and sustained use of improved cookstoves. Energy Policy 39, 7557–7566.

Sehjpal, R., Ramji, A., Soni, A., Kumar, A., 2014. Going beyond incomes: Dimensions of cooking energy transitions in rural India. Energy Policy 68, 470–477.

Sesan, T., 2012. Navigating the limitations of energy poverty: Lessons from the promotion of improved cooking technologies in Kenya. Energy Policy 47, 202–210.

Sheha, H., Makame, O., 2017. Adoption of the new highly efficient cooking stoves by urban households in Zanzibar, Tanzania. Journal of Development and Agricultural Economics 9, 320–327.

Silk, B.J., Sadumah, I., Patel, M.K., Were, V., Person, B., Harris, J., Otieno, R., Nygren, B., Loo, J., Eleveld, A., Quick, R.E., Cohen, A.L., 2012. A strategy to increase adoption of locally-produced, ceramic cookstoves in rural Kenyan households. BMC Public Health 12.

UNEP, 2017. “Atlas of Africa energy resources”, United Nations Environment Programme,Nairobi 00100, Kenya.

Urmee, T., Gyamfi, S., 2014. A review of improved Cookstove technologies and programs. Renewable and Sustainable Energy Reviews 33, 625–635.

USAID, 2017. Clean and Efficient Cooking Technologies and Fuels 70.

Vahlne, N., Ahlgren, E., 2014. Energy Efficiency at the Base of the Pyramid: A System-Based Market Model for Improved Cooking Stove Adoption. Sustainability 6, 8679–8699

Venkataraman, C., Habib, G., Eiguren-Fernandez, A., Miguel, A., Friedlander, S., 2005. Residential biofuels in South Asia: carbonaceous aerosol emissions and climate impacts. Science, 307: 1454-1456.

WHO (Ed.), 2014. WHO guidelines for indoor air quality: household fuel combustion. World Health Organization, Geneva, Switzerland.

Wilkinson, P., Smith, K.R., Joffe, M., Haines, A., 2007. A global perspective on energy: health effects and injustices. The Lancet 370, 965–978.

Yohannes Zerihun, 2015. The benefits of the use of biogas energy in rural areas in Ethiopia: A case study from the Amhara National Regional State, Fogera District. African Journal of Environmental Science and Technology 9, 332–345.

Zenebe Gebreegziabher, 2006. Land Degradation in Ethiopia: What do Stoves have to do with it? 18.

Zenebe Gebreegziabher, Oskam, A., Demeke, B., 2010. Urban fuel demand in Ethiopia: an almost-ideal demand system approach. Environment for Development, Discussion Paper. Ethiopian Journal of Economics 19.

Zenebe Gebreegziabher, Oskam, A.J., Kooten, G.C. van, Woldehanna, T., 2007. Household fuel consumption and resource use in rural-urban Ethiopia.

APPENDICES

APPENDIX 1

1. Household Survey questionnaire

I am a student at Hawass University, Wondo Genet College of forestry and natural resource. Now I am undertaking a research study for my master of a degree in **renewable energy utilization and management**. My research entitled to determinants of improved biomass stove adoption and their contribution to carbon emission reduction at the rural household level. Therefore, you are kindly requested to give your invaluable response to all the questions herein after. Your response will be highly appreciated and will be treated with confidentiality. It will only be used for academic purposes. Please answer the questions as honest as possible. Thank you for your invaluable time and cooperation.

- Interviewer ____________________________Date of interview_________________
- Name of Respondent ____________________Time of interview________________

Section I. demographic characteristics (write your answer in the side box)

No	**Questions with possible response**	**response**
1.	Sex of household head? 1. Male 2. Female	
2.	Age of household head in years?	
3.	The education level of household head in the year (grad)?	
4.	Family size of household in number?	

Section II. Economic characteristics

5. Type and number of livestock owned and yearly income from their sale (Birr)?

item	cow	ox	heifer	bull	calf	goat	sheep	donkey	mule	Hen	chicken	hive
number												
Income from sales												

6. Average yearly income (Birr) from the sale of livestock products?

Income	Milk	Butter	Egg	Honey
Yearly income from sales				

7.Income from the production of cereals, oilseeds, and pulses in 2009/2010 E.C production year?

Crop type	Cereals(quintal)					Oilseed (quintal)		Pulses in (quintal)			other
	Teff	Wheat	Barley	Maize	Sorghum	Flax	Rape-seed	Chickpea	Lentils	Vetch	
Total amount produced											
Amount soled											
Price per Unit of product											

8. Income from sale of other crop types and planted trees in 2009/2010 E.C production year? If any

Crop type	Vegetables (garlic, onion, cabbage, potato etc.)	Spices (basil, rue, ginger, fenugreek etc.)	'Gesho', fruits etc.	Planted tree	others
Income from sale					

9.Household income from off farm/non-farm activities and other sources per month/year? If any

Item	trade	carpentry	Daily labour	Selling local beer	pension	Remittance	salary	others
Monthly income(Birr)								
Yearly income(Birr)								

10. Size of land holding in a hectare? ________________ Or in 'Timad'____________

11. Do you have your own house? 1. Yes, 2. No

12. How do you see the price of "Mirt" improved cookstoves?

1. Expensive 2. Not expensive

Section III. The major source of energy and Amount of energy consumption

13. What is the **main** type of fuel you use for cooking in your home? 1. Fuelwood 2.Charcoal 3. Dung 4. Crop residue 5. Electricity 6. Others (specify)________

14. What type of energy sources do you **often** use in your home for lighting? 1. Kerosene 2. Electricity 3. Candle 4. Crop residues 5. Firewood 6. Dry cells 7. Solar lantern 8.Others (specify) ___________________________

15. What type of energy source do you **often** use in your home for baking? 1. Firewood 2. Crop residue 3. Dung 4. Electricity 5.Others (specify)_____________

16. What is/are your **main source** (s) of fuelwood energy? 1. Own plantation 2. From community forest 3. Purchasing 4. Others, specify,______________________

17. What is the **main source** of your dung fuel? 1. Own cattle 2. Collecting from fields 3. Purchasing 4. Others (specify)____________________________

18. What is the **main source** of your charcoal fuel? 1. Purchase 2. Preparing by our self's 3. Others (specify)______________________

19. For users of '**Mirt' improved biomass stove only**, what is the average monthly solid fuel consumption? (Before using mirt and After using mirt)

Fuel type	Average monthly consumption		Energy amount used for		Average monthly expenses in Birr (If purchased only)
	Before	After	cooking	lighting	
Fire-wood (in bundle)					
Charcoal (in sack)					
Crop-residue (in bundle)					
Animal dung (in sack)					
Others (specify)					

20. For users of **Traditional biomass stove only**, what is the average monthly fuelwood consumption? (before 5 years and after 5 years)

Fuel type	Average monthly consumption		Amount of energy used for		Average monthly expenses in Birr (If purchased only)
	Before	After	cooking	lighting	
Fire-wood (bundle)					
Charcoal (sack)					
Crop residue (bundle)					
Animal dung (sack)					
Others (specify)					

21. On average, information on availability, distance traveled and time spent to collect fuelwood?

Fuel type	Availability 1. More available 2. Moderately available 3. Less available	Distance traveled in one trip to collect fuel (km)	Total time taken for collecting fuel in one trip (hour)	How often do you collect fuel per week? 1. Once 2. Twice 3. 3times and above 4. None
Firewood				
Crop residue				
Cow dung				
Charcoal				
Others (specify)				

22. Information on the adequacy of fuel obtained from own sources?

Fuel type	Adequacy: - 1.More adequate 2. Moderate 3. Less adequate 4. None	Others
Firewood		
Charcoal		
Cow dung		
Crop residue		

23. On average, how much time you spent for cooking per day? __________Hours
24. On average, how much time you spent for baking per day? __________Hours

Section IV. Stove types and energy end uses

25. Do you have 'Mirt' improved biomass cook stove in your home? 1. Yes, 2. No,
If yes, continue to Q.#26-29 and if No go to Q. #30
26. Do you save cooking time 'Mirt' improved biomass cookstoves? 1. Yes, 2. No
27. Do you save fuelwood consumption 'Mirt' biomass cookstoves? 1. Yes, 2. No
28. Do you have less smoke "Mirt" biomass cook-stoves compared to the traditional stoves?
1. Yes, 2. No

29. Can you rank the top important reasons for adopting improved cookstoves?

No	reasons	Rank
1	Own interest	
2	Fuel problem for domestic use	
3	Encouraged by the extension officer	
4	Influenced by friend/neighbors	
5	The high cost of energy resources	
6	Others, specify	

30. Does the design of the mirt stove fit the surrounding? 1. Yes, 2. No
31. Does the size of Improved "Mirt" stove affect your cooking? 1. Yes, 2. No
32. Do you have access to technical services for repair/maintenance of stoves?
1. Yes, 2. No
33. Do you have access to technical services for Mirt stove installation? 1. Yes, 2. No
34. Which types of stove do you use currently for baking in your home?
1. Modern ('Mirt') stove 2. Electric 'Mitad' 3. Traditional closed mud- made stove
4. Three stone stove 5. Others, specify______________________________
35. What types of stove do you use currently for cooking?
1. Improved Lakech charcoal stove 2. Improved Mirchaye charcoal stove
3. Improved Tikkle stove 4. Traditional metal charcoal stove 5. Three stone stove
6. Electric stove 7. Kerosene stove 8. Others, specify___________________
36. Do you have Access to credit for mirt improved cookstoves? 1. Yes , 2. No
37. Do improved cookstoves available in the market? 1. Yes, 2. No
38. What is the distance to the improved cookstove market from your home?____________km
39. Please, tell the **main end uses** of the following fuel types? Make √

End use	wood	charcoal	dung	Crop residue	biogas	kerosene	Dry cell	Wax/ candle	others
Baking (injera/bread)									
Cooking (except injera/bread)									
Boiling water									
lighting									

40. If you use the wax/candle, dry cells, and kerosene, please specify your average monthly consumption and expenses in Birr?

S. No	Fuel type	unit	Average monthly consumption		Average monthly expenses(Birr)	
			Before	After	Before	After
1	Wax/candle	pieces				
2	Dry cell	# of a pair				
3	kerosene	Liter				

Section V. Access to other alternative energy sources

41. Do you have electricity connection? 1. Yes, 2. No
42. If yes, on average how much money do you pay per month?_______________ Birr
43. For what purpose do you use electricity in your home? (answers could be more than one)
    1. Baking 'Injera'/'Bread' 2.cooking 3. Lighting 4. Boiling water
    5. Radio/ television/ mobile 6. Ironing 7. Refrigerator 8. Others_________
44. Do you have photovoltaic/ solar energy/ in your home? 1. Yes, 2. No
45. If yes, for what purpose do you use it? (answers can be more than one)
    1. Lighting 2. Water boiling 3. Mobile charging 4. Others, specify_______

Section VI. Knowledge and perception

46. How do you perceive the use of improved cookstove technology is compatible with the existing culture of the community? 1. Strongly disagree 2. Disagree 3. Neither (can't say) 4. Agree 5.strongly Agree
47. Can you rank the top important problems related to health, physical discomfort or injuries associated with the use of traditional biomass energy sources?

No	Problems	Rank
1	A headache	
2	Eye irritation	
3	Coughing	
4	Difficulty of breathing	
5	Burning accident	
6	Injury/violence during collection	
7	Others, specify	

48. Do you have awareness about the benefits of improved cookstoves? 1. Yes, 2. No, If Yes continue Q.# 49-50, if not got Q.#51
49. Where did you get the information? 1. Government/ NGO 2. TVs/Radio/Newspaper 3.friend/ neighbor 4. Exhibition/ promotion 5. Others, specify____________
50. What are the top most important benefits related to using improved cook stove?

	Benefits	Rank
	Minimizing fire-related accident	
	Save cooking and fuelwood collection time	
	Reduce fuelwood consumption	
	Reduce indoor air pollution	
	Minimize forest degradation	
	Improve health	
	Others, specify	

51. What are the main reasons for not adopting improved biomass cookstoves?

N<u>o</u>	**Reasons for not adopting**	**Rank**
1	Lake awareness	
2	It is expensive	
3	Lack of stove quality	
4	Lack of credit access	
5	High smoke	
6	Not affordable	
7	Not save fuel	
8	Note save cooking time	
9	Not accessible/ Not easy get in the market	
10	Others, specify	

THANK YOU!!

APPENDIX 2

2. Checklist for Key Informants and Focus Group Discussion

A. Regional mines and energy Agency

1. How do you evaluate fuel-wood availability (scarcity) as a region?
2. How do you evaluate the improved cook stove dissemination?
3. What are the main challenges or opportunities to disseminate improved cook stoves?
4. How do you evaluate the level of awareness of the rural households on improved cook stoves?
5. What is the rate of adoption as a region by type of technologies?
6. What is the future plan on improved cook stoves dissemination?

B. for Woreda level experts

1. How do you evaluate the current wood fuel availability (scarcity) in the woreda?
2. What are the measures being taken against the problem of wood fuel scarcity in your locality?
3. What are the factors affecting improved cook stove technology adoption?
4. Are there plans to further promote alternative sources of energy?

C. For development agent (kebele level expert)

1. How do you evaluate the current fuel wood availability in your area?
2. What are the main reasons of households in adopting the ICS?
3. What is the status of improved cook stove technology adoption in your locality?
4. What are the factors affecting improved cook stove technology adoption?
5. How do you understand the benefits of improved cook stoves?

D. Checklist for rural households

1. What are the major energy sources in your area?
2. Is there an energy source problem in your area?
3. What are the measures being taken against the problem of wood fuel scarcity in your locality?
4. What is the acceptance status of improved cook stove technology in your area? Do you think the technology has been disseminated to the expected level?
5. If you think adoption is low what are the main reasons?
6. What are the factors affecting improved cook stove technology adoption?
7. Do you think improved cook stoves have a benefit? What are the main benefits?
8. Do improved cook stoves have a contribution for reducing forest degradation?
9. Do you think using biomass energy in traditional way have an impact on the environment, health of household, forest resource depletion and soil fertility?

E. Stove producers

1. What initiated you to produce improved cook stove technology?
2. What types of improved cook stoves you produce currently?
3. What are the main challenges for large scale dissemination of improved cook stoves?
4. What are the main problems facing you to produce the stoves?

APPENDIX 3

3.Some of the Pictures taken during the study

A. Focus group discussion with men and women participants

B. FGD with regional expert (Left) and kebele Development Agent (Right) participants

C. An example of Mirt improved cookstove at producer centers