HOUSEHOLD FUEL AND FUEL SAVING TECHNOLOGY CHOICE IN CASE OF

HAWASSA CITY, SOUTHERN, ETHIOPIA

MASTER’S THESIS

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HAWASSA UNIVERSTIY, THE SCHOOL OF NATURAL RESOURCES AND

ENVIRONMENTAL STUDIES, WONDO GENET, ETHIOPIA

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WONDO GENET, ETHIOPIA

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MASTER'S THESIS SUBMITTED TO

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DECLARATION

I, Mulugeta Feleke, do hereby declare that the thesis entitled "Household Fuel and Fuel Saving Technology Choice in Case of Hawassa City, Southern Ethiopia." Submitted in partial fulfillment of the requirements for the award of the Degree of Master of Science in Renewable Energy Utilization and Management of the Graduate program of the school of Natural Resource and Environmental studies, Wondo Genet College of Forestry and Natural Resources, my original work has not been presented for the award of any other degree or diploma, of any other Universities or Institutions.

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Place: Hawassa University, Ethiopia.

APPROVAL SHEET-I

This is to certify that the thesis entitled *‘‘Household Fuel and Fuel Saving Technology Choice in Case of Hawassa City, Southern Ethiopia’’* is submitted in partial fulfillment of the requirements for the degree of master of science with specialization in Renewable Energy Utilization and Management of the Graduate program of the school of Natural Resource and Environmental studies, Wonedo Genet College of Forestry and Natural Resources, is record of original research carried out by Mulugeta Feleke. Id. No REUM/R010/09, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the courses of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirement.

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APPROVAL SHEET-II

We, the under signed, members of the Board of examiners of the final open defense by Mulugeta Feleke have read and evaluated his thesis entitled "*Household Fuel and Fuel Saving Technology Choice in Case of Hawassa City, Southern 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 of the Graduate program of the school of Natural Resource and Environmental studies, Wondo Genet College of Forestry and Natural Resources.

Name of the Chairperson	Signature	Date
Name of Major Advisor	Signature	Date
Name of Internal Examiner	Signature	Date
Name of External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon the submission final copy of the thesis to the SGS through the DGC/SGC of the candidate's department.

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ABBREVIATIONS AND ACRONYMS

CCT	Controlled Cook Test
CIESIN	Center for International Earth Science Information Network
CRGE	Climate Resilient Green Economy
CSA	Central Statistical Agency
GDP	Gross Domestic Product
GHG	Green House Gas
GIT	Deutsche Gesellschaft für Internationale Zusammenarbeit
GIZ	German Technical Cooperation Agency
HAPHR	Household Air Pollution and Health Report
ICS	Improved Cookstove
IEA	International Energy Agency
LPG	Liquefied Petroleum Gas
MoWE	Ministry of Water and Energy
NCCSPE	Ethiopia National, Clean Cookstoves Program
OECD	Organization for Economic Cooperation and Development
SFC	Specific Fuel Consumption
SNNPR	South Nations Nationalities and People Region
SPSS	Statistical Packaging of Social Science
UNDESA	Department of Economic and Social Affairs of the United Nations
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change

WB	World Bank
WBT	Water Boiling Test
WEA	World Energy Assessment

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ABSTRACT

In Ethiopia, heavy dependency on biomass energy sources creates deforestation, land degradation, soil erosion, and climate change and energy poverty. Household fuel and fuel saving technology assessment plays a key role in the evaluation of the energy access modalities and socio-economic features that may influence the household fuel and fuel saving technology choice. This study was aimed to investigate the household fuel and fuel saving technology choice determinants in Hawassa city, SNNPRG, Ethiopia. Multivariate probit model analysis was employed to assess the fuel choice determinants in the households. Three biomass stoves were tested using controlled cooking test. Household fuel choice determinants such as family size, household head's age, education, occupation, and dwelling type, income level and separate kitchen utilization were evaluated. The model examines choices between a set of cooking and baking fuel such as firewood, charcoal and electricity. The result confirmed that income level ($P < 0.01$) and household head year of formal education ($P<0.05$) were main factors in choosing fuels. Result of baking test shows statistically significant ($p<0.05$) variation between three stone and Yequme Mideja specific fuel consumption, total baking time and average baking power. About 47.70% specific fuel consumption, 26.30% total baking time and 30.19% average baking power were reduced compared to three stone to Yequme Mideja, which is significantly($p<0.05$) higher than that of three stone to Mirt (best) stove 39.95% specific fuel consumption, 17.3%total baking time and 26.59% average baking power were reduced between three stone and Mirt stove. The test result showed that there was no statistically significant ($p<0.05$) difference in three measured parameters between mirt and Yequme Mideja. The study concluded that use of Stand or Mirt stove per household reduces firewood consumption for baking and reduces deforestation rate over the three stone stove. The contribution of clean fuel and improved cookstove to reduction of environmental and economic problem and workload can be improved by increasing penetration level of clean fuel and improved cookstove. This indicates that further design improvement of improve baking stove and awareness rise will be needed.

Key words: - fuel choice, household, specific fuel consumption, total baking time, average baking power

1. INTRODUCTION

1.1. Background

Access to modern energy services and technologies is a critical component of economic development and achievement of the Millennium Development Goals and Sustainable Development Goals 7 (Mehta *et al*, 2006; WHO, 2014; UN, 2017).At the end of the twentieth century, urban areas in the world have grown considerably. According to the Department of Economic and Social Affairs of the United Nations (UNDESA, 2014), in 1990 less than 7% of global urban population were inhabit anted in 10 so called "megacities" with more than 10 million inhabitanted. After two decade the global "megacities" were rise to 27, the population they contained grew to 460 million, and these agglomerations accounted for 6.7% of the world's population (Kennedy *et al*., 2015). Since 2008, cities host more than 50% inhabitants of the planet with the share expected to increase up to 67% by 2050 (Rosenzweig *et al*., 2010; UN-HABITAT, 2012). Furthermore, cities are located on less than 5% of the Earth's land surface and yet use around 80% of the resources (Madlener and Sunak , 2011; CIESIN, 2015; UNEP, 2015), and are responsible for approximately 80% CO_2 global emissions (IEA, 2008; Seto *et al*., 2014). About 94% of Africa's rural population and 73% of its urban population use wood-based fuels as their primary energy source. Urban dwellers rely heavily on charcoal, while communities in rural areas tend to depend more on firewood (IEA, 2014).

In Ethiopia, energy consumption is heavily dependent on biomass energy (fuel wood, charcoal, crop residues and animal dung, including biogas) that accounts for 81% (IEA, 2015). This heavy dependence and inefficient utilization of forest biomass (mainly firewood) is unsustainably harvested (Bailis *et al*., 2015). In urban areas of the developing world, although modern cooking fuels like electricity are both unreliable and unaffordable for many in the near future, the use of solid biomass for cooking is likely to continue. The efforts to develop adopt and use improved biomass cookstoves is the best intermediate solution of improving the way biomass is supplied and used in addressing the adverse impacts of three stone-fires (GIZ, 2013). Improved biomass cookstoves have multiple economic, social, environmental and health benefits (Jacob, 2013; HAPHR, 2016).

Therefore since 1970s, many improved biomass cookstove programs have been set and promoted by governments, donors and non-governmental organizations and other (Gifford, 2010; Puzzolo *et al.,* 2013). Effective action in the energy sector is, consequentially, essential to tackling the climate change problem. The adoption of energy efficiency measures offers a wide group of benefits, well beyond their contribution to climate policies (IEA, 2015).

In Ethiopian households energy use for preparation of food can be broadly categorized into two categories, cooking and baking. An important staple of the Ethiopian diet, Injera, (similar to a large flatbread or pancake) is the main product of baking and is usually baked on a large blackened clay plate (Mitad) that can be 54 to 60 cm in diameter. Injera is usually baked over an open fire with fuelwood or using an electric Mitad (Gaia Association, 2014d). A clay plate containing electric resistance heating coils has been developed to cook Injera using electricity. Cooking injera uses an estimated 50% - 60% of household cooking fuel (Practical Action Ethiopia; Bizzarri, 2010). As about 90% of

Ethiopia’s total energy demand is from the household sector, baking injera consumes roughly half the nation’s energy.

Therefore, this study investigated determinates of household fuel and fuel saving technology choice, and using controlled cooking tests (CCTs), compared the fuel wood use of the traditional three stone fire and improved stoves based on the “baking” design in laboratory settings. Normalized firewood use was reported as SFC, defined for this study as the weight of firewood consumed during cooking divided by the total weight of cooked food, measured after cooking. In addition to SFC, it would report the time required and baking power for specific task.

1.2. Statement of the Problem

About 93% of Ethiopian population use biomass energy for their domestic use (UNDP, 2009; IEA, 2010; DGEP, 2011; and CSA, 2012). This heavy dependency on biomass energy sources creates deforestation, land degradation, soil erosion, climate change and energy poverty in those countries (World Bank, 2000; Yonas, *et al.,* 2013). The three stone stove is very inefficient about 85–90 percent of the potential energy is wasted (Dunkerley *et al.*, 1981; Gebreegziabher, 2007), which implies increased demand for traditional or biofuels and increased pressure on local forests.

According to Ethiopia National, Clean Cookstoves Program (NCCSPE, 2011) the household sector dominates and continues to dominate, accounting for about 90% of total energy consumption (ESMAP, 1996; NCCSPE, 2011). Injera-baking alone, stands for 50% of the primary energy utilization in Ethiopia, and over 75% of the total household use of energy. The dish requires a flat, large sized stove for baking, named “Injera stove”, used for this purpose only (Beyene and Koch, 2012), and causes carbon emissions, environmental degradation and negative effects on women and children health; through (indoor) air pollution, firewood collection and burns from cook fires (Wosenu, 2004; Yosef, 2007).

The Ethiopian government has several national policies and programs that address the development and promotion of improved cookstoves and specifically ethanol fuel and ethanol cookstoves. These include (1) the Ministry of Mines and Energy Bio-fuel Development and Utilization Strategy (2007) (Ministry of Mines and Energy, 2007), (2) the Growth and Transformation Plan, both GTP I and GTP II, produced by Ethiopia's National Planning Commission, with GTP II issued in 2016 (National Planning Committee, 2016), (3) the National Improved Cookstoves Program (NICSP), produced by the Ministry of Water and Energy, (4) the Climate-Resilient Green Economy Strategy (2011), produced by the Environmental Protection Authority (Federal Democratic Republic of Ethiopia, 2012), and (5) the Nationally Appropriate Mitigation Actions (NAMA), established by the Environmental Protection Authority in 2010.

Ethiopian Energy Studies and Research Center (EREDPC) had developed the 'Mirt' Injera baking stove as one intervention and it is on the process of disseminated to improve household energy efficiency (MoWE, 2012; Megen power Lted, 2008; ESMAP, 1996). 'Mirt' stove has tremendous potential for reduction of fuel wood consumption, by up to 50 per cent compared to the traditional three stone open-fire, and can reduces dangers of burning and increases fuel efficiency (GIZ, 2012; Simons, 2012; Wosenu, 2004).

Unfortunately, studies about the determinant factors of household fuel choice are limited in Ethiopia. Alem et al. (2015) modelling household cooking fuel choice, Mekonnen and Köhlin (2009) determinants of household fuel choice in major cities in Ethiopia, Damte and Koch (2011) in Ethiopian urban areas, Kooser (2014) the value of clean cookstoves in Ethiopia and Gamtessa (2003) at household's consumption pattern and demand for energy in urban

Ethiopia, To contribute in overcoming this limited empirical study in Ethiopia, (Alem *et al.*, 2015; Damte and Koch (2011) recommended further research to be conducted.

As far as the researcher's knowledge is concerned, there was no study conducted on determinants of 'fuel and fuel save technology' choice in urban areas of Hawassa city. Apart from this, all of the previous studies in Ethiopia did include only variables of household characteristics, price of fuel, having separate kitchen house, and to some extent social influence in analyzing determinants affecting fuel and fuel saving technology choice. All of the previous studies in Ethiopia did not include dwelling and institutional factors in identifying determinants affecting urban households' fuel and fuel saving technology choice.

Key factor determinants of fuel choice household size, gender, formal education in year and age of household head (Mekonnen and Köhlin, 2009) and implementation, promotion as well as dissemination of improved cookstoves in a given country is its existing institutional infrastructure and set up (Makonese *et al*, 2006). Institutional factors such as awareness creation to potential users, regulation of the improved cookstoves' standard and price, financing options such as credit access and decentralizing production site are important variables that influence the households improved cookstoves adoption decision (GIZ, 2013; Puzzolo, 2013). Mekonne and Köhlin (2009) recommended that more studies be conducted to examine these issues to find out how important they are for smaller towns in Ethiopia and for other countries.

The aim of the present study was, therefore, to analyze the determinants of household fuel and fuel saving technologies in Hawassa city, taking three sub-cities as the study areas. This study adds an original contribution to the existing knowledge with regard to determinants of households' fuel choice and fuel saving technology.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this study is to investigate the fuel and fuel saving technology determinants of Household in Hawassa city.

1.3.2. Specific objectives

- To analyse household fuel and fuel saving technology choice pattern in Hawassa city
- To analyze the influence of socioeconomic factor on fuel and fuel saving technology choice of household.
- To analyse the efficiency of the most adopted biomass stoves of household energy technologies.
- To rank and recommend stoves type based the test result.

1.4. Basic Research Questions

The purpose of this study was to answer the following questions.

1. What are the existing household fuel and fuel saving technology choice pattern in Hawassa city?
2. What are the socioeconomic factors that determine households' household fuel and fuel saving technology patterns in the study area?
3. What are determinant fuel choices of household?
4. How efficient were the biomass stoves the most adopted by household in the study area?

1.5. Scope and Limitation of the Study

1.5.1. Scope of the study

This study was delimited in two ways. Firstly, it is geographically, this study was limited to Household fuel and fuel saving technology choice of Hawassa city. Secondly, conceptually the focus of the study is to identify Household fuel and fuel saving technology, and determinants of these choices.

1.5.2. Limitation of the study

This study include randomly selected three-sub city of urban part of the Hawassa city. It is limited to only to Household fuel and fuel saving technology choice and mostly in use biomass stove test. Additionally, the study does not take into account consumption Household fuel and does not include other clean cookstoves test of renewable technologies. Also, there is the shortage relevant literature on similar topic and logistics especially in baking test of CCT.

1.6. Significance of Study

This study is important in several ways. Firstly, it investigates determinants of household to choose fuel and fuel saving technology in Hawassa City. Secondly, by analyzing the determinants of household to choice fuel and fuel saving technology and by estimating the impact of determinants on choice in Hawassa City, the study contributes to the existing literatures. Thirdly, the output of this study will be important for policy makers, researchers, practitioners and development actors as a guideline and key direction to design and implement appropriate development and project interventions to improve the fuel and technology use of urban households.

1.7. Organization of the study

The thesis has five chapters. Chapter one presents the introductory parts of the thesis. In chapter two literature reviews was presented which briefly discuss definitions of terms, the theoretical and empirical literatures. Chapter three is about data sources and methods of data collection, theoretical framework, multivariate probit model and model variables.

Chapter four provides data analysis using both descriptive statistic and multivariate model methods. Finally, in chapter five conclusions and recommendation are presented.

2. LITERATURE REVIEW

The purpose of this section is to identify the determinants of fuel choice and technology for household use (including performance test of selected energy technology of household) and benefit of energy technology, as described by literature.

2.1 Concept of household fuel choice

The energy ladder hypothesis is predicated on the economic theory of consumer (Hosier and Kipondya, 1993). However, when income increases, households not only consume more of the same good they also shift to more sophisticated goods with higher quality. Thus, the theoretical assumption underlying the energy ladder hypothesis is that low living standards induce greater dependence on firewood and other biomass fuels owing to a combination of income and substitution effects (Baland *et al.,* 2007). As their income increases, households do not consume more of the traditional fuels, but they shift to newer, more improved fuels which are more efficient and user friendly indicating that traditional fuels are inferior goods while the modern fuels are normal economic goods (Rajmohan and Weerahewa, 2007; Demurger and Fournier, 2011)**.** Thus low level of income means more dependence on traditional fuels due to a combination of income and substitution effect (Baland *et al.,* 2007; Ogwumike et al., 2014).

However, energy ladder theory criticized on the grounds that it cannot adequately describe the dynamics of households' fuel use (Masera et al., 2000). Instead, they note that fuel stacking is common in both urban and rural areas of developing countries. Fuel stacking corresponds to multiple fuel use patterns—where households choose a combination of fuels from both lower and upper levels of the ladder. Indeed, modern fuels may serve only as partial, rather than perfect substitutes for traditional fuels (van der Kroon *et al.*, 2013). Households choose different fuels as from a menu instead of moving up the ladder step by step as income rises (Mekonnen and Köhlin, 2009). They may choose a combination of high-cost and low-cost fuels, depending on their budgets, preferences, and needs (World Bank, 2003). This led to the concept of fuel stacking (multiple fuel uses) as opposed to fuel switching or an energy ladder (Masera *et al.*, 2000; and Heltberg, 2005). The reasons for multiple fuel uses are varied and not dependent on economic factors alone although the affordability or cost of the energy service also has an important bearing on households' choices.

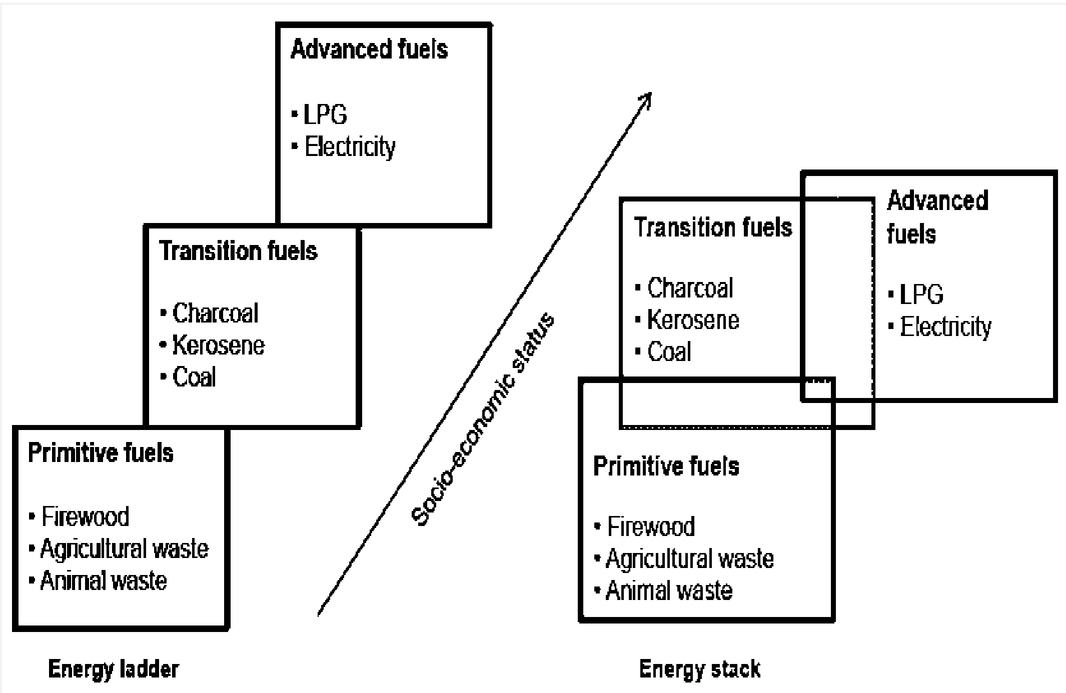

Figure 2-1:- Fuel stacking as compared to fuel switching (source: - Schlag and Zuzarte, 2008).

Fuel choice depends upon a complex interaction between economic, social, cultural and environmental factors (Masera *et al.*, 2000; Schlag & Zuzarte, 2008). Evidence from a growing number of countries is showing multiple fuel use to be common; (Mekonnen *et* *al*, 2009; Taylor *et al*, 2011) also argue that income alone does not determine choice; family size, age and education are significant and matter more in determining whether or not a household adopts. In some cases, households use more than one fuel because they want to increase the security of supply. In other cases, the choice is dependent on cultural, social or taste preferences (Pachauri, 2004). Similarly portfolio of household energy sources spanning different points of the energy ladder does not fit easily with the traditional energy ladder model (Barnes and Qian, 1992; Hosier and Kipondya, 1993; Davis, 1998). An investigation of household fuel choices for a sample of households residing in the city of Bangalore uses a binomial logit model (Reddy, 1995). A binomial logit is defined as a model, which determines the choice between each pair of energy sources. This model according to Reddy (1995) helps to explain the shift in the energy pattern of consumption of different fuels used for cooking and water heating. The findings confirm that urban households ascend an energy ladder and the choice is determined by income. However, other factors worth noting that play a significant role in fuel switching amongst households is family size and occupation of head of the household (Reddy, 1995). In dealing with simultaneous binary decisions, previous studies have used either multinomial logit models (Gensch and Recker, 1979; Heltberg, 2005; Mekonnen and Köhlin, 2009) or multivariate probit models (Song and Lee, 2005). The multinomial logit model relies on the assumption of the independence of irrelevant alternatives (IIA). The IIA states that the odds of choice do not depend on the alternatives that are not relevant. As explained by Tabet (2007), this assumption implies that if a choice A is preferred to choice B out of a choice set A, B, then adding a third choice C, and expanding the choice set to A, B, C, must not make B preferred to A. It is difficult to enforce the IIA in a study using cross-sectional data. The multivariate probit model relaxes this property of the multinomial logit model.

2.2. Global Overview of Household Fuel Choice

The household is responsible for about 15 to 25 percent of primary energy use in many developing countries. It is estimated that approximately 2.5 billion people in developing countries rely on biomass fuels to meet their cooking needs (Mekonnen and Kohlin, 2008) for many of these countries more than 90 percent of total household fuel is biomass. Without new policies, the number of people that rely on biomass fuels is expected to increase to 2.6 billion by 2015, and 2.7 million by 2030(about one third of the world's population) due to population growth (IEA, 2006).

2.2. 1. Household fuel choice in Africa

Africa's energy sector mainly depends on affordability and easily accessible energy source the so-called biomass account 94% of Africa's rural population and 73% of its urban population use wood-based fuels as their primary energy source. Urban dwellers rely heavily on charcoal, while communities in rural areas tend to depend more on firewood IEA (2014). Like Africa, in Sub-Saharan Africa firewood remains the most common cooking fuel (Denton, 2002; Gustafson, 2001; Misana, 2001). Space heating is required in areas with cold climates, and is often catered for by energy used for cooking. The bulk of energy consumed in rural areas is used in households (World Energy Council, 1999; Karekezi and Kithyoma, 2002).

2.2.2. Urban household fuel choice in Ethiopia

Developing countries like Ethiopia, urban households have long been dependent on rural areas for their fuel (Barnes et al., 2004). Deforestation in Ethiopia has resulted in growing fuel scarcity and higher firewood prices in urban centers (Gebreegziabher, 2007). The environmental impact of urban fuel demand in general, and the reliance on biofuels in particular, in terms of contributing to forest degradation, were well documented (Heltberg

2004; Edwards and Langpap, 2005). The urban energy transition is a multidimensional challenge that must address three interrelated such as decarbonisation (Karvonen, 2013), energy security (Hodson and Marvin, 2009) and energy access ((Singh et al., 2014), but sometimes competing, objectives. Urbanisation is highly correlated with higher consumption of energy and higher Green House Gas (GHG) emissions (Seto *et al.*, 2014).Urban change can be gradual and incremental or radical and transformative (a transition), depending on the speed at which change takes place. There is a consensus now that moving towards a sustainable society is akin to delivering a radical transformation of human-ecological relations, certainly beyond incremental, efficiency-related gains (Haberl et al., 2011; Markard et al., 2012).

Similarly, Mekonnen & Kohlin (2009) examined the determinants of household fuel choice and demand in major Ethiopian cities. In urban areas, this entails a substantial modification of the relationship between urban societies, the resource systems that sustain them and the technologies/structures that mediate resource transformations. However, it has recently been argued that households in developing countries do not switch to modern fuel source but instead tend to consume a combination of fuels rather than completely switching from one fuel to another (Davis, 1998; Moss, 2006; Hetlberg 2005). Due to these Ethiopia is indeed one of only four countries that have highest levels of firewood consumption per capita, household air pollution disease burden and non-renewable biomass utilization (Bailis HH., 2015). During the decade, traditional fuel use increased by 10% while modern energy use increased by 50% (Araya and Yissehak, 2012). Therefore, in Ethiopia, increasing the efficiency of biomass energy utilization and reduction of wastage are an important intervention (Melis, 2006; Dessie and Nigus, 2014). As a result, the recent studies applied energy staking hypothesis and recommend that future researches should not rely excessively on the energy ladder model; for households in poor developing countries, such as those in Ethiopia, more attention to be paid to other nonmonetary aspects besides income in the analysis (Mekonnen *et al,* 2009).

In this paper, I am interested in investigating determinants of Household fuel and fuel saving technology choice in urban households of Hawassa City. Fuel and fuel saving technology choice household, which will be modeled empirically using a discrete choice framework and the substitution relationships between fuels examined. The analysis also helps to identify several socio-economic variables that are important in determining household fuel and fuel saving technology choice.

2.2.3. Determinants of household fuel choice

As it was reviewed in the previous section, there are factors that found to be determinant in determining household fuel choice decision. These factors are discussed.

Family Size: - With regard to family size, Hosier and Dowd (1987) conclude that larger households are more likely to adopt kerosene over wood, but less likely to progress to electricity. A review by Knight and Rosa (2012), who address the energy ladder hypothesis within the context of ecological footprints, find that a smaller household uses less biomass, specifically firewood, per capita. This finding supports Hosier and Dowd's previous claim. Contrastingly, Heltberg (2005) finds that in Guatemala household size did not affect the likelihood that a family uses firewood, but that smaller households were more likely to use LPG exclusively. He also determines that a larger household size led to fuel stacking (Heltberg, 2005). Households with more members tended to use more of both biomass and LPG, the two fuels he concentrates his efforts on.

Income of household: - Households' income position is one of the important factors determining fuel choice and adoption of new or improved technologies. The energy ladder model predicts that households follow a simple linear movement from inefficient to efficient fuels and appliances as income increases (Alam *et al.,* 1998; Davis, 1998 and Leach). In general, it emphasizes the role of income and relative fuel prices in determining fuel choices. The energy ladder model characterizes three levels of fuel use. At the first level, there is strong reliance on biomass fuels such as firewood and animal waste. These fuels are inefficient because they pollute the air. At the second level, because of an increase in income and other factors, households abandon the use of firewood and use coal, charcoal, and kerosene. These fuels are labeled "transitional fuels" in the energy ladder model. At the third level, because of higher incomes, households can afford to purchase improved stoves and move to cleaner fuels (Leach, 1992 and Barnes, 2014).

However, recent empirical findings have criticized this traditional thinking of the energy ladder model, because households' energy use decisions are subject to other factors related to social, economic and cultural preferences (Masera *et al.,* 2000). A rigorous study in some Ethiopian cities by Mekonnen and Kohlin, (2008) shows that, household income is not the sole factor in household energy use decision-making. This empirical study shows that modern cooking fuels are often used in combination with other traditional solid fuels by a large number of urban households with different levels of income. Similarly, a study by (Alem *et al.,* 2014) suggests that households in Ethiopia tend to use multiple fuels as they get richer, instead of entirely shifting to modern fuels as their income increases. According to GIZ (2008), the low level of income of the households depending on biomass fuels is a major barrier to increasing the dissemination of improved stoves. For poor households, stoves represent a high initial investment cost which prevents them from purchasing the products.

Education: - A number of studies found evidence that education influences fuel choice. More highly educated households are more likely to adopt non-solid fuels and to transition away from lower rung fuels (Van der Kroon et al., 2013; Kowsari and Zerriffi 2011; Peng, Hisham, and Pan 2011). Heltberg argues that educational attainment influences fuel use through relative opportunity costs. Time usually commands a higher value with schooling, making the tasks of gathering biomass relatively more costly for more educated individuals (2004). Van der Kroon et al. (2013) suggest that perhaps individuals with more education possess more knowledge of alternatives to biomass and a stronger understanding of the associated benefits. Van der Kroon et al. (2013) conclude based on their meta-analysis that the effect of education on fuel choice exists within both rural and urban study areas (2013). Heltberg (2004) further argue that, since households with higher education are aware of the health impacts inherent with using those traditional fuels like firewood and charcoal, such households have the tendency to switch onto other efficient and clean modern fuels. Similar findings are also stated in Mokennen and Kohlin, (2008) where the woman (housewife) in the household is educated and has good paying job outside the household For such households, using efficient and time saving fuels and cookstoves lowers time and budget losses. The study by Mom and Tabi (2012) found that the level of education attained by the head of household, the distance separating the household from the center of City, the family's status as homeowners or renters, and the modern or traditional style of the house influence a Household choice of cooking fuels. This previous literature about the effect of level of education on fuel choice decision enables one to expect effect of education on urban households' fuel choice decision in the study area. Thus, positive or negative and significant correlation is expected between education level and fuel choice.

Age:-In contrary, Gebreegziabher HH (2010) found household head's age to be positive and statistically significant determinant factor of Mirt stove adoption decision. The authors analyze the factors that explain urban households' choice of fuel among five options: wood, charcoal, dung, kerosene, and electricity. Based on survey data the paper finds that the likelihood of the electric Mitad adoption increases with household expenditure, age of household head and family size. Furthermore, fuel choices more generally are found to be determined by the prices of substitutes, household expenditure, age and education of household head, and family size, with the probability of using transitional and modern fuels (such as kerosene and electricity) positively correlated with the price of wood and charcoal, household expenditure, and the age and education of the household head.

Dwelling category: - Dwelling characteristics have also been identified as a factor which defines Household energy necessities (Rao, 2007 and Özcan, 2013).

In general, various studies have pointed out factors affecting household energy consumption (Leach and Gowen ,1987; Sander *et al*., 2011): current disposable income, household size, household type, fuel accessibility, fuel affordability, fuel reliability, fuel flexibility, low-pollution, climatic conditions, effective household size, dwelling type and Sardianou (2007) summaries key findings from a number of studies by (Barr et.al., 2005; Curtis et.al., 1984; Brandon and Lewis,1999; Walsh, 1989) to demonstrate why home ownership is often associated with greater availability of, and access to, energy efficiency measures. Compared to renters, homeowners are more likely to invest in energy efficiency measures because they tend to be wealthier and have greater financial security, hold longer tenure, and receive greater return on energy efficiency investments.

2.3. Overview of Household Energy Saving Technology

With a global human population exceeding six billion people, a lot of food is being cooked using a lot of something. Other determining factors may include baking and cooking fuel saving technology characteristics, since they imply different domestic technologies of fuel use. Obviously, not all sources of energy are compatible with using traditional furnaces, for example. In that sense, the choice of fuel may be simultaneous with device acquisition or may be constrained by the devices already available at home.

However, the empirical evidence in this regard is scant. Chen et al. (2006) find in Chinese villages that the possession of improved stoves does not affect fuelwood consumption but results in lower coal consumption. Hughes-Cromwick (1985) and Manning and Taylor (2014) suggest that ownership of modern cooking and heating appliances is a necessary condition for adopting higher-grade energy sources. Similarly, Edwards and Langpap (2005) claim that in Guatemala the high upfront cost of appliances is a significant impediment to the adoption of LPG as an alternative to firewood. These results point to joint choices of fuel and fuel saving technology, while they need confirmation.

2.3.1. Cookstove used in Ethiopia

In Ethiopia, like in many developing country, energy supply is heavily dependent on biomass fuels, technical advances in energy efficiency are critical. In order to reduce pressure on forests and the adverse impact of indoor air pollution, the government of Ethiopia is trying to increase the availability of fuel saving technologies such as ICSs (Cooke, 2008). Access to cleaner cooking fuels and technologies is limited by many factors in the developing world although poverty was a key underlying issue for most

(Puzzolo et al., 2013). Understanding household energy consumption intensities were paramount in assessing energy efficiency development (Lusambo, 2002; OECD, 2002 and Alan, 2004). In this regard, non-governmental organizations, mainly GIZ, have been working on afforestation programs and dissemination of more efficient ICS technologies (Gebreegziabher, 2006). Despite the fact that ICSs are a better option than three stone stoves, studies indicate that adoption of ICS has fallen behind expectations (Haider, 2002).

In urban areas, both firewood and electricity fuels are used almost exclusively for Injera baking. In Addis Ababa, only about 15% of households use an open fire for baking, while 50% use an electric Mitad stove Mitad (Gaia Association, 2014d). However, the study and development of cooking stove technology have been ongoing for the past 35 years or more by different researchers (Bello and Umahi, 2013; Ogbuagu et al., 2015). Improved Cookstoves (ICS) are designed to reduce the fuel consumption per meal and to curb smoke emissions from three stone fires inside dwellings. In contribution to the standardization of the designation of these stoves, a codification considering their characteristics will be proposed (Anjorin et al., 2010).

2.3.2. The technique of the cooking stove test

In many developing countries, particularly in rural areas, traditional fuels such as fuel woods, charcoal and agricultural waste constitute a major portion of a total household energy consumption (Dzioubinski and Chipman, 1999). The efficiency of a traditional fuel wood cooking stove is as low as 10-12 percent, compared with a liquefied petroleum gas (LPG) stove efficiency of more than 40 percent. Improved stoves, designed to reduce heat loss and increase combustion efficiency could significantly reduce indoor air pollution, and ensure efficient fuelwood use (Karekezi and Kithyoma, 2002; Kammen et al, 2001; Zhou, 2001; ITDG-EA, 1999; Desanker and Zulu, 2001; Akarakiri, 2002). Adopting energy efficiency measures in the household can reduce the amount of fuelwood required.

According study on solid fuel household cookstove performance and emission characteristics (Jetter et al., 2009) testing result show that some stoves currently used in the field have improved fuel efficiency and lower pollutant emissions compared with traditional cooking methods. Test standards were required in order to achieve the significant improvements in biomass cookstove emissions needed to have an impact on human health and the global environment. To study performances the cooking stoves three-test methods usually used (Anjorin et al., 2010).

a. The water boiling test (WBT),
b. The controlled cooking test (CCT),
c. The kitchen performance test (KPT).

The WBT was designed to be a simple laboratory test to be used to compare fuel consumption between stove designs and acknowledged that it may not directly correlate to stove efficiency during actual cooking. The KPT was designed as a field evaluation of stove fuel efficiency in homes during actual cooking practices. The CCT was developed to be an intermediary test, a test where stoves are used to cook real meals but under more repeatable conditions (Bussman et al., 1985).

2.3.3. The controlled cooking test

The controlled cooking test (CCT) has as principal objectives to compare the consumption and the time of cooking as well as culinary practices using different stoves. This method reveals the possibilities in households under ideal conditions but not necessarily, what is actually obtained in a study area. To improve household energy efficiency in ‘Injera’ baking, the Ethiopian Energy Studies and Research Center (EREDPC) had developed the improved cooking stoves as one intervention and it is on the process of dissemination

(MoWE, 2012). An improved stove have tremendous potential for reduction of fuel wood consumption, by up to 50 percent compared to the traditional three stone open-fires, and can reduces dangers of burning and increases fuel efficiency (GIZ, 2012; Simons, 2012). However Ethiopian Energy Studies Research Center in the early 1990s was designed Mirt Injera stove to alleviate or lessen this problem. This stove is being promoted and widely distributed in the country because it is believed that it can achieve the fuel efficiency up to 40%. As stated by Konemund (2002), field test results indicate that an average household using an improved Mirt stove for Injera baking saves about 570 kg fuel wood per year.

The three stone stove was used as a tradition stove and a baseline for comparing the performance of the three ICS. the so called CCT Version 2.0 which was prepared by Bailis (2004) for the Household Energy and Health Programme, Shell Foundation. In this paper, I were examine the assess fuel consumption, average baking powder and the speed of cooking (time of cooking) performance of three-type Ethiopia improved cookstoves in comparison with a 3-stonefire (TSF) using standard (CCT). Both Mirt and Yequme Mideja are improved stove technologies, recently introduced to help with the growing fuel problem. This study in part set out to determine whether a cleaner burning biomass-fueled cookstove adoption would reduce fuel consumption and total cooking time in urban Hawassa compared with continuation of traditional three stone stove.

3. MATERIALS AND METHODS

3.1. Study Area Descriptions

3.1.1. Locations

The study conducted in Hawassa city, Southern Nations Nationalities and Peoples Regional State (SNNPRS). It is located in the Great Rift Valley region; 275 km south of Addis Ababa via Debre-Zeit. The city serves as the capital of the Southern Nations Nationalities &Peoples Regional State and Sidama Zone. Geographically, it lies between 7^0 3’ latitude North and 38^0 28’’ longitude East. It is bounded by the lake in the West, Oromia Region in the North, Wondo Genet woreda in the East and Shebedino Woreda in the South. Hawassa has a total area of 157.2 sq.Km divided into Eight(8) sub cities which divided into 32 Kebeles, These Eight sub cities are Hayek Dar, Menaheriya, Tabore, Misrak, Bahile-Adarash, Addis-Ketema, Hawela-Tula and Mehal-ketema sub city.

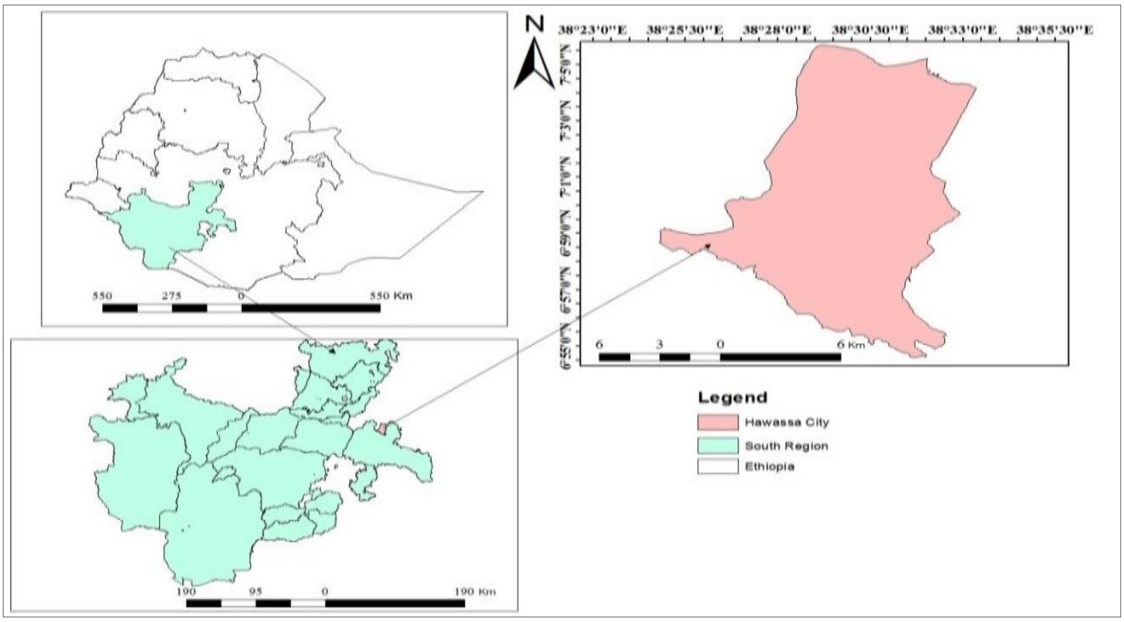

Figure 3-1:- Hawassa city administration.

3.1.2. Climate and topography

Topography of the study area is characterized by flat and moderately gentle lands in low altitude and south western part boundary by Tabor mountainous land in upper altitude.

Hawassa gets rainfall twice in a year. The main rainy season lasts from May to September while the dry season goes from November to February similar to the rain pattern of most Ethiopian plateau. The average annual rainfall estimated to be about 960mm. Mean monthly temperature in Hawassa varies between 5^0C in winter and 34^0C in summer. Hawassa city with altitude level of 1680 - 2970 meters above sea level experiences sub humid-called 'Woyina-Dega' type of climate and classified as temperate. It has the highest and lowest temperature of 34 ^{0}C and 5^0C respectively. The average annual temperature is 20.3^0C. The minimum and maximum temperatures in Hawassa show that monthly variations in temperature are relatively low which characterize the dry sub-humid nature of the climate prevailing in the area.

3.1.3. Population

Currently Hawassa city consists of 8 sub cities and 32 villages/kebeles with their own administration office. According Hawassa city socio-economic profile (HCSEP, 2014), gives the estimated population of Hawassa for 2015 as 343,175 with an annual population growth rate of just over 4%. The population is relatively young, with 65% under 25 years of age and around 5.5% over 50 years of age. As HCSEP (2014) report 84,642 households were counted in this zone, which results in an average of 4.22 persons to a household, and 67,469 housing units.

3.1.4. Economic activities

Hawassa is the one of the most important energy consumer center of the country and the core of its industrial and commercial activity. Nowadays the city serves as the center for public corporations and of privately owned industrial and commercial companies. Among Hawassa main industries are food processing and those producing consumer goods (e.g., beer, textiles, and footwear), and for domestic markets. Construction and various service industries also contribute to the city's economy.

3.2. Research Design

Based on the methods of data collection and analysis, the study design of this research is mixed research because it included collecting, analyzing data by qualitative and quantitative methods in the research process.

3.2.1 Sample Design and Sample size

Multistage sampling techniques were used to select sample respondent households for the study. In the first phase, Hawassa city was selected by purposive sampling technique because in Hawassa city has higher availability of stoves, biomass, energy technology, types of fuels than other cities in SNNPR. In the second phase, three sub-cities and three kebeles in Hawassa city were selected as a sample sub-cities and kebeles by simple random sampling technique. This technique was used due the fact that, the members of the total population in sample have equal chance to be included in sample size. It is less biased than other methods. Particularly, lottery method was used as simple random sampling technique. Sample households were selected by simple random sampling technique. Thus; ample households were selected randomly using formula provided by Yemane (1967) tables and formulas to determine sample size was more appropriate (Israel, 1992) to determine the required sample size at 92% level of confidence and marginal error of 8%.

$$n = \frac{N}{1 + N(e)^2} ------------ 1$$

Where'' n= 156'' is the sample size, ''N= 5183'' is household heads size, and ''e=0.08'' is the level of precision (Israel, 1992).

Table 3-1: Sampling distribution in selected kebeles is presented

City	Sub city	Kebele	Total HH	How to compute	Sample HH
Hawassa	Mehal-Ketema	Nigat Kokeb	1908	(1908x total sample / total HH)= **1908x156/5183**	57
	Bahil Adarash	Andinet	753	(753x total sample / total HH)= **753x156/5183**	23
	Misrak	Wukero	2522	(2522x total sample / total HH)= **2522x156/5183**	76
	Total		**5183**	1908x156/5183+753x156/5183+2522x156/5183	**156**

3.2.2 Stove test site

This study was conducted in the population using three stone, Mirt and Yequme Midejas for assessing the impact of the stove energy conservation. Stove tests were carried out in the form of experimental type study in a fixed place. The experiment was conducted in Hawassa. Specific location of the study site was in the Misrak sub city of the city. For this experiment, a temporary arrangement that can represent an ordinary kitchen was established in the Mine and Energy Alternative energy technology research and workshop located in Wukero Kebele of Misrak sub city. It was clean and convenient for the cook. The floor is cement paved.

3.3. Data Type and Collection Technique

Household questionnaires were used to collect relevant data on fuel and fuel saving technology choice for the study. They had both open and closed ended questions to suit collection of qualitative and quantitative data that is easier to analyze. The reason behind using this sampling technique was its simplicity, fast and low costly (Zou, 2006). To overcome some flaws of this technique the researcher did checkup whether the households were systematically arranged or not, in each kebele frame. And the households were not arranged systematically. The selection of respondents of the questionnaire the household heads were selected.

3.4. Data Analysis Approach

The data obtained was analyzed with the aid of the statistical package for SPSS statistical software version (SPSS 16.0), Rstudio (Version 1.1.383) and Controlled Cook Test (CCT version 2.0). Multivariate probit model was used to check the socio-economic factors that influence the choice of household fuel in the study area. The CCT version 2.0 was used to identify and rank fuel efficient biomass stove. The statistical differences in SFC, total baking time and average among baking power among the stoves were computed by one way Analysis of Variance (ANOVA) using Rstudio (Version 1.1.383) at 5% level of significance. The least significant difference test was conducted for mean separation of significant differences.

Descriptive statistics*:*- Descriptive statistics was used to analyze the characteristics of the population studied. According to Trochim (2006), descriptive statistics were used to describe the basic features of the data in a study providing summaries about the sample and the measures. Thus means, median, standard deviation, frequency, pie charts, percentages, and other statistical parameters were used accordingly. These were used to describe demographic data such as age, education, employment status, asset, proportion of household energy technology types used by resident, etc.

Multivariate probit model*:* - The consideration of what combination to pick from among the possible fuel mixes potentially accessible to the household is done simultaneously and decisions were correlated with each other. Therefore; the determinants of fuel choice were analyzed using the multivariate probit model, and as shown by Greene (2003) and used by

Cappellari and Jenkins (2003), if a household i was face with J different choices, then the multivariate probit model can be constructed as:

$Y_{ij}^{*}=\beta_j X_{ij}+\varepsilon_{ij}$, J=1,……..J ---------------------- 2.

$Y_{ij}=1$ if $Y_{ij}^{*}>0$ and 0 otherwise.

Where, ε_{ij} =error terms distributed as multivariate normal, each with a mean of zero, and variance-covariance matrix ε, where ε has value 1 on the leading diagonal and correlations

$\rho_{jk}=\rho_{kj}$ as off diagonal elements.

J= the number of different choices available

Y_{ij}= outcomes for J different choices.

Whereas, the multivariate probit model can be used to fit a probit model for cross-sectional data allowing for a free correlation structure (Cappellari and Jenkins, 2003). The equations need not have the same set or number of explanatory variables. This allows the most appropriate explanatory variables to be used in each equation.

3.5. Controlled Cooking Test

Based on CCT procedures, Yequme Mideja and Mirt stoves were compared against the tradition 3 stone stove as they perform a standard cooking task that was closer to the actual cooking that local people do every day. However, the tests were designed in a way that minimizes the influence of other factors, and allows the test conditions to be reproduced. CCT analysis covers biomass stove with the exception of electric analysis that covers based on available technology survey data. The controlled cooking test was used to evaluate three parameters:

- the Specific Fuel Consumption (SFC) in g/kg,

$$\mathrm{SFC}=\frac{[(M_{ci}-M_{cf})(1-\varphi_c)-1.5M_{cp}]}{M_{pf}-M_{vi}} \text{---------------------------- --------3.}$$

- the duration baking of the test (t) in min,

$t = t_f\text{-}t_i$--4

- The average baking power (p) in kW.

$$P = \frac{Pci[\,(M_{ci-}\,M_{cf})(1-\varphi_c\,) - 1.5M_{cp}]}{60(t_f - t_i)} ----5$$

Where,

- M_{ci} is the initial mass of fuel in kg;
- M_{cf} is the final mass of fuel in kg;
- M_{vi} is the mass of the pot empties in kg;
- M_{Pf} stands for the final mass of the pot and its contents cooked in kg;
- M_{cp} is the charcoal mass recovered in kg;
- t_i is the initial moment of the min test;
- t_f represents the final moment of the min test;
- φ_c stand for the moisture content of fuel in % And
- P_{Ci}: the lower calorific value in kJ/kg.

.6. Experiment setup

Three household stove test conducted in SNNPRG Mine and Energy Agency Alternative Energy Resource and Technology Work Shop and laboratory in January 2018. Each test included measurement of firewood and consumed and baking time for equal quantities of batter per each test of stoves type. Three tests conducted per each stove type, which means nine tests, conducted to complete test. In the test experiments, all factors other than the stoves controlled as follows;

Baking Practices: - the same 15kg of batter prepared each batch of Injeria using their normal baking methods while allowing for key measurements of fuel and Injeria. The fire stopped, and weighing of firewood and Injeria conducted per test. Finally, experimental testing of stoves carried out under careful planning, preparation and control to ensure that all experimental factors are consistent for testing days. Meanwhile, in the following sections the data from experiments analyzed per stove separately then compared to rank the least burden stove

Firewood: - each set of tests used the same batch of Eucalyptus Camaldulensis wood, subsequent moisture content measurements were taken on test time using two-pin moisture meter.

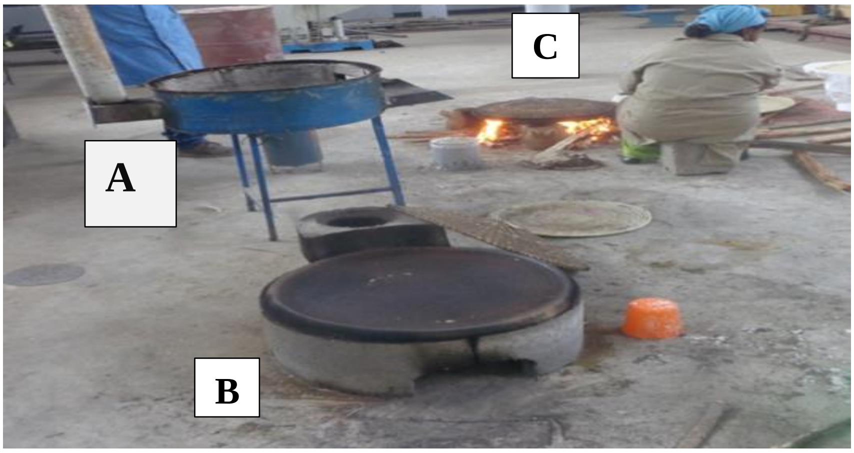

Figure 3-2:- Three Stove used for baking test

(A-Yequme Mideja, B-Mirt Stove and C-Three stone stove)

Measurement: - quantity of batter and Eucalyptus Camaldulensis wood were measured before and after baking using weighing balance measurement. A batch of firewood was set aside and weighed before baking for each batch of batter. The remaining wood was weighed after baking and the amount consumed was computed by difference. The weight of coal remaining in the stove after baking each of batter was measured by weight balance. The measuring instruments and raw material used for the test were:-

- Digital balance with 0.1gm accuracy
- Moisture meter
- Stop watch
- Batter container
- Charcoal pan

- Eucalyptus Camaldulensis wood of the calorific value (Pci= 20160 kJ/kg).
- Infrared thermometer (FB70328)
- Probe thermometer (DT 310) A.G. Germany (830-T1)
- Thermo-anemometer for the wind velocity measurement
- Injeria container, locally called ‘Moseb’
- Mitad is the local name for a stove that is exclusively used for baking injera, the staple bread in Ethiopia.
- Mirt (mean in English Best) made from mortar- a mixture of scoria (red ash) or pumice or river sand with cement.
- Yequme Mideja (mean in English Stand stove) made from mortar- a mixture of scoria (red ash) or pumice or river sand with cement, sheet metal and Galvanized Steel (GI) square pipes for standing.
- Three stone stove made of clay soil.

Figure 3-3:- Measurement technique during baking using digital balance

4. RESULTS AND DISCUSSIONS

4.1. Socio- Economic Characteristics

This part of the study was summarizes the socio- economic characteristic that influences the households' cooking fuel(s) and fuel saving technology choices. Briefly, socio-economic characteristics including the household head sex, age, education level, occupation, income, household size, and house dwelling unit and ownership were described.

4.1.1. Gender of the respondents

In the present study, demographically, 67.31% (105) of the respondents were males while 32.69% (51) were females (Figure 4-1). Despite random sampling technique was employed in this study, the number of males were higher than females. But having more female respondents provides more accurate information on most issues pertaining cooking fuels. This has also been supported by study done in Kisumu Kenya were it was believed that fuel procurement and cooking are largely responsibilities of women (Moses and Fraser, 2003).

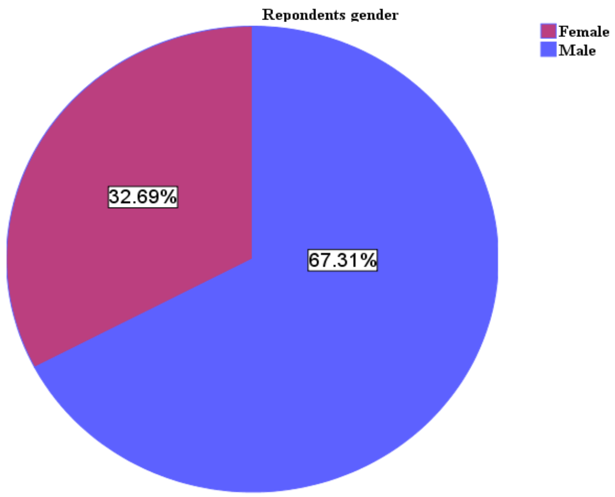

Figure 4-1:- Gender of the respondents

4.1.2. Household characteristics on fuel choice

The minimum and maximum household head age, family size and household formal education for firewood choice was 24 and 65, 2 and 8, and 0 and 17 respectively (table 4-1). But firewood choice for household head age, family size and household formal education in year were different by mean (45.57, 4.47, 10.30) and standard deviation (10.07, 1.47, 3.94) and the t-value shows that there are significant relationship between the household head age, family size and household formal education for firewood choice and non-choice of firewood. Similar findings were reported by other studies on household fuel choice (Pundo and Fraser, 2006) found that older household heads are more likely to choose solid fuels.

Table 4-1:- Age and education of household and family size and firewood choice

	Firewood	Minimum	Maximum	Mean	Std. Dev	t-value	sig
Household head age	Non choice	25	65	38.55	10.71	-4.177	$4.9*10^{-5}$
	Choice	24	65	45.57	10.07		
Family size	Non choice	2	6	3.29	1.54	-48.34	$3.21*10^{-6}$
	Choice	2	8	4.47	1.47		
Household head formal education	Non choice	4	17	13.50	2.38	5.826	$3.2*10^{-8}$
	Choice	0	17	10.30	3.94		

As table 4-2 reveals, the minimum and maximum household head age, family size and household formal education for charcoal choice was 24 and 65, 2 and 8, and 0 and 17 respectively. The mean (44.21, 4.19, 11.28) and standard deviation (10.85, 1.44, 3.70) for household head age, family size and household formal education for charcoal choice and the t-value shows that there are significant relationship between the household head age, family size and household formal education for charcoal choice and non-choice of charcoal. Accordingly, an HH with 13 years of formal education was tending to choice electricity which slightly exceeds the mean of charcoal 11, and fire wood 10. This could explain that different mean household age has the different choice of fuels. This study is also consistent with the empirical works of (Pandey and Chaubal, 2011) that indicated an inverse relationship between family size and the use of clean fuel.

Table 4-2:- Age and education of household and family size and charcoal choice

	Charcoal	Minimum	Maximum	Mean	Std. Dev	t-value	sig
Household head age	Non choice	25	58	36.06	8.34	3.847	$1.747*10^{-4}$
	Choice	24	65	44.21	10.85		
Family size	Non choice	2	8	3.1	1.97	-3.453	0.001
	Choice	2	8	4.190	1.44		
Household head formal in year education	Non choice	3	17	13.13	3.46	2.482	0.014
	Choice	0	17	11.28	3.70		

As Table 4-3 presents, the minimum and maximum household head age, family size and household formal education for electricity choice was 24 and 65, 2 and 8, and 0 and 17 respectively. The mean(38.9,3.54 and 13.42) and standard deviation (10.59,1.5 and 2.3) of the household head age, family size and household formal education for electricity choice respectively and the t-value shows that there are significant relationship between the household head age, family size and household formal education for electricity choice and non-choice of charcoal. This finding is similar to the previous studies Mekonnen and Kohlin (2008) found that in Ethiopia modern fuels are relatively more adopted by younger household heads. This indicates that age of the household head has some influence on the use/adoption of households' cooking fuel(s). In line to this study, Pundu and Fraser (2003) found that the effect of education improves knowledge of fuel attribute tastes and preference for better fuels. Therefore, this study may suggest that highly educated household head are likely to lack the time and see it inconvenient to prepare food by using traditional fuels and they may prefer to use the alternatives one.

Table 4-3:- Age and education of household and family size and electricity choice

	Electricity	Minimum	Maximum	Mean	Std. Dev	t-value	sig
Household head age	Non choice	26	65	46.90	9.61	4.913	$2.27*10^{-6}$
	Choice	24	65	38.90	10.59		
Family size	Non choice	2	8	4.47	1.58	3.785	$2.19*10^{-4}$
	Choice	2	6	3.54	1.50		
Household head formal education	Non choice	0	17	9.61	3.99	-7.386	$8.9*10^{-12}$
	Choice	4	17	13.42	2.30		

4.1.3. House hold fuel choice portfolios

Traditional energy sources such as firewood and charcoal was significantly large in household fuel choice. Hence, as data findings indicate, the most popular fuel type was charcoal 122(78.28%) followed by firewood 91(58.35%) and electricity 83(53.2%) and the result indicated that households tend to switch to a multiple fuel-use strategy (fuel stacking) (see table 4-4 below). This study came up with similar findings (Gaia Association, 2014c) that found firewood use in urban households is also high, at 70%, but the urban fuel market is dominated by charcoal, with over 90% of households using it for cooking

Table 4-4: Household cooking fuel choice (percentage of households choosing)

Fuel type	Frequency	Percent
Firewood	91	58.3
Charcoal	122	78.2
Electricity	83	53.2

**Total for each column cannot be executed as one household uses more than one fuel.

A great proportion of the total households surveyed (78.2%) utilize charcoal, and almost half of them (58.3%) and (53.2%) utilize firewood and electricity, respectively. Multiple uses of fuels have been mentioned to be the reason why most residents in the Sub-Saharan Africa are reluctant to switch to more efficient household energy alternatives (Osiolo, 2010). As described in Figure 4-2 the major three fuel combinations adopted for use as main fuels by the Hawassa city urban household in percentages:-

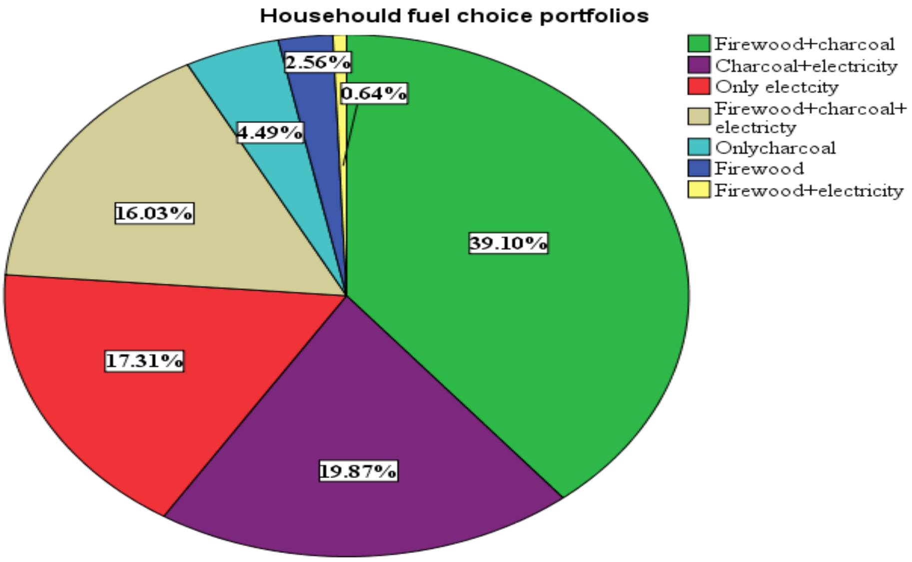

Figure 4-2:- Combinations of Household Fuels

As it can be noted, above pie chart the household fuel choice portfolio in study area was asked 156 household respondents. Accordingly, 17.31% household choice electricity as their fuel but the major energy accesses in study area were: firewood and charcoal 39.1%, followed by charcoal and electricity 19.87% which followed by firewood, charcoal and electricity account for 16.03%.The finding of this study is similar to previous works (Mekonnen and Kohlin, 2009) found that use of multiple fuels for a particular purpose in major Ethiopian cities were reported.

4.1.4. Household head occupation

Occupation of the respondent is more likely to show how much the purchasing power a household has, which is believed to improve the income of the household. Respondents with better jobs are more likely to have higher purchasing power for fuels and demand for better fuels as it elevates the social status of the household (Pundo and Fraser, 2006). About 38% and 22% respondents were government employees and labor workers, respectively, while 18% were merchantmen (table 4-5). Furthermore, the findings showed that 1% of the respondent was NGO workers, and 5% of the respondents were retired.

Table 4-5:-Household head occupation and choice of fuel

Fuel type	Occupation type						
	Labour	Merchant	Government	Private institution	Retired	NGO	Total
Firewood	2	0	2	0	0	0	4
Firewood+charcoal	15	13	20	7	6	0	61
Firewood +charcoal+electricity	5	2	13	3	0	2	25
Charcoal+electricity	8	5	13	7	1	0	34
Firewood+electricity	0	1	0	0	0	0	1
Only electricity	3	5	8	7	1	0	24
Only charcoal	1	2	3	1	0	0	7
Frequency (%)	34(22)	28(18)	59(38)	25(16)	8(5)	2(1)	156(100)

Note: Numbers in brackets indicates percentages

There was almost an equal choice of respondents that work for the government and those that work in the merchants as well as those that have labor jobs towards traditional and modern fuels, while those works at private institution have a higher preference on using modern fuels (for about 68%) than traditional fuels (for about 32%). This finding is similar to the previous studies (Dzioubinski and Chipman, 1999) found that the household head who have entered the formal workforce demand more convenience in their use of household fuel. This leads to preference in more better, cleaner and less time-consuming fuels in meal preparation.

4.1.5. Households head monthly income level and patterns of fuel use

About 62(39%) of the respondents earn less than 3001, with the majority earning level between 3001-6000birr (Table 4-6). The survey result revealed that people with low incomes level use firewood and charcoal in order to meet their domestic energy needs. Similarly to mixed fuel, there were 12.1% of households were using only electricity as their main cooking and baking energy source. In other word, there is a clear order in the distribution of energy shares by primary fuels (Table 4-6). Firewood and charcoal the two extreme are more likely to be used with electricity in income level of household head between of 3001-6000. Moreover, at the income level of household head between 0-3000, households were more likely to use two fuels. But the findings contradict to that people were more likely to switch from traditional fuel to more efficient and modern energy sources is greatly influenced by household income (Hills, 1994; Rao and Reddy 2007; Daioglou *et al*., 2012; Khandker *et al*., 2012). This finding was similar to the previous studies by (Masera *et al*., 2000; Nansaior *et al*. 2011; Huang, 2015) that found increased incomes do not always lead to households switching to cleaner fuels.

Table 4-6:- Household fuel choice and income level of household head

Fuel type	Frequency (%)	Income level(birr)			
		0-3000	3001-6000	6001-9000	9001 and above
Firewood	4(3)	3	1	0	0
Firewood+charcoal	61(39)	33	25	3	0
Firewood +charcoal+electricity	25(16)	4	16	5	0
Charcoal+electricity	30(19.2)	9	16	5	0
Firewood+electricity	1(1)	1	0	0	0
Only electricity	28(18)	8	14	2	4
Only charcoal	7(5)	4	3	0	0
Total	156(100)	62	75	15	4

Source: Own survey data (2018). Note: Numbers in brackets indicates percentages

Thus, the direction of the relationship between income and the demand for clean energy remains uncertain and thus requires further investigation (Khandker *et al*., 2012). Similarly, Hosier and Kipondya (1993) found that electricity accounts for the larger share of energy requirement and the importance of charcoal vary little as income increases. This shows that even if the households' income increase people will always use a combination of fuels and households in the study area disclosed no sign of completely switch from one fuel to another although they will indeed shift from using traditional fuel to modern fuel(s).

4.1.6. House Dwelling category and own status, and fuel choices of household

The findings presented in table 4-7 below shows that all of the respondents in the study stay in three category dwelling which consists 55.8% were built from wood wall, earthen floor and iron sheet cover followed by 28.2% concrete floor, block wall and iron sheet cover. One of the most important findings of the survey was that households influence of house ownership towards the choice of household cooking fuel use. Household fuel choice was approximately 21.2% and 9.6% preference towards both firewood and charcoal, and electricity respectively by those who own their own houses (table 4-7).

Table 4-7:- Dwelling category and fuel choice

Fuel type	Frequency (%)	Dwelling category		
		Wood, Mud Sheet metal cover	Integrate from all construction material	Concrete, Brocket wall with sheet metal cover
Firewood	4(3)	4	0	0
Firewood+charcoal	61(39)	42	8	11
Firewood +charcoal +electricity	25(16)	15	2	8
Charcoal+electricity	30(19.2)	14	1	15
Firewood+electricity	1(1)	0	1	0
Only electricity	28(18)	7	11	10
Only charcoal	7(5)	5	0	2
Total	156(100)	87(55.8)	23(14.7)	46(29.5)

Also, the findings suggest that respondents that live for rent their houses use only electricity more (approximately 2.6%) than both firewood and charcoal account (approximately 14.7%). The findings were shown in table 4-8, the ownership of the houses differs, whereby about 58% owned their houses and about 42% were renting their houses.

However, it provides a different insight on the relationship between house ownership and multi-fuel use behaviour more clearly for baking and cooking fuel. Thus, by having a quick look at table 4-6, one can easily understand that the number of households who utilize only a single fuel type is very few. 2.6% of households exclusively use firewood and from household live for rent 0.6% uses firewood and 0.6% combining firewood and electricity and electricity, and the same 5% use electricity exclusively.

Table 4-8:-House own and fuel diversity

Fuel type	Frequency (%)	House ownership	
		rental	own
Firewood	4(3)	1	3
Firewood+charcoal	61(39)	22	39
Firewood+charcoal+electricity	25(16)	13	12
Charcoal+electricity	30(19.2)	12	18
Firewood+electricity	1(1)	1	0
Only electricity	28(18)	10	18
Only charcoal	7(5)	7	0
Total	156(100)	66(42)	90(58)

Source: - Own survey data (2018). Note: Numbers in brackets indicates percentages

This prompt a question on why do people that rent houses prefer to use modern fuels than traditional fuels. The respondents that rent houses stated reason for this which included; lack of storage space, less time to procure traditional fuels, poor quality of traditional fuel and few members in the household. This means that the opposite of this reason may be true for respondents that own their own houses. The findings show consistence to the initial thinking for people who lives for free as they may prefer modern fuels to traditional fuels.

4.1.7. Household energy technology pattern

To assess the pattern of baking fuel saving technology choice by urban households in Hawassa city, household respondents were asked about their baking stoves. Of total 156 surveyed respondents, 37.2% were found used electric stove while 24.4% were used three stone as baking stove (Table 4-9). About, 17.9% and 16% respondents replied that they were choice Mirt and Yequme Mideja for baking purposes, respectively.

Table 4-9:- Baking stove penetration

Baking Stove typ(	Frequen(	Percent
three stone	38	24.4
Mirt stove	28	17.9
Yequme Mideja	25	16
Electric Mitad	58	37.2
Non user	7	4.5
Total	156	100

This implies that, in the study area, 37.2% and 24.4% of the households were using three stone and electric Mitad for baking, respectively. According to GACC (2011) and GIZ (2013), the significant role of improved cookstoves were improving household health conditions, reduces the rate of deforestation and mitigating global climate change. Similar to baking stoves, different energy inefficient and efficient stoves were in use for cooking in the study area.

Table 4-10:-Cooking stove choice

Cooking Stove	Frequency	Percent
Three stone stove	5	3.2
Charcoal stove	102	65.4
Electric stove	28	18
Charcoal +electric stove	25	16
Total	156	100

About 15.4% of the households used stoves were the electric stove. But 65.4% were still used the charcoal stove which was energy efficient. Over, 3.2% of the households used three stone stove which was energy inefficient.

4.1.8. Household head monthly income and baking stove choice

The sample households use one of four types baking stoves. Electric is most commonly used stove in urban area of Hawassa city. Following electric stove three stone stove widely used which in turn followed by Mirt and Yequme Mideja (table 4-11). The finding in this study shows that most of the households in study area access to use one of all types of baking stoves except those with income above 9000 birr per month. The findings in (table 4-11) suggest that households with income of above 9000 birr per month can access to the use of electric Mitad only.

Table 4-11:- Distribution Baking stove across in household head income level

Baking stove type	Frequency (%)	Income level(birr)			
		0-3000	3001-6000	6001-9000	9001 and above
Three stone	22(14.1%)	20(12.8)	2(1.3)	0	0
Mirt stove	41(26.3)	13(8.3)	24(15.4)	4(2.6)	0
Yequme Mideja	29(18.6)	9(5.8)	16(10.3)	4(2.6)	0
Electric Mitad	58(37.2)	17(10.9)	30(19.2)	7(4.5)	4(2.6)
None user	6(3.8)	3(1.9)	3(1.9)	0	0
Total	156(100)	62(39.7)	75(48.1)	15(9.6)	4(2.6)

Moreover, the findings suggest that households with income above 9000 birr per month use only electricity as their principal baking fuel except those who have income below than birr. 9000, these households use either firewood or electricity. This shows that households with income below birr 9000 per month are more likely to use one of three (Mirt, Yequme Mideja and Electric Mitad) baking stoves than those with income above. This study came up with similar findings of (Inayat, 2011; Rwiza, 2009) that found household income is an indicator of prosperity and may be expected to have positive effect on adoption of technologies as wealthier households may have higher probability of investing in and using improved stoves. Therefore, since the majority of households that use three stone stoves were poor, the design and price of new and improved biomass cookstoves should consider poor household capacity to purchase the new technology.

4.1.9. Household head monthly income and cooking stove choice

The Table 4-12 shows the penetration level of cooking stoves use across for different income level households. The households in all the income level are found to use charcoal stove for the purpose of cooking but penetration level for charcoal stove 46(29.5%) in income level between 0-3000 birr per monthly is the highest compared to that of45(28.8%) and 8(5.1%) by the income level of 3001-6000 and 6001-9000 birr per month respectively. The penetration level of using electric stove 14(9%) for cooking purposes varies across income level (3001-6000) birr per month highest 3001-6000 to other income group. This result is inconsistent with the previous works of (Burton et al., 2003; Fuglie and Kascak, 2001) that found income is determinants of technology adoption.

Table 4-12: Distribution cooking stove across in household head income level

Cooking stove type	Frequency (%)	Income level			
		0-3000	3001-6000	6001-9000	9001 and above
Three stone stove	4(2.5)	3(1.9)	1(0.6)	0	0
Charcoal stove	99(63)	46(29.5)	45(28.8)	8(5.1)	0
Electric stove	28(18)	8(5.1)	14(9)	2(1.3)	4(2.6)
Charcoal +electric stove	25(16)	5(3.2)	15(9.6)	5(3.2)	0
Total	156(100)	62(39.7)	75(48.1)	15(9.6)	4(2.6)

4.1.10. Household house ownership and Baking stove choice

The household baking stove use patterns presented in the house ownership categories gives detail picture. Table 4-13 illustrates the use of the each stove by households for the total sample and house ownership, respectively. The use of the basic firewood consuming stoves such as three stone, Mirt and Yequme Mideja were widespread in the sample. Over 92(60%) of households stated to use firewood consuming stoves such as three stone stove 22(14.1%), mirt stove 41(26.3%) and Yequme Mideja 29(18.6%) of the total sample household. The similar picture is drawn for Electric Mitad which is used by 58(37.2%) of the sample household.

In general the result indicated in table 4-13, choice of three stone stove for baking is very high for household own their house 15(9.6%) followed by household living by rent 7(4.5%). The finding table 4-13 suggest that is approximately 36(23.1%) and 31(19.9%) preference towards mirt and electric Mitad respectively than three stone 15(9.6%) and

Yequme Mideja 8(5.1%) by those who own their own house. Also the finding suggests households that lives for rent may choice to use more of electric Mitad for about 22(14.1%) and Yequme Mideja for about 21 (13.5%) than both Mirt 10(6.4%) and three stone stove 7(4.5%).

Table 4-13: Baking stove choice and respondent house ownership

Baking stove	Frequency (%)	House ownership	
		rental	own
Three stone	22(14.1)	7(4.5)	15(9.6)
Mirt stove	41(26.3)	10(6.4)	31(19.9)
Yequme Mideja	29(18.6)	21(13.5)	8(5.1)
Electric Mitad	58(37.2)	22(14.10	36(23.1)
None user	6(3.8)	6	0
Total	156(100)	66(42.3)	90(57.7)

4.1.11. Barriers of fuel and fuel saving technology choice

As it was discussed earlier, the majority of households 47(30.1%) in the study area were three stone stove users for baking due to different barriers. As it is observed from Table 4.12, majority of the respondents 44.9% explained that cost of technology; lack of awareness 16%, followed by family reluctance 14.7%, were the most likely barriers of fuel and their energy efficient technology adoption.

Table 4-14:- Barriers of fuel and energy efficient technology

Barriers	Frequency	Percent	Mean	Std. Dev.
Lack of awareness	25	16		
Family reluctance	23	14.7		
Cost of technology	70	44.9	1.9103	1.19877
Problem of separate kitchen	17	10.9		
Access	21	13.5		
Total	156	100		

To generalize, lack of awareness about its health, economic and environmental benefits, family members' reluctance, cost of technology, the problem of a separate kitchen and access to fuel specially electricity were found to be the barriers of choice of fuel and their energy efficient improved stove adoption in the study area. The main reason for households' lack of awareness about the relative benefits of energy efficient technology was attributed to the absence of urban energy expert at a city and sub-city level. The household revealed that at kebele level there is no person or expert assigned by the government concerning fuel type and their technology.

4.1.12. Source of information of fuel choice and energy saving technology

The study identified various channels of information that sensitize the household about the appropriateness, efficiency and advantages of adopting energy technology. These included radio, health extension workers, newspaper, TV, and in community meeting who had adopted energy efficient technology. The research findings indicate (table 4-15) show that 37.8% of the sample population received information from both Newspaper and TV whereas, 5.1% were sensitized by community meeting, and health extension workers had 23.1% contribution in the awareness creation of their fuel and energy efficient technology in the kebeles of the city.

Table 4-15:- Source of information

Source info	Frequency	Percent	Mean	Std. Dev.
Radio	18	11.5		
Newspaper and TV	59	37.8	1.9038	1.34778
Radio and TV	35	22.4		
Community meeting	8	5.1		
Health extension workers	36	23.1		
Total	156	100		

4.2. Multivariate Probit Model and the Determinants of Fuel Use

In the previous section, factors affecting urban households' fuel choice decision were analyzed using descriptive statistics. Further, to understand the extent to which these factors affect fuel choice decision multivariate probit model was employed. The explanatory variables included and analyzed in the model were summarized in table 4-16. As table 4-16 above shows, the multivariate probit model estimation result investigated that there were factors that have explanatory power to determine urban households 'fuel choice' in the study area at 1 percent, 5 percent, and 10 percent level of significance. The multivariate probit result that choice of firewood and charcoal as household fuel is positively correlated with family size.

Table 4-16:- Multivariate probit model results for household choice of fuel

Multivariate probit model		Number of observation= 156		
Log likelihood = -78.48	LR chi2(6)=50.91	Prob >chi2=0000	PseudoR2=0.2449	
Uwood (yes=1)				
variable	Coefficient	Std. Error	Z	Pr(>|Z|)
Fsize	0.1854	0.0918	2.02	0.043413**
HH Age	0.01623	0.01507	1.077	0.281677
HH YearEduc	-0.16891	0.05007	-3.373	0.000742***
HH gender	0.37218	0.28074	1.326	0.184935
HH own	0.1136	0.31892	0.356	0.721691
HH incoLev	-0.03458	0.18742	-0.185	0.853605
HH TyOccup	0.05052	0.10677	0.473	0.636108
DwellCatego	-0.5113	0.18304	-2.793	0.005215***
SepKitch	0.03582	0.10859	0.33	0.741508
Charcoal use(yes=1)				
Fsize	0.1893	0.10199	1.856	0.06343*
HH Age	0.02271	0.01607	1.413	0.15774
HH YearEduc	-0.0277	0.04469	-0.621	0.53432
HH gender	0.32025	0.27543	1.163	0.24494
HH own	-0.4239	0.32897	-1.289	0.1975
HH incoLev	0.39255	0.22652	1.733	0.0831*
HH TyOccup	0.03908	0.11563	0.338	0.73541
DwellCatego	-0.5165	0.17209	-3.001	0.00269***
SepKitch	0.02414	0.11921	0.202	0.83955
Electric use(yes=1)				
Fsize	0.03615	0.08411	0.43	0.66737
HH Age	-0.0266	0.0161	-1.653	0.09832*
HH YearEduc	0.1133	0.04619	2.453	0.01417**
HH gender	-0.1988	0.2714	-1.653	0.46372
HH own	-0.2684	0.31174	-0.861	0.38912
HH incoLev	0.65942	0.20849	3.163	0.00156***
HH TyOccup	0.19814	0.10885	1.82	0.0687*
DwellCatego	0.37008	0.18402	2.011	0.044**
SepKitch	-0.26155	0.10872	-2.406	0.01614**

Source: - Own survey data (2018). '***, '**' and '*' show significant at 1%, 5%, and 10% significant level respectively.

The estimation of functions of household energy sources in correlation to household characteristics (Appendix 3-4).

4.2.1. Multivariate probit result interpretation

Variables that have significant explanatory power in determining the fuel choice decision are interpreted in this section. The coefficient and standard error of these powerful explanatory variables was interpreted blow.

Household head age: As it was expected the age of household head found to be a negative and slightly significant, result shows that with an increase in the age of household head, the likelihood of using electricity decrease. This variables has p-value, standard error and coefficient of 0.09832, 0.0161 and -0.0266, respectively. The coefficient of -0.0266 for household age, also, indicates that the probability of choice decreases by 0.0266 relatively as one year increment in the household age. This study came up with similar findings of (Gebreegziabher et al., 2012; Rahut et al., 2014) that found older household heads are less likely to consume electricity. Such choice for traditional fuels support the notion that older people tend to perpetuate traditional habits, related to fuels, more than young people.

Family size: Family size was found positively and significant factor that fuel choice decision with the p-value of 0.043 and 0.063 and coefficient of 0.1854 and 0.1893 firewood and charcoal, respectively. This finding is similar to the previous studies (Nnaji et al., 2012; Liu et al., 2003 ; Carr et al., 2005) found that firewood is by far the fuel of choice for a majority of households with relatively larger size and household size linked with increase in firewood consumption because of increased energy demand and increased laborers available for fuelwood collection.

Household head education: The household head a formal year of education was found the significant factor that affects positively or negatively urban Household fuel choice. According to result in table 4-16, when the household formal year of education in year increases (p-value of 0.000742 and coefficient of -0.16891) the probabilities of choosing firewood as source of fuel decrease. The coefficient of -0.16891 for household head formal year of education, also, indicates that the probability of choice decreases by 0.16891 relatively as one year increment in the household head formal education in year. The finding of this study is in line with previous studies (Chambwera et al., 2007; Zenebe, 2007; Alemu, et.al, 2008; Nyembe , 2011 ; Yonas et.al., 2013; Gebreegziabher et al., 2012) found that the higher the education level, the less likely the households will choose firewood, while the more likely the households will choose electricity. It indicates that educated households use more modern and expensive energy sources for their domestic energy consumption. Whereas, the less educated households head prefer more traditional and cheap energy type.

Household head monthly income level: Table 4-16 shows that with an increase in wealth, there is also an increase dependency on electricity than other fuels such as wood and charcoal. Moreover, the coefficient of income household head level was 0.218 (significant at the 5% level) for a choice of electricity. The finding in this study is consistent with the previous studies (Hosier and Kipondya, 1993; Chambwera et al., 2004; Zenebe, 2007; Alemu et al., 2008; Nyembe, 2011) that found electricity accounts for a larger share of energy requirement as income increases. Therefore, energy is a necessity good for city households.

Dwelling: As Table 4-16 shows, the dwelling category have negatively and a significant factor that affects fuel choice with p-value of 0.005215, and 0.00269 and with coefficient of -0.5113 and -0.5165 for firewood and charcoal, respectively, and positively and significant factor that affects with p-value of 0.044 and coefficient of 0.37008 to electricity. The results show that if a household resides in a modern type house, the household is less likely to use charcoal or firewood. In fact, they have statistically significant p-values at the

5% confidence level indicating that there is strong evidence to believe that if a household resides in a modern type house, the household is likely to use electricity. The finding of this study is in line with previous studies Christophe and Huijie (2018) found that diverse measures of dwelling characteristics have been used: material used for floor, roof and wall, modern or traditional dwelling unit, and number of room. The dwelling characteristics are often considered as proxies of a household wealth and living conditions. They can also be seen as constraints to choices.

4.3. Stoves CCT

A total of three stoves were successfully tested using Controlled Cooking Test (CCT) method in energy technology development and research laboratory SNNPRG Mine and Energy, with up to 3 tests samples acquired per stove. The following subsections summarize the main performance results of stove. Given the small number of stoves test and quantity of collected data, detailed tabular results have been provided in Appendices 3 and 4.

4.3.1. Description of baking test of stove

Table 4-17 demonstrates the means calculated for the three stoves tests. Means are one statistically way to represent the distribution of results obtained in the number of replicates of tests conducted on the stoves. Both, alternative stoves, the Mirt stove and Yequme Mideja, reduced mean SFC for baking of batter of 15Kg relative to the three stone stove and Yequme Mideja reduced mean SFC relative to Mirt stove. Mean SFC among stoves tests result using Eucalyptus Camaldulensis as fuel were 303.31 g/Kg for Yequme Mideja, 348.35 g/Kg for the Mirt stove, and 580.09 g/Kg for the three stone stove (see detail in Appendix 3). Three stone stove consumed the highest SFC in comparison with other stoves types; 323.29 g/Kg for Yequme Mideja, 364.96 g/Kg for Mirt stove, and 606.8g/Kg for the three stone stove. In this study, the total bkking time, the result of experimentation gathered in Appendix 5 and 6. Compared with other two stoves that were tested, the three stone stove took a time to baking of batter that was quite good, but not as fast as two stoves. Specific fuel consumption, total cooking time and average power tended to be in the middle of the groups for all stoves tested (table 4-17).

Table 4-17: Summary of cookstove performance

Stove Type	SFC (g/Kg)		Total baking time (min)		Average baking power (Kw)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Three stone	580.09	27.98	109.00	2.65	20.05	1.74
Mirt	348.35	18.46	90.33	11.24	14.72	2.42
Yequme Mideja	303.31	33.52	80.33	5.69	14.00	1.78

4.3.2. Baking test result of stoves

While these results indicated that Yequme Mideja was the most firewood, saving baking stove type. On the other hand, it was desirable to reduce average baking power consumption and achieve higher levels of firewood saving in order to cut down on the environmental burdens related to firewood.

Table 4-18:- Baking test result

Comparison of three stone and Mirt Stove	Unit	% difference	T-test	Sig @ 95% ?
Specific fuel consumption	g/kg	39.95	11.97645	YES
Total baking time	min	17.13	2.8	YES
Average baking power	KW	26.59	3.097073	YES
Comparison of three stone and Yequme Mideja	Unit	% difference	T-test	Sig @ 95% ?
Specific fuel consumption	g/kg	47.71	10.98073	YES
Total baking time	min	26.3	7.916942	YES
Average baking power	KW	30.19	4.212124	YES
Comparison of Mirt and Yequme Mideja	Unit	% difference	T-test	Sig @ 95% ?
Specific fuel consumption	g/kg	12.9294	2.038846	NO
Total baking time	min	11.0701	1.375048	NO
Average baking power	KW	4.9003	0.415737	NO

Source: - Own survey data (2018).

As it can be seen from table 4-18, the SFC comparison between three stone and Mirt stove was 39.95%.The t-value (t=11.97645; P=yes) shows that there was a statistically significant difference between three stone and Mirt stove SFC. The finding of this study is similar to previous works (Yosef, 2007; Shanko et al., 2009; GIZ, 2012) that the test result discovered SFC reduced by 50% by improved stove. This is inconsistent with the findings of previous research showing that Mirt Injera stove does not seem to save time as compared to open fire (Yosef, 2007).

4.3.3. Comparison of means baking test

Mean comparison of laboratory results was made by conducting a series of CCT on different stoves at the Alternative Energy Research and Development laboratory at Hawassa. Two –sided q-test employed to mean of experiment result of three stoves. The difference between the means SFC for Yequme Mideja and three stone stoves is 276.78233g/Kg, with a standard error of 22.34425 for this mean difference (table 4-19). The 95% confidence interval of the difference is (208.2241, 345.3406), indicating that the mean SFC reduction is statistically significant.

Similarly, as shown, on table 4-19, the difference between the mean SFC for Yequme Mideja and Mirt stoves is 45.039g/Kg with a standard error of 22.34425. The result indicated that at 95% confidence interval mean SFC reduction is not statistically significant between Yequme Mideja and Mirt stoves. The result of testing presented, used mean baking time comparison, two-sided q-test to test if the baking times for three types of stoves are different. The results presented in table 4-19. The two-sided q-test, the difference between the mean baking times for stand and three stone stoves was 28.6667min, and the standard error was 6.06752. The 95% confidence interval was (10.0498, 47.2835) min and the difference were statistically significant. The difference between the mean baking time for Yequme Mideja and Mirt stoves was 10min with a standard error of 6.06752 (table 4-19). The result indicated that at 95% confidence interval mean baking time reduction is not statistically significant between Yequme Mideja and Mirt stoves (table 4-19). The Yequme Mideja has a better energy efficiency compared to both Mirt and three stone stoves. Overall, they ranked from first to last Yequme Mideja and Mirt according decreasing trends of CCT and ignoring three stone stove due to its low efficiency.

Table 4-19:-Baking test means comparison

(I) stove	(J) stove	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
SFC(g/Kg)						
three stone stove	Mirt stove	231.74333*	22.344	0.00	163.185	300.3016
	Yequme Mideja	276.78233*	22.344	0.000	208.224	345.3406
Mirt stove	Yequme Mideja	45.039	22.344	0.2	-23.5193	113.5973
Baking time(min)						
three stone stove	Mirt stove	18.66667*	6.068	0.0	0.050	37.28
	Yequme Mideja	28.6667*	6.068	0.01	10.050	47.28
Mirt stove	Yequme Mideja	10	6.068	0.30	-8.62	28.62
Average baking power (Kw)						
three stone stove	Mirt stove	5.33043*	1.64	0.04	0.31	10.352
	Yequme Mideja	6.05162*	1.64	0.02	1.03	11.07
Mirt stove	Yequme Mideja	0.7212	1.64	0.9	-4.30	5.743

*. The mean difference is significant at the 0.05 level.

5. CONCLUSIONS AND RECOMMENDATION

5.1. Conclusion

This paper investigates factors that influence household fuel and fuel saving technology choice and transition in urban households of Hawassa city, using data collected from household survey questionnaire, interviews and field observation. Unlike This study investigated that households do not substitute one fuel for another while they ascend the ladder but follow a rather multiple fuel approach. The firewood and charcoal 39.1%, followed by charcoal and electricity 19.87% which followed by firewood, charcoal and electricity account for 16.03%.

The descriptive analysis showed that, firewood, charcoal and electricity are universal baking and cooking fuels in Hawassa city and are likely to dominate the fuel-portfolio even in the long run. The findings indicate that majority of the households were dependent on charcoal (78.2%), firewood (58.3%) and electricity (53.2% were entire both baking and cooking fuels. Furthermore, socioeconomic factors were considered to influence fuel choice. The study area fuel-portfolio was found to be dominated by charcoal, as majority fuel, followed by firewood and electricity, respectively. Charcoal is found to be the primary fuel for the relatively high income; hence, both income growth and urbanization seem to induce switching out of wood towards charcoal. This trend, over time, would increase the distance between charcoal production and consumption points as the nearby stock of forests continue to be depleted with the obvious implications for cost of fuel and the de-greening of the economy. Urban low-income households more frequently used firewood followed by charcoal and electricity. The choice for Yequme Mideja among households' own house is particularly for baking limited. Limited number renter households were using electric stove as baking fuel, compared with the sampled living household in their own house.

The socioeconomic characteristics of the households were estimated to be important factors influencing the of fuels choice. Results of the multivariate probit analysis confirmed that households were multiple fuels dependent and their fuel choices were determined by their level of permanent income proxied by the asset index. In addition, formal education of the households' heads, as well as the residence in concrete, brocket wall with sheet metal cover integrated dwelling tend to encourage the choice of clean fuel and fuels saving technology with higher efficiency and cleaner combustion. Large size households and wood, mud sheet metal cover integrated household significantly induce firewood use including other smoker fuels and inefficient stoves with incomplete combustion. Also, this study provides a quantitative assessment of the potential of enclosed biomass stove specifically designed for Injera baking. The stoves increase the efficiency of available energy utilization. Yequme Mideja (47.71%) and Mirt stoves (39.91%) test result point out of the performance 45Kg batter baking 'injera' against to three stone stoves, their respective order. The efficiency could also be improved since there was a slight difference between the "Mitad" and the ICS stoves and between stoves. The reduction of fuel consumption and baking time in the kitchen due to the installation of Mirt and Yequme Mideja were very high, and the trend observed is consistent throughout all of the tests in this study. On the other hand, the level of reduction between Mirt and Yequme Mideja was not significant. An insignificant difference of reduction of fuel consumption, baking time and average power might have come from small sample size and therefore comparisons of the Mirt and Yequme Mideja in terms of fuel consumption, baking time and average baking power may not be conclusive. Finally, the thesis investigated the socioeconomic factors that help to speed up the choice of clean fuel and fuel saving technologies in urban Hawassa City.

5.2. Recommendation

The regional government and city administration should: (a) Promote, disseminate and scale-up the uptake of clean fuel use and improved firewood baking stoves. The stoves should be affordable, durable and consider the safety of end-users. The overarching message to end-users should stress saving fuel expenditure and improving health of the users. It would be prudent for the government to institute a body responsible for quality control of the improved stoves (b) Promote other alternative fuels for household cooking and baking purposes such as briquettes (saw-dust/charcoal dusts), LPG and natural gas. (c) Regularly and consistently provide adequate and well-targeted extension education services to the community to change their habits, way of thinking and attitudes towards environmental issues. Therefore; since the majority of households that depend on biomass are low income, the design, and price of new and improved biomass cookstoves should consider poor households' capacity to purchase the new technology. Policies aiming at reducing the rate of deforestation need to focus on changing the behavior of the large-scale charcoal harvesters. Recent literature indicated that, the availability of electricity is an access proxy for fuel market development and it acts as catalyst for people to switch from traditional to modern fuels, (Barnes et al. 2004). The extent to which a household substitute or complement fuel uses is difficult to ascertain from the present data, however, fuel stacking could be very common and is an issue that requires further investigation. To reiterate, improved cookstoves should be designed, tested and rated in their contexts of use, lest interventions will continue to fail policy makers, users and the environment.

International donor agencies should also invest in raising education levels and developing economies. As educated household heads are more aware of the negative impacts of the use of charcoal and firewood, enhancing education systems in resource-poor developing economies can reduce the number of people suffering the negative consequences of using biomass and other dirty energy sources. Finally; it is believed that it can give an insight for further study on issues related to design improvement of improve baking stove and awareness rise will be needed to get overall benefit, and noted, given the importance of reducing the current problem health and the environment, understanding the determinants of choice, as well as the speed of use, can provide information that policymakers can use to increase the speed of adoption, generally.

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Questionnaires

Ethical Considerations

During the research undergo, researcher legality all the feeling relationships, cultural and norms of the community the real environment of the studied area used considered and respected .During the questionnaire distribution to the respondents all sample targets of the population treated in an ethical manner. At the beginning of the data collection, the researcher made to explain the overall objectives of the study to make respondents confident enough to their responses .The researcher have told that the data collected will use only for academic purpose and will keep confidentiality all personal secrets.

The interview schedule

INTERVIEW SCHEDULE FOR IDENTIFYING FACTORS INFLUENCING CHOICE HOUSEHOLD FUEL AND FUEL SAVING TECHNOLOGY CHOICE: *THE CASE OF HWASSA CITY, SOUTHERN ETHIOPIA.*

Any information you will give will be handled with confidentiality and will be used for no any other purpose other than for academic purposes. Thank you in advance.

INSTRUCTION

1. Understand clearly all the questions before starting the interview
2. Introduce yourself to the respondents; make them clear about the purpose of the interview and ask their permission politely.
3. Be patient during the interview and explain the questions in understandable way to the respondents.
4. Reliable information leads to right generalization. Hence, please write the respondents' own response properly for each question.
5. Check that all questions are asked and responses are filled accordingly

PART 1

A. Demographic and socio-economic information

Kebele ___________________________

Sub city ___________________________

Part A: Baseline Household Information

1. Name of the household head:____________________
2. Sex: 1. Male 2. Female 3,Age: years ______old
3. Marital Status: 1. Single 2. Married 3. Widowed 4.Divorced
4. What is the highest level of education you have attended? ______________year

5. How much is your monthly household head income?
    a. 0-3,000birr
    b. 3,001-6,000
    c. 6,001-9,000
    d. 9,001 and above
6. **Total number of household(size) ___________________**

- **Use coding to fill Occupation in the table**

(Daily labour worker(0), Unemployed(1), Business men(2), Government employee(3), Private employee(4), Non-Government Organization employee(5), Pensioner(retired)(6) and others, please specify(7))

Household member	Sex	Age	Education level	Occupation	Income (birr)

7. **Ownership of House:**
    A. Owned B. Rented C. Living with relatives D. Provided by employer F. Others, please specify: __________________
8. What types of shelter is the household living in?(check all that apply)
    a. Plastic sheeting
    b. Biomass (wood, straw)
    c. Brick or cement
    d. Combination(list__________, ____________,________________)
    e. Other specify ___________________________
9. How much land size do you have? ______________________
10. How much size your house occupied? ____________________
11. Among the following household expenditures, which takes the largest share of your monthly expense? (Choose ONE) A. Food B. Water C. Fuel D. Education fee E. Others, specify: _____________________
12. Where does household get public information?
    a. TV
    b. Radio
    c. Print media

d. Extension agents

13. What types of food are cooked regularly?

a. Injeria
b. Wotte
c. Bread(Kita)
d. Vegetable sauce
e. Other (specify)____________________

14. Who cook food for household?

a. Spouse
b. Family members
c. Hired cook
d. Relative
e. Other

Household fuels information.

Part 2:- Fuel type, use and Expenditure

15. What types of cooking fuel are you using regularly? Check on (√)

It no	Household Fuel Type	Check on (√)
1	Firewood	
2	Charcoal	
3	Kerosene	
4	LPG	
5	Electricity	
6	Other	

16. For what purpose you use the fuel? Use to fill coding (cooking (1), Baking(2), Both(cooking and baking) (3),)

It. No	Household Fuel Type	Use
1	Firewood	
2	Charcoal	
3	Kerosene	
4	LPG	
5	Electricity	
6	Other	

17. How do you get access to the fuel (energy) sources in your area? Use coding on accessibility of energy source

(i) Purchase (0) (ii) open collection (1) (iii) Self prepared around backyard (3)

It. No	Household Fuel Type	Unit	quantity	Price per quantity	Way of Accessibility
1	Firewood	Kg			
2	Charcoal	Kg			
3	Kerosene	Liter			
4	LPG	cylinder			
5	Electricity	KW			
6	Other(specify)				

18. If you bought your fuel, what do you think about the cost?
    a. Fair(mean cheap)
    b. Unfair(mean cost)
    c. Medium
19. If you purchase fuel, how do you evaluate the trend in the last 10 years?
    a. increasing
    b. stable
    c. decreasing
20. Who decides in the fuel choice (if your household fuel choice?) indicate the person who decide more with "1" the next person who also decide but less with a "2" and so on until all persons who normally choice fuel are?

    Rank

    a. Father ______________
    b. Mother ______________
    c. Son(s) ______________
    d. Daughter(s) ______________
    e. Other ______________
21. What are concerns or problems with your fuel supply at present? Read the possible responses as written. Read the words in the parenthesis () if only the respondent ask for classification.(more than one choice possible)
    a. Scarcity of fuel
    b. Seasonal reliability of fuel (i.e. difficult to get/ make rainy season, etc)
    c. Price in market for purchase
    d. Inefficient means of cooking/ source of heat /source of light
    e. Health concerns
    f. Other (specify)__________________
22. Are you experiencing problems with the current source of fuel?

a. Yes
b. No

If yes, check at list two that apply

I. High price
II. Poor quality
III. Problems with personal security in obtaining fuel(specify)__________
IV. Fuel shortages
V. Long distance must be traveled to collect fuel
VI. Seasonal function in full availability
VII. Competition between groups for access to fuel or foraging land
VIII. Other specify______________

Part: - 3 Household Technology type and costinformation.

23. What is your current stove made out of?

It. No	Household energy technology(stove type)	Check on (√)
1	Three-stone fire(made with stones or bricks)	
2	Mud (with clay/sand/glass/etc)	
3	Metal (e.g.:- electric stove)	
4	Combination of sand and metal (like Yequme Mideja)	

24. What type of stove for cooking are you using?

It. No	Household energy technology(stove type)	Check on (√)
1	Charcoal stove	
2	Three stone stove	
3	Electric stove	
4	Kerosene stove	

25. What type stove for baking are you using?

It. No	Household energy technology(stove type)	Check on (√)
1	Three-stone fire(made with stones or bricks)	
2	Mud (with clay/sand/glass/etc)	
3	Improved stove	
4	Improved Yequme Mideja	
5	Electric stove	

26. Did you use improved/modern energy efficiency technology? Yes______, No__________

- If yes, which type you use?
- If no, why? ___________________

27. How did you get this stove?

    a. Made it at home
    b. Given to me by a friends/family member/
    c. Given to me by relief organization
    d. Bought it

What was the cost?_________________

    e. Other (specify)________________

28. If you bought your stove, what do you think about the cost?

    a. Fair(mean cheap)
    b. Unfair(mean cost)
    c. Medium

29. Does your stove produce a lot of smoke when you cook?

    a. Yes
    b. b. No

30. If yes, is this good thing or bad thing?

    a. Good
    b. Bad
    c. Neither good nor bad

Why____

31. Where do you usually cook?

    a. In the main building used for living or sleeping (with partition)
    b. In the main building used for living or sleeping (without partion)
    c. In the separate room used as kitchen
    d. In a separate building used as kitchen by sharing with other household
    e. Outdoors (with one or two make shift walls and roof)
    f. Outdoors (open air with no walls)
    g. Others,

32. What solution (coping) mechanism did you take related to fuel?

APPENDICES

Appendix-4: Summary of variable included in multivariate probit model

Variables	Type	Code	Description
Firewood	Dummy	Uwood	'1' if household use firewood, and otherwise '0'
Charcoal	Dummy	Uchar	'1' if household use charcoal, and otherwise '0'
Electricity	Dummy	UElec	'1' if household use electricity, and otherwise '0'
House ownership	Dummy	Houown	'1' if household own, and if rent '0'
Family size	Continuous	Fsize	Total member of persons in the household
Age	Continuous	HHage	Number of year household head
Education level	Continuous	HH YearEdu	Total monthly income level in Eth. Birr.
Income level	Continuous	HH inGroup	Household head income level
Type Occupation	Dummy	HH TyOccup	Household occupation type
Dwelling Category	Dummy	DwellCatego	Dwelling category of household
Separate Kitchen	Dummy	SepKitch	Household has separate kitchen

Operational Definitions and Descriptions of Variables

This study included variables of Household fuel and fuel saving technology choice and household characteristics. Here under these variables are defined and described.

Dependent variable: fuel such as firewood (Uwood), charcoal (Uchar) and electricity (UElec) were given a value of '1' to user while '0' was assigned to non-user and similarly to fuel saving technology. To assess the status of choice by urban households, respondents were asked whether they choice or not in the form of 'Yes' or 'no' response question. Similar studies, for instance, ((Tabet, 2007; Treiber, 2012) used such type objective response and direct measure of binary dependent variable in determining the fuel choice.

Independent variables: The independent variables were selected based on the existing theories and empirical studies (Damte & Koch, 2011; Puzzolo et al, 2013). The definitions of these selected explanatory variables are given below.

Household gender (HH gender): In this study gender is a dummy which refers to the Household head sex. A value of '1' was given to male and '0' for female.

Age (HH Age): Here refers to the household head age in years. It is in this study continues variable.

Education level in year (HH YearEdul): By number of year household head education in this study is a continuous which refers to whether the respondent is level of schooling.

Family size (Fsize): The total number of persons in a household. In this study continues variable

Separate kitchen (Sepakich): It is about whether the household has access to separate kitchen house or not.

Dwelling Category type (DwellCatego): It is the households housing type material. A value of '0' value of Wood, Mud, and Sheet metal, a value of '1' for all local and fabricated material integrated and A value of '2' for Concrete, brocket and sheet metal cover built house.

House ownership (Houown): In this study type of house is a dummy valued '1' for a household that has own covered and '0' for has rent.

Monthly income of households head (HH incolevel): The amount of Household head monthly income for meeting different requirements of the household and the same is true for choice of fuel and fuel saving technologies.

Appendix-2: pair-wise correlation coefficient

	Houown	HHHgen	Age	Fsize	Educlev	incomRa	TypOcc	TypHou	Kitchen	fuelchoice
Houown	1									
HHHgender	0.012	1								
Age	.442**	0.033	1							
Fsize	.336**	0.114	.562**	1						
Educlevel	-0.03	.264**	-.434**	-.293**	1					
incomRang	.222**	0.117	-0.079	0.113	.232**	1				
TypOccup	-0.008	0.057	0.087	-0.076	.201*	-0.126	1			
TypHous	.335**	0.095	0.054	0.019	.177*	.240**	0.007	1		
Kitchen	0.149	0.041	.369**	.249**	-0.152	0.018	0.035	0.051	1	
fuelchoice										

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix -3 Multivariate Probit Model Output

multivariate probitmodel outputs Uwood Uchar UElecHouown FsizeHHage HH YearEdu HH inlevHHTyOccupDwellCatego SepKich

Iteration 0: log likelihood = -103.93944
Iteration 1: log likelihood = -78.979176
Iteration 2: log likelihood = -78.484677
Iteration 3: log likelihood = -78.484348
Iteration 4: log likelihood = -78.484348

Multivariate probit model Number of obs = 156
LR chi2(3) = 50.91
Prob > chi2 = 0.0000
Log likelihood = -78.484348 Pseudo R2 = 0.2449

variable	Coefficient	Std. Error	Z	Pr(>|Z|)
Uwood (yes=1)				
Fsize	0.1854	0.0918	2.02	0.04341
HH Age	0.01623	0.01507	1.077	0.28168
HH YearEduc	-0.16891	0.05007	-3.373	0.00074
HH gender	0.37218	0.28074	1.326	0.18494
HH own	0.1136	0.31892	0.356	0.72169
HH incoLev	-0.0346	0.18742	-0.185	0.85361
HH TyOccup	0.05052	0.10677	0.473	0.63611
DwellCatego	-0.5113	0.18304	-2.793	0.00522
SepKitch	0.03582	0.10859	0.33	0.74151
Charcoal use(yes=1)				
Fsize	0.1893	0.10199	1.856	0.06343
HH Age	0.02271	0.01607	1.413	0.15774
HH YearEduc	-0.0277	0.04469	-0.621	0.53432
HH gender	0.32025	0.27543	1.163	0.24494
HH own	-0.4239	0.32897	-1.289	0.1975
HH incoLev	0.39255	0.22652	1.733	0.0831
HH TyOccup	0.03908	0.11563	0.338	0.73541
DwellCatego	-0.5165	0.17209	-3.001	0.00269
SepKitch	0.02414	0.11921	0.202	0.83955
Electric use(yes=1)				
Fsize	0.03615	0.08411	0.43	0.66737
HH Age	-0.0266	0.0161	-1.653	0.09832
HH YearEduc	0.1133	0.04619	2.453	0.01417
HH gender	-0.1988	0.2714	-1.653	0.46372
HH own	-0.2684	0.31174	-0.861	0.38912
HH incoLev	0.65942	0.20849	3.163	0.00156
HH TyOccup	0.19814	0.10885	1.82	0.0687
DwellCatego	0.37008	0.18402	2.011	0.044
SepKitch	-0.26155	0.10872	-2.406	0.0161

Appendix-4: Stove Efficiency Evaluation Protocol

SHELL FOUNDATION HEH PROJECT CONTROLLED COOKING TEST

DATA AND CALCULATION FORM

Shaded cells require user input; unshaded cells automatically display outputs

Qualitative data

Name(s) of Tester(s)		Type of stove: Stove 1	
		Type of stove: Stove 2	
Test Number		Location	
Date		Wood species	Average Hardwood

Quantitative testing conditions	data	units	variable		data	units	variable
Avg dimensions of wood (length x width x height)		cm	--	Empty weight of Pot # 1		g	P1
Wood moisture content (% - wet basis)		%	m	Empty weight of Pot # 2		g	P2
Local boiling point of water	100	ºC	T_b	Empty weight of Pot # 3		g	P3
(default value is 100 ºC - correct if local value differs)				Empty weight of Pot # 4		g	P4
				Weight of container for char		g	k

Other comments on test conditions

Appendix-5: CCT Data and Calculation Form for biomass injeria stove

CCT-1 for the ______ Wind conditions: no wind

Shaded cells require user input; unshaded cells automatically display outputs Air temperature ____ °C

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g		f_i		f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g				$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i		t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g		$W_f = \sum_{j=1}^{4} (P_{jf} - P_j)$	Specific fuel consumption	g/kg		$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g		$\Delta c_c = k - c_c$	Total cooking time	min		$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g		$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

Description of stove (indicate the construction material of the stove, the way that the pot(s) fits in the stove, and the presence of insulation, chimney, workspace, etc):

Biomass Injera Stove
Stove type: -- Test No: ---------------
Cook: -------------------------------- Bucket No: ------------ Date: ----------------- AM/PM
Stove condition: --
Mitad Diameter: ----------------------- Mitad thickness: ------------------------------
Batter temperature: ------------------ Amount of water: -----------------------------
Ambient temperature: ------------------------------
INITIAL MEASUREMENTS
Empty Injera bucket wt: ---------- + 16kg (of batter) = Filled bucket weight: -----------------------
Sefied weight: ----------------- Empty charcoal tub weight: ------------------------
Fuel weights: ------------------- + ----------------- = -----------------------------
Fuel moisture: ----------------------
Time fire lit: ----------------------
Time first batter poured: -------------------------
FINAL MEASUREMENTS
Time last injera removed: --------------------------
Bucket + unused batter weight: --------------------------
Unburned fuel remaining: -------------------------- Charcoal + Tub weight: ------------------
Injera weight + sefied weight = ---------------------- Number of Injera: -------------------
CALCULATIONS
Total fuel consumed: --
Cooking time: --
Fuel per Injera: ---
Time per Injera: --
Used batter weight: --
Fuel per kg injera: --
Fuel per kg batter: --
Evaporated water: ---
Charcoal weight: --

Appendix-6: Summary of cookstove Injeria baking performance

Test no.	Stove type	Fuel consumption (g)	Moisture (%)	Batter (Kg)	Total weight of injeria baked(g)	no of injeria	Fuel/per injeria (g/no.)	Fuel/batter (g/Kg)	Fuel/ injeria(g/g)
1	3-stone	6559.8	11	15	10810	28	234.278	437.32	0.61
2	3-stone	6050	14.5	15	10980	29	208.621	403.33	0.551
3	3-stone	6875	10	15	11660	31	221.774	458.333	0.59
	Mean	6494.93	11.83	15	11150	29.33	221.558	433.00	0.582
	SD	416.31	2.36	0	449.78	1.528	12.8301	27.75	0.029
	CV	0.064	0.20	0	0.040	0.052	0.058	0.0641	0.05
1	Mirt	4001.736	11	15	10965	29	138.0	266.78	0.365
2	Mirt	3652.7	14.5	15	11120	30	121.76	243.51	0.33
3	Mirt	4064.6	10	15	11560	31	131.12	270.97	0.352
	Mean	3906.34533	11.8333	15	11215	30	130.29	260.423	0.348
	SD	221.900737	2.36291	0	308.67	1	8.15	14.79	0.018
	CV	0.0568052	0.19968	0	0.028	0.033	0.063	0.057	0.053
1	Stand	3113.18	11	15	11765	32	97.2869	207.5453	0.2646137
2	stand	3374.8	14.5	15	10480	27	124.993	224.9867	0.3220229
3	Stand	3491.54	10	15	10800	28	124.698	232.7693	0.3232907
	Mean	3326.506667	11.8333	15	11015	29	115.659	221.7671	0.3033091
	SD	193.7479211	2.36291	0	668.9357	2.646	15.9115	12.91653	0.0335172
	CV	0.058243659	0.19968	0	0.06073	0.091	0.13757	0.058244	0.1105051

1. CCT results: 3-stone Stove	units	Test 1	Test 2	Test 3	Mean	St Dev.
Total weight of food cooked	g	10810	10980	11660	11150	449.78
Weight of char remaining	g	315	430	525	423.33	105.16
Equivalent dry wood consumed	g	6559.8	6050	6875	6494.92	416.29
Specific fuel consumption	g/kg	606.8	551	582.47	580.09	27.98
Total cooking time	min	110	111	106	109	2.65
the average power	KW	20.04	18.314	21.79	20.048	1.74
2. CCT results: Mirt Stove	units	Test 1	Test 2	Test 3	Mean	St Dev.
Total weight of food cooked	g	10965	11120	11560	11215	308.67
Weight of char remaining	g	250	235	220	235	15
Equivalent dry wood consumed	g	4001.7	3652.7	4064.6	3906.35	221.90
Specific fuel consumption	g/kg	364.95	328.48	351.61	348.35	18.46
Total cooking time	min	100	93	78	90.33	11.24
the average power	KW	13.45	13.20	17.51	14.72	2.42
3. CCT results: Stand stove	units	Test 1	Test 2	Test 3	Mean	St Dev.
Total weight of food cooked	g	11765	10480	10800	11015	668.94
Weight of char remaining	g	175	290	405	290	115
Equivalent dry wood consumed	g	3113.2	3374.8	3491.5	3326.51	193.75
Specific fuel consumption	g/kg	264.61	322.02	323.29	303.31	33.52
Total cooking time	min	85	82	74	80.33	5.69
the average power	KW	12.31	13.83	15.85	14.00	1.78
Comparison of 3-stone and Mirt Sto	% differ	T-test	Sig @ 95% ?			
Specific fuel consumption	g/kg	39.95		11.98	YES	
Total cooking time	min	17.13		2.8	YES	
the average power (p)	KW	26.59		3.10	YES	
Comparison of 3-stone and Stand st	% differ	T-test	Sig @ 95% ?			
Specific fuel consumption	g/kg	47.71		10.98	YES	
Total cooking time	min	26.3		7.92	YES	
the average baking power	KW	30.19		4.21	YES	
Comparison of Mirt and Stand stove	% differ	T-test	Sig @ 95% ?			
Specific fuel consumption	g/kg	12.93		2.04	NO	
Total cooking time	min	11.07		1.38	NO	
Average baking power	KW	4.90		0.42	NO	

BIOGRAPHICAL SKETCH

The author was born in July 1986 and at age of eight; he was enrolled in Gucha primary school and attended secondary school at Mudulla High School. He joined Gondor University in 2005 and graduated with B.Sc degree in Applied Physics. He began professional career under the SNNPRG Water and Irrigation Bureau as expert for biogas and biomass in Tembaro Woreda water, mine and energy office of Kembatta Tembaro Zone and served as research expert of Alternative energy sources and technologies of SNNPRG Mine and Energy Agency until know