Institute of Health

Faculty of Public Health

Department of Environmental Health Sciences and Technology

Assessment of Potential of Biomass Energy, its Consumption Pattern and Challenges of Adopting Household Improved Energy Technologies in rural areas of Limmu Kossa Woreda, Jimma, South West Ethiopia

By

Ashenafi Getaneh

Thesis Submitted to the Department of Environmental Health Science and Technology, Institute of Health Science, Faculty of Public Health, Jimma University; in partial fulfillment for the requirement of Masters of Science degree in Environmental Science and Technology

January, 2022

Jimma, Ethiopia

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January, 2022

Jimma, Ethiopia

Approval sheet

As thesis research advisors, we hereby certify that we have read and evaluated this thesis prepared under our guidance by Ashenafi Getaneh entitled ‘Assessment of Potential of Biomass Energy, its Consumption Pattern and Challenges of Adopting Household Improved Energy Technologies in rural areas of Limmu Kossa Woreda, Jimma, South West Ethiopia’. We recommended that it could be submitted as fulfilling the thesis requirement.

Gudina Terefe (PhD, Associate professor) Signature: ________________ Date: ___________

Kasahun Eba (MSc, PhD candidate) Signature: _______________Date: ___________

As member of the board of examiners of the MSc. thesis open defense examination, we certify that we have read and evaluated the thesis prepared by Ashenafi Getaneh and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Environmental Science and Technology.

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Internal Examiner Signature Date

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External Examiner Signature Date

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Department of Environmental Health Science and Technology appreciates the successful completion of his thesis

Abstract

Background: *Traditional biomass energy sources are common for household energy consumption in Limmu Kossa woreda. The highly reliance on biomass energy in inefficient ways have direct impact on the forest coverage and its emissions have significant health issues.*

Objectives*: To determine the potential of biomass energy, its consumption pattern and challenges of adopting improved energy technology.*

Methods*: Cross sectional survey was conducted from June 13th - 24th 2021 on sample of 411 non biogas adopters and 32 adopters sampled using systematic random and purposive sampling techniques in 4 kebeles of the woreda. A questionnaire involving household's fuel use, types of stoves, current status of installed biogas and socio economic and demographic characteristics influencing the adoption of biogas technology, improved cook stoves and solar energy were used to collect the data. Background data related to household survey was collected from 14 key informants and 13 focus groups purposely selected. Analysis of the data was done by the use of Statistical Package of Social Science (SPSS) version 23 and Microsoft Word-Excel. Descriptive statistics as well as multiple linear regression model were used to establish the relationships between variables. Biogas and crop residue energy potentials were quantified based on different literature values.*

Result and discussion*: About 422*m^3 *of biogas energy potential was available from animal livestock manure and human excreta per day; water source was available at 15-20 minutes' walk. 1,146ton of collectible biomass energy potential from cereal crops was available. Annually, in average 2,952 kg of mix biomass, 18.2L of kerosene and 18.2KWh of electricity was consumed at household level. The annual consumption of biomass, kerosene and electricity among study respondent households were 1,213t, 5,984L, 7,480 megawatt hour respectively. Age, income, educational level, gender, family size and availability of firewood were found to be factors influencing adoption of biogas, improved cook stoves and solar energy adoption in the study area. From focus group discussion and key informant interview, lack of awareness, lack of after sell service, poor product quality; lack of subsidy and poor stakeholder cooperation were observed as key challenges of biogas, improved cook stoves and solar energy technology adoption.*

Conclusion: *Improved energy technology had significant impact on sustainable environmental management and healthy lives among the adopters. Income, educational level, subsidy, awareness, stakeholder engagement and technical service were found to be the major accelerator of rapid adoption. Promotion enhancing to efficient energy technology adoption should be strengthened and targeted on localities.*

Key word: -Biomass, biogas, consumption, adaptation, improved energy

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List of abbreviations

CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
CO_2	Carbon Dioxide
EC	Ethiopian Calendar
EEPCO	Ethiopian Electric Power Corporation
EFCCA	Environment, Forest and Climate Change Commission
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization
FGD	Focus group Discussion
GHGs	Green House Gases
HH	House Hold
IAP	Indoor Air Pollution
ICSs	Improved Cook Stoves
IEA	International Energy Agency
Ktoe	Kilotons of Oil Equivalent
LPG	Liquid Petroleum Gas
Mt	Mili Ton
MW	Mega Watt
NBPE	National Biogas Program Ethiopia
OECD	Organization for Economic Cooperation and Development
SDG	Sustainable Development Goal
SNV	Netherlands Development Organization
SSA	Sub-Saharan Africa
TWh	Tera Watt hour
WHO	World Health Organization

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Finally, I must express my very profound gratitude to my family for providing me with unfailing support and continuous encouragement throughout my study and through the process of this thesis. This accomplishment would not have been possible without them.

Chapter 1: Introduction

1.1 Background

Energy plays a central role in the national development process as a domestic necessity and a major factor of production (Amigun *et al*., 2012). Its contribution is holistic because it serves social, economic, political, and environmental aspects of development including access to healthcare, water, agricultural and industrial productivity, education, and other vital services (Amare, 2015). The International Energy Agency report (IEA, 2018) predicts that the share of renewables in meeting rising global energy demand will grow by one fifth to reach 12.4% by 2023.

Challenges of 21 centuries is to provide clean and healthy environment as well as fulfillment of energy demand, a renewable energy supply because of depletion of earth's fossil fuel resources which are directly linked to greenhouse gases (GHGs) emissions and climate change. However, the trend of primary energy sources indicates that renewable energy will be the fastest-growing energy source over the next two decades (Bahadori, 2021).

The way of producing, converting and consuming energy throughout the world is not sustainable. Majority of existing practices of energy production consume non-renewable raw material for energy production such as coal, petroleum products which leads to release of pollutants in the environment. In 2018, an estimated 55.3 $GtCO_2e$ of greenhouse gases (GHGs) were emitted into the atmosphere annually, where G20 members account for 78 percent (G. A Desta *et al*., 2020).

Clean and renewable energy technologies directly help to mitigate the climate change by reducing greenhouse gases emission in the global and a long term process. Harvesting the renewable energy in decentralized manner is one of the options to meet the rural and small scale energy needs in a reliable, affordable and environmentally sustainable way (Ravindranath *et al*., 2009).

However, 1.5 billion people (over 20% of the world population) do not have electrical power, and approximately 3 billion people (some 45% of the world population) rely on solid fuels such as firewood, crop residues, cattle dung, and coal to meet their cooking needs (UNDP, 2019).

Despite the continually rising energy demands however, millions of communities and households, particularly in developing countries, still lack access to basic energy services such as electricity, liquid fuels, and natural gas. But in Africa, in spite of the availability of various energy sources, more than 80% of the total population in most countries is still rely on traditional biomass as the main source of energy for cooking (Diefenderfer *et al*., 2016). Approximately 280 million tons of oil equivalents of solid biomass are now utilized in SSA, accounting for 90% of household energy (Hailu *et al*., 2021 and Outlook, 2014). This reliance, particularly on biomass fuels like fuel wood, agricultural wastes and animal dung, is primarily concentrated in low-income developing countries (Jeuland *et al*., 2015). Hence this is contributing to indoor and outdoor air pollution, forest degradation and climate change (Bailis *et al*., 2015).

According to Bruce (2012), there is substantial evidence that household air pollution from burning solid fuels increases the risk of acute lower respiratory infections in children under 5. It also increases the risk of a number of adverse pregnancy outcomes, and may impair cognitive development. Furthermore, the WHO estimates that exposure to wood smoke can more than double the risk of severe and fatal respiratory infections in under 5 children.

In Ethiopia 95% of population relies on biomass energy (Geremew *et al*., 2014), though reliance on commercial fuels is expected to increase in the coming decades (Mondal *et al*., 2018). To ease the transition to modern fuels like LPG, electricity and biogas, improved biomass cook stoves (ICS) have been introduced around the world as an intermediate step. These stoves seek to provide efficiencies by cooking meals with less fuel, resulting in less fuelwood consumption (Mondal *et al*., 2018) and potentially offer improved performance in other ways compared with traditional technologies (Gebreegziabher *et al*., 2018). These stoves are typically not sophisticated, are often cheap (Hanna *et al*., 2016) and generally require minor changes in cooking habits of households (Jeuland and Pattanayak, 2012).

In Limmu Kossa woreda electric supply coverage was 10.4% & about 90% of the total population relied on fuel wood (woreda electric utility office report, 2020).

To overcome those problems, alternative energy sources have recently become more and more attractive due to the increasing demand for energy, the limited resource for buying fossil fuel, the environmental concerns, and the strategy to survive post-fossil fuel economy era (Zebider, 2011). Biogas technology has the potential to replace biomass in Ethiopia (Mwirigi *et al.*, 2014). Hence, several countries in the developing world have developed biogas program initiatives in partnership with donor organizations. However, little success has been reported on their installation and functionality in Ethiopia (Desalegn, 2014).

In order to eliminate the negative effects of relying on traditional biomass for cooking, this study aimed to determine household available biomass energy resources and its consumption pattern, adoption of biogas technology, improved cook stoves and solar energy and factors influencing the adoption at the household level in Limmu Kossa woreda.

1.2 Statement of the Problem

In the 21 century access to electricity is a critical part of human civilization. A number of studies show that electrification is linked to level of development improvements, such as higher income, employment, and better health and educational outcomes (Adina *et al*., 2017). Lack of access to electricity is a major constraint on growth and development in rural areas of developing countries (Laufer *et al*., 2011).

Globally, about 2.4 billion people rely on biomass fuel as their main source of domestic energy and most of those people live in developing countries, where more than 90% of people cook using biomass fuel (Gall *et al*., 2013).

In sub-Saharan Africa, 77% of energy needs of households are met by burning biomass fuels, mainly for household cooking and heating (Fakunle *et al*., 2017). Nearly 99% of rural communities and 80% of urban dwellers in Ethiopia primarily use solid fuel for cooking and heating. The overall biomass fuel consumption in the country is about 95% (Admasie *et al*., 2018).

Exposure to biomass fuel smoke from a traditional stove is one of the factors leading to acute respiratory infections among under-five children (Sharma *et al*, 2015).

In rural part of Ethiopia, where about 95 % of the population resides, suffers disproportionately from the problems of ever deteriorating qualities of traditional biomass fuels and their manifold adverse impacts, as well as inaccessibility of modern fuels (Geremew *et al*., 2014). Thus, to address the problems of domestic energy and improve rural peoples' access to modern fuels, the government of Ethiopia has been undertaking various intervention measures. One of these measures is the development and disseminations of domestic biogas and improved cook stoves (Bekele, 2019).

It is difficult to predict whether biogas technology can be successfully adopted in Ethiopia and other African countries. Reports from previous studies indicate that a household's energy choice could be influenced by various socioeconomic variables, environmental changes, demographic compositions, and social factors (Kamp, 2016).

According to Challa (2019) the ever increasing demand of woody fuel and the inefficient household biomass energy utilization which results in a huge amount of energy loss during cooking and heating are the main causes of subsequent degradation of woody biomass and environmental degradation in Ethiopia. This is because of modern fuel devices are either unavailable or unaffordable sources of energy especially for the people of rural Ethiopia. This is also true for poor urban people of the country.

Hence, with increasing of cost of fuel wood, households are forced to increasingly rely on lower quality of combustible materials such as dung and crop residues. Even worse in areas experiencing shortage of grazing lands, most of the crop residues must be devoted for animal feeds (Gebreegziabher, 2007).

Generally, there are many studies about the determinants of renewable energy technologies like biogas, improved cook stoves and solar energy adoption at the household level worldwide. Similarly, in Africa specifically in Ethiopia, different researchers have found socioeconomic and demographic factors such as household head, age, education level, gender, marital status and household income, ownership of cattle, farmland and household location from market service that determine household adoption of biogas, improved cook stoves and solar energy in a different part of rural areas in Ethiopia (Berhe *et al*., 2017).

But, its rate of adoption did not go as expected or it was not successful. Ethiopia has high potential to install domestic biogas plant, but now on the ground the adoption of domestic biogas plants throughout the country is low (Linda, 2015).

In Limmu Kossa woreda the adoption of biogas technology, improved cook stoves and solar energy at households are still at bottleneck. But, there is no study which shows the current status of installed biogas, available biomass energy potential, its consumption pattern and the factors that influence the adoption of biogas, improved cook stoves and solar energy at the household level.

Without determination of the available biomass energy potential and factors affecting the adoption rate, it becomes difficult to design and implement appropriate sustainable and improved energy technology strategies in the study area.

This gap directed the researcher to assessment of potential of biomass energy, its consumption pattern & challenges of adopting households improved energy technologies in rural areas of Limmu Kossa Woreda. Hence, it is a major issue that needs intervention which must be based on research to address the problems in the woreda for improved and sustainable energy technologies.

1.3 Research Questions

The study is intended to answer the following research questions:

1. What are the current household energy use in Limmu Kossa woreda?
2. What potentials of biomass energy are there in the woreda?
3. What factors determine household preference toward household energy sources?
4. What are the different types of cooking stoves utilized in the house holds?
5. What are the household characteristics and its association with the pattern of household energy consumption in the woreda?
6. What are the key factors influencing the adoption of biogas technology, improved cook stoves and solar energy by households in Limmu Kossa woreda?

1.4 Significance of the Study

This study is expected to give updated information on the existing biomass energy resource, consumption pattern in the woreda. This study revealed socio-economic status and available biomass energy potential at household level, its consumption and level of improved energy use and factors influencing the adoption of biogas energy technology; solar PV and improved cook stoves. So, the outcome of this study will provide information for concerned renewable energy and Environmental protection policy makers; to make plan and evaluations of household energy consumption pattern and the implication it has on socio-economic and the environment based on the existing levels of energy consumption.

In addition, the result could inform the governmental and non-governmental organizations working on improved cook stoves, biogas and solar PV disseminating initiatives, programs or projects at different level. Moreover the study lays foundations for the basis of adoption of biogas technology, improved cook stoves and solar energy technology to contribute towards achieving sustainable Development goals (SDGs).

The finding of the research may also help households in the study area specially womens and girls who lost long time to collect firewood and spent in kitchen, improved cook stoves producers, households in in Limmu Kossa woreda, water and energy office, Environment Protection, Forest and Climate Change authority office, various operators and national improved cook stoves program of Ethiopia, national biogas program of Ethiopia to know about the determinant factors which influence household improved energy technology adoption decision.Besides, this study can be used as a reference for further and detailed study.

1.5 Scope of the Study

Due to the vast and huge area of the woreda, it is difficult to assess the existing biomass energy potential, its consumption pattern and factors influencing the adoption of improved energy technologies in all kebeles. This study limited to specific places and covers accessible & reliable biomass energy potential assessment, household biomass resource consumption and assessment of factors influencing adaptation of rural household improved energy technology from 411 randomly sampled households from four kebeles in the study area.

1.6 Conceptual framework of the study

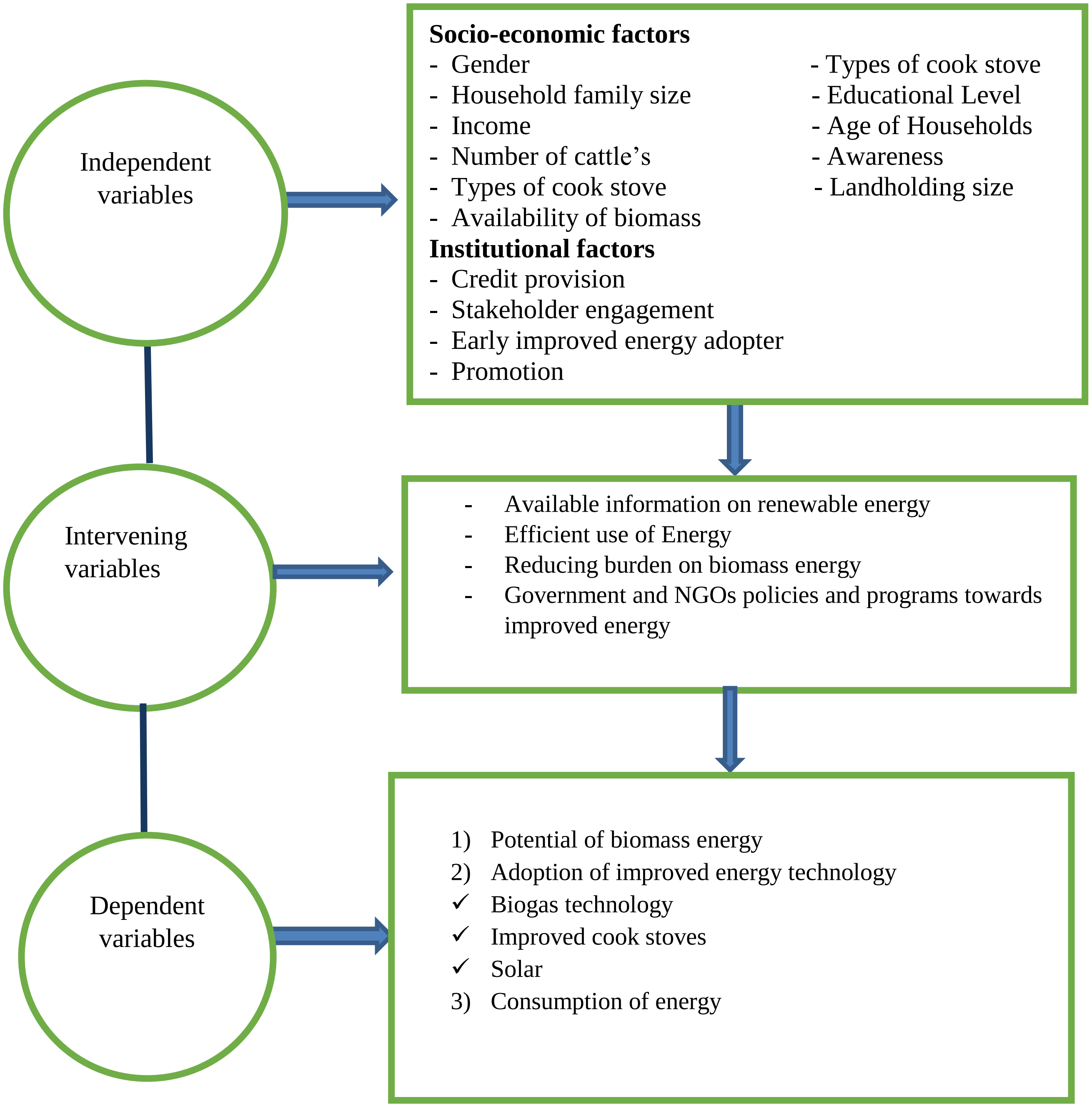

Figure 1: Conceptual Framework

Chapter 2: Literature review

This chapter explores worldwide biomass energy potential assessment, its consumption and experiences of biogas technology, improved cook stoves and solar energy in Ethiopia and experiences and steps towards adoption. The chapter further reviews literature related challenges faced to adoption process, benefits of improved energy technology and factors influencing adoption of renewable energy technologies and the relationship between fuel wood consumption, human health and forest degradation.

2.1 Global Energy Consumption and Renewable Energy Resources

While our activities are posing severe social and environmental impacts to our planet, our energy demands keep escalating. According to IEA (2009) report revealed that the world total energy consumption has almost doubled from just 4,675 Mtoe in 1971 to 8,286 Mtoe in 2007. While fossil energy sources dominantly supply these energy demands providing over 81% of the world's primary energy supply, renewable energies provide a little less than 13% and nuclear power accounts for 6% of the share. Of these energy systems, biomass contributes to more than three-fourth of the renewable energy supplies while hydro represents about 17% and about 5.5% of the supply comes from other forms of renewable energies such as geothermal, solar, wind, heat, etc. While oil accounts for about 42.6% of the total energy consumption as of 2007, more than 60% of the oil was directly associated with the transportation sector and only about 9% linked to the industrial sector.

By the year 2015, total primary energy supplies worldwide were 13,647 Mtoe, having more than doubled from 6,101 Mtoe in 1973 (IEA, 2017).

2.2 Overview of Africa's energy sources

Africa's total primary energy supply in 2015 was 787.62 Mtoe, up from 495.59 Mtoe in 2000. This accounted for 5.8 per cent of the world total. In 2015, total final energy consumption for Africa was 572,945 ktoe compared with 368,805 ktoe in 2000. The share of traditional biomass in the total final energy consumption mix in North Africa in 2010 was only 2.5 per cent compared with 65.3 per cent for sub-Saharan Africa in the same year and coal is especially important in South Africa. Natural gas and oil are particularly important in the North African countries where 99 per cent of the population has access to non-solid fuels in 2010 compared with 32 per cent in sub-Saharan Africa (WB and IEA, 2017)

2.3 Energy potential and consumption status of Ethiopia

Ethiopia is one of the countries in Africa in which energy resources are underexploited, as evident from the past, significant energy demands are still met from traditional resources. Currently final energy consumption of country was around 40,000 GWh, in which about 92% are consumed by domestic appliances, 4% by transport sector and 3% by industry. However, energy supply thereby is covered by bio mass energy which accounts about 90% of final energy consumption. In 2019, only about 45% of the country population has access to electricity. From this urban population has 97% access to electricity, while in rural areas electricity access remains extremely low at about 31%. The annual theoretical hydro energy potential of the country was estimated at 954TWh, out of which its geographic potential is 286 TWh (Tucho *et al.*, 2014).

Renewable energy accounts for 96.5% of total generation; however, despite the county's enormous biomass energy potential, only 0.58% of power is generated using biomass. Ethiopia has surplus woody biomass, crop residue and animal dung resources which comprise about 141.8 million metric tons of biomass availability per year. At present the exploited potential is about 71.9 million metric tons per year (Benti, 2021).

The abundant of solar energy resources is estimated to be about 5.2 kWh/m^2/day (Mondal et al., 2018, IEA, 2019). The estimated exploitable biomass potential of Ethiopia was 141.8 Million tons per year (Ashebir, 2020).

Although over 90% of domestic energy needs are met by biomass, which contributes to deforestation, soil nutrient loss, and organic matter loss. In any case, Ethiopia is one of the countries that places a high value on biomass (Outlook, 2017). The energy consumption of Ethiopia was 35,192 ktoe from which, the share of biomass was 90% (31,699 ktoe) and 8.5% (2973 ktoe) and 1.5% (520 ktoe) was fulfilled by petroleum products and electricity, respectively. Even if energy demand as well as the consumption in Ethiopia is growing very rapidly as much as almost doubling it in not more than four decades. However, the increase in energy consumption is shown only in the biomass energy sector which indirectly implies that there is excessive direct consumption of biomass (MWE, 2015).

2.4 Availability of biomass energy potential

2.4.1 Crop residue availability

Agricultural bio-wastes are produced when cereal crops are collected from farm lands. These types of bio-wastes are produced as straw, husk, and stalk and are referred to primary or field residues. Agricultural bio-wastes also include dung from livestock animals. These waste streams are relatively abundant in rural areas although the amounts available at households depend on the sizes of their land holing size (CSA, 2014).

The technical potential of crop residue assumes a recoverability fraction. The recoverability fraction is based on a number of assumptions. The first assumption is that some residue will be left on farm plots for re-fertilization, in line with global agricultural principles. The second assumption is that there will be practical challenges when collecting field residues, due to poor road condition to, especially, small-holder farms in rocky and mountainous agricultural fields. These account for the low recoverability of field residues. Process residues are assumed to be widely available since processing could take place in centralized locations (Esteban *et al*., 2016).

In view of this, the quantities of bio-wastes produced from crops residues and their availabilities are determined based on the average residue to product ratio (RPR) of cereal crops and area of crop production (Nzila *et al*., 2010, Rosillo-Calle, 2007). Therefore, the estimate of the agricultural crop residues was done taking into account: types of crops and crop residue removal rate according to the environmental constraints and the requirements for soil conservation; competitive use of crop residues for animal bedding and (Scarlat *et al*., 2010).

The amount of collectable crop residues that can be removed from land was estimated by subtracting the amount of crop residues which must be left in the field to meet all the environmental and harvesting constraints. Sustainable removal rates were considered in order asses the residues that might be removed from land (Esteban *et al*., 2016). Thus, the amount of crop residues sustainably removed for energy varies from 30%–70%. The sustainable residues removal rate was

40% for wheat and barley, and 50% for maize and rice for the assessment of agricultural crops residues in the European Union (Scarlat *et al*., 2010).

One of the problems faced by bio energy researchers is the difficulty of accurately estimating available resources. The inability to fully address the indigenous biomass resource capability and its likely contribution to energy and development is still a serious constraint on the full realization of bio energy's potential. In developing countries, the main problem is the lack of periodic data on agricultural production (Esteban *et al*., 2016). Hence, to realize the bio energy project at different level assessing the available resource must be needed.

2.4.2 Availability of human waste energy potential

Human excreta are sufficiently available in rural areas with essential nutritional compositions. They contain high amounts of organic matter capable of being converted to biogas and also provide huge sanitation and fertilizer benefits (Jewwit, 2011). Unlike other bio-wastes, human excreta contain both solid and liquid components produced as feces and urine. The amount of excreta a person produces varies from place to place due to living conditions, varying nutritional composition, and type and amount of foods consumed (Langergraber , 2005).

Energy from human livestock waste has been regarded as a unique and important source, which is able to supplement current energy needs and solve waste management problems (Owusu & Banadda, 2017). A number of studies have investigated different aspects regarding the production of biogas from animal waste (Adebayo, Jekayinfa & Ahmed, 2018). There is an aversion to the use of human waste for energy generation in developing countries. However, Oseji, Ana & Sokan-Adeaga (2017) found that treating human waste by anaerobic digestion is a credibly ethical sanitation technology and a potent way of reducing the biochemical oxygen demand and chemical oxygen demand. Most importantly, anaerobic digestion reduces pathogens and averts serious public health risk posed by the waste.

2.4.3 Availability of animals Livestock manure energy potential

Waste anaerobic digestion of livestock manure provides sanitation by reducing the pathogenic content of substrate materials. The potential quantities of livestock manure resources are estimated using number of livestock, average annual manure production per livestock, recoverability fraction, and dry manure fraction. The biogas produced from animal manure and slaughterhouse waste are affected by various factors such as diet, the type of animal, body weight, the proportion of total solid waste, and availability (Avcioğlu and Türker, 2012). According to Maithel (2009), NBPE (2008), Sasse (1988) showed that the available average fresh manure obtained from, cattle is 4.5kg/day/cattle, sheep and goat 1kg/day/head and chicken is 0.08kg/day/head. For range-fed cattle the accessible dung produced was mostly about 40% (Haileslassie et al., 2006, Bond & Templeton, 2011). The average biogas yield of cattle, is 0.24m^3/kg DM, sheep and goat is 0.37m^3/kg DM where as chicken is 0.4m^3/kg of DM and the dry matter content of cattles manure was 16.7%/kg and 30.7%/kg for sheeps, goats and chickens (Jørgensen, 2009, Teodorita Al Seadi, 2008, Nicholson, 1999).

2.5 Energy policy and biogas technology dissemination in Ethiopia

Ethiopia’s energy policy aims at maximizing the use of renewable energy sources that will reduce dependence on imported fuel and biomass energy sources. The country has updated its energy policy to emphasize on energy efficiency and conservation. Furthermore, the current climate change has presented the necessity and opportunity to switch to the use of renewable energy sources. Thus, the energy policy is aligned with the Climate Resilient Green Economy strategy of Ethiopia to protect the country against the adverse effect of climate change and to build a green economy. It is also part of the Growth and Transformation Plan of Ethiopia (Mengistu, Simane, Eshete & Workneh, 2015). There are over 1.2 million potential households, who can adopt biogas technology in Ethiopia (NBPE, 2017).

The NBPE has been launched to resolve the declining biomass resources and growing energy insecurity in rural Ethiopia, and to ensure environmental sustainability. Findings from previous studies have indicated: biogas technology has the potential to replace biomass in Africa Mshandete and Parawira (2009), Amigun (2012), Ghimire (2013), Mwirigi (2014),Mengistu *et al* (2015) and in Asia Dong (2012), SNV (2013), Cheng *et al* (2014) and Luthra *et al* (2015).

2.6 Theories of technology adoption process

Technology adoption refers to the process through which an individual or organization decides to fully use an innovation in their daily business. In other words, adoption refers to the decision to use a new improved technology. The adoption process in biogas technology can be explained as a series of stages that an individual/institution passes through; i.e first from hearing about biogas technology (the stage of awareness), to information gathering about biogas technology's on expected usefulness in terms of its profitability and ease of operation (the stage of valuation). If the information is adequate and the evaluation is positive, the potential user will first experiment with the technology by installing it. Every potential adopter evaluates an innovation on its merit and the compatibility with pre-existing system (Rogers, 2003).

Rogers (2003) identified five stages involved in innovation-decision process. First, they must learn about the innovation (knowledge stage) i.e. “what the innovation is, how it works and why it works”. This calls for education, knowledge sharing and promotional messages on the multiple benefits of biogas technology These multiple benefits should highlight on sanitation and hygiene, lower cost of energy (LPG, Fuelwood, and Charcoal), environmental protection, soil nutrient improvement from bio-slurry, poverty reduction and employment creation.

Second, they must be persuaded or convinced about the value of the innovation (persuasion stage), normally through social networks like colleagues and peers. This is where government, through its regulatory agencies, must encourage institutions, especially SHS with boarding facilities, to adopt biogas technology using the existing users of biogas for instance the four schools already using biogas as a guide.

Third, they must decide to adopt it (decision stage). The adoption of an innovation increases when there is opportunity for partial trial. Biogas installers must showcase biogas plants that are well-functioning so that others can also be convinced and adopt.

Fourth, the innovation must then be implemented (implementation stage). There is the need to provide technical assistance at this stage in order to reduce the degree of uncertainty. This requires constant follow-ups with technical assistance in order to resolve minor and major challenges on biogas plants. These can be effective if there are installation guides and maintenance manuals on biogas technology or there are follow up calls to users by installers.

Fifth, the decision must be confirmed or rejected (confirmation stage). A positive message about the innovation confirms an individual’s decision on the adoption of an innovation/technology.

However, an individual may reject or discontinue with an innovation adoption when negative messages are given or when the individual is not satisfied with the performance of the innovation.

2.7 Socio- economic factors influencing biogas adoption

There are several issues that biomass fuel consumers consider before rejecting or adopting an innovation and technology cost is one of the major considerations. Due to low income and difficulties of credit service households in rural areas go for technologies that have low initial cost than those that are likely to reduce operation costs which may extend for a long period of time (Geddafa *et al*., 2021). Socio economic factors like; costs of technology, educational level, gender of households head, age of households head, income, land holding, livestock holding, water availability and access to credit facilities were directly determining the adoption rate of biogas technology (Mwirigi *et al*., 2018, Shallo *et al*., 2020).

2.8 Technical challenges influencing biogas adoption

The productivity of biogas plants depends on the operator experience, skilled staff, and well-trained personnel. A low number of specialized companies, qualified specialists, construction businesses, and technologists specializing in designing, constructing, and exploiting agricultural biogas plants is a challenging task for the adoption of biogas technologies (Sefordzi *et al*., 2018). In addition, insufficient knowledge of the use and fertilising value of digestate among farmers hampers successful production of biogas and biofertiliser. Lack of technical knowledge during installation and operation led to failed biogas plants, which had a problem with longevity. In Pakistan, biogas plants have failed after one year in the absence of proper maintenance (Yasar *et al*., 2017).

In Ethiopia, during Sometimes there is a lack of basic technical skills to operate and maintain a biogas digester (Gebreegziabher, 2014). Hence,farmers should therefore be educated in the proper use of biogas technology (Nevzorova, 2019).

Unavailability of local biogas technologies also can be a challenge to the deployment of biogas as a source of energy. In Ethiopia, there is a dependence on non-local materials, which increases investment costs and maintenance problems. This fact also creates high equipment costs and dependency on imports materials (Kamp, 2016).

2.9 Economic challenges of biogas adoption

The installation of biogas power plants is becoming more complicated due to lack of financial institutions loans with preferential terms (Balussou *et al.*, 2014, Roopnarain, 2017). A lack of subsidies, financial support programs, and soft loans are influential economic barriers which reduce the attractiveness of biogas projects to the investors (Chen, 2017).

Furthermore, the area of agricultural land can affect the possibility of building biogas plants. Higher competition in the land market leads to increasing land prices; this affects biogas farms, which may not achieve higher profitability due to increased rental prices (Appel *et al.*, 2016). The high cost of managing and maintaining biogas plants further affects farmers' commitment to using biogas (Chen *et al.*, 2014).

The lack of government incentives contributes to the low adoption rate of biogas technologies. In the case of sub-Saharan Africa, installation costs for conventional biogas systems are unaffordable for many potential users because of insufficient credit schemes and other financial support (Rupf *et al.*, 2015).

In Ethiopia, the initial investment for bio-digester installation is unaffordable for a considerable number of rural households. Thus, households' access to credit was expected to positively influence biogas technology adoption (SNV, 2017).

2.10 Institutional challenges of biogas adoption

In many cases, there is a lack of political support and specific programs to promote biogas technologies throughout the world (Muradin, 2014). Kamp (2016) point out that an incomplete network of stakeholders and actors of the highly centralized and hierarchical nature of programs hinder the contribution of the private sector. The energy sector has not received significant attention in policy debates within developing countries (Surendra *et al.*, 2014). Bureaucratic issues are still need to overcome in order to receive financing for biogas enterprises Piwowar *et al.*, 2016). Too many formal requirements, complex administrative and legal procedures create difficulties and slow down the process of installing biogas plants (Msibi, 2017).

Political instability also prevents the adoption of biogas technology as a source of energy. In case of Ethiopia, there are internal and external consequences of political instability. From an internal prospect, this fact hinders entrepreneurial activities and suspend private sector investments. From an external prospect, Ethiopia faces significant geopolitical risks due to its latent border conflicts with Eritrea and Somalia, as well as wars in its neighboring countries (e.g. Sudan and South Sudan, and Somalia) (Kamp, 2016). Political decisions or measures encouraging adoption and implementation, training and capacity building, flexible financing mechanisms and dissemination strategies are required if biogas production is to benefit the communities (Smith , 2013).

Several authors defined a lack of private sector participation and poor coordination between the public and the private sectors as challenging factors to biogas uptake (Mittal *et al*., 2018) ,L€onnqvist *et al*, 2018). This is an essential point because private sector plays a key role in promoting biogas energy to the market and making it commercially stable (Msibi, 2017).

2.11 Determinants of adoption of improved cook stove

Clean and improved cook stove is defined in different ways by different researchers. Improved cook stove (ICS) is a device that is designed to improve combustion efficiency of biomass, consume less fuel, save cooking time, convenient in cooking practice and creates smokeless environment in the kitchen or reduce the volume of smoke during cooking against the traditional stove (Worabo, 2020). According to Damte & Koch (2011), it is a solid fuel stove that improves on traditional baseline biomass technologies in terms of fuel savings via improved fuel efficiency that improves, or minimizes, the adverse health, environmental, and economic outcomes from cooking with traditional solid fuel technologies. Also, as Kooser and Shannon (2014) and World Bank group (2015) defined that improved and advanced biomass cook stoves as stoves that reduce emissions, improve health and the environment. Improve cook stove means a device constructed by artisans or household members that are energy efficient, safety, remove smoke from home, dramatically, improve the health and quality of life for poor people (Makori, 2016).

2.11.1 Benefit of Adopting Improved Cook Stoves

Energy saving project implanters such as global, national and regional, programs initiatives, non-organization and organizations and also other mandatory can be achieved the least developing countries more powerful in maintain efficiently important for mirt stove in enhancing communities' economy and social health conditions, improving the livelihood of the poor, reduce environmental pollution and mitigate the climate change and reduce poverty (WHO, 2016; IEA, 2015; Kooser & Shannon, 2014).

2.11.2 Determinant Factors of Improved Cook stoves adoption

2.11.2.1 Age and improved cook stoves adoption

The previous studies found that contradictory results of correlation between age and improved cook stove adoption. For instances, according to Dawit (2009, Inayatullah (2011, Lewis and Pattanayak (2012, Tigabu (2014, Warkaw (2015), the household's age is negatively and statistically significant determinant factor for adoption of improved cook stove. In contrary, Gebreegziabher et al (2010) found that household head's age to be positive and statistically significant determinant factor of cook stove adoption decision.

2.11.2.2 Marital status and improved cook stoves adoption

Studies by Damte& Koch (2011); Tigabu (2014); Markori (2016) found that female headed household is more likely to adopt improved cook stove as compared to male headed household. These authors argue that in patriarchal society, husband has more power to make economic decisions in the household. That is married women's cook stove purchasing decision depends up on the willingness of their husband to pay.

2.11.2.3 Educational level and improved cook stoves adoption

Different studies conducted by Inayatullah (2011); Bogale (2020); Lewis and Pattanayak (2012); Amogne (2014); Tigabu (2014); Warkaw (2015); Markori (2016) found that household head's education is positively and statistically significant determinant factor on the adoption of improved cook stove. They argued that educated household is more likely to be aware of the benefit of improved cook stoves as compared to less educated households.

2.11.2.4 Household Family size and improved cook stoves adoption

Regarding to family size, previous studies found that contradiction findings. Studies by Bogale (2020); Gizachew *et al.*, (2018); Gebreegziabher (2010), Inayatullah, (2011), Lewis and Pattanayak (2012), Warkaw (2015) found that household size is positive and statistically significant determinant factor for improved cook stove adoption decision. These authors claim that large family size consume more fuel wood as compared to households with smaller family size. In contrary, Koores & Shannan, 2014) found that family size is negatively and statistically significant determinant factor for adoption of improved cook stove decision. Those authors claim that households with more children, especially female children, have lower value for new stove technology because they have more people that participate in cooking and fuel wood collection. Moreover, with regard to the influence of a household size improved cook stoves adoption decision, work of Tigabu (2014) found inconsistency result among family size and improved cook stove adoption.

2.11.2.5 Income and improved cook stoves adoption

The systematic work of Dawit (2009), Zenebe (2011), Inayatullah (2011), Lewis and Pattanayak (2012), Amogne (2014), Tigabu (2014) found that household income level had significant determinant factor in determining cook stove adoption decision. These authors claimed that household income level and cook stove adoption decision are proportionally correlated. As the income of the household increased, the demand and adoption for modern cook stove also increased.

2.11.2.6 Source of fuel wood and improved cook stoves adoption

A study by Bogale (2020) and Geddafa *et al* (2021) found that the free availability of fire wood is one of the determinant factor that lead to decision not to adopt improved cook stove. Access to free open forest had significant influence on the probability of improved cook stove adoption. Also they investigated that lack of access to open forest and improved cook stoves adoption have positive correlation. Those authors hypothesize that household that get fuel wood with charge to be more adopters as compared to households that obtain fire wood for free efficient use of wood may be not their concern while fuel saving is the priority for those buy wood.

2.11.2.7 Access to credit and improved cook stoves adoption

Financial incentives, fuel costs and credit availability are consistently reported to be core drivers for sustained adoption of improved cook stoves stove adoption. Credit treatment with different payment arrangements, help households to buy improved stoves were particularly important in poorer rural communities that traditionally use foraged fuel wood or charcoal and indigenous low-cost cook stoves. Providing credit to low-income communities to ease their financial burden was also a popular choice. Other incentive included delivering cook stoves free of charge to poorer users (petter *et al*., 2015).

2.12 Key barriers to solar energy technology adoption

The major impediments to the technology adoption are series of barriers which makes it hard to implement. According to ICGET (2017) the key barriers to adopt solar energy technology includes: technical barriers; Social and cultural behavior; institutional/legal barriers; Political/Policies issues and market distortions issues.

Table 1 : Key barriers of solar energy adoption in Ethiopia

Barriers category	**Barriers**	**Remarks**
Technical Barriers	Lack of skilled personnel, lack of standard, lack of maintenance and operation, lack of training facilities and entrepreneur's development mechanism, lack of Reliability	The barriers lead to poor plans, poor standard, and constraints of the competitive market, inadequate knowledge to know how about the technology and risk acceptance. All these barriers resulted in technology locked up.
Social, Cultural Behavior	Lack of consumer awareness about the product, lack of understanding of benefit of solar photo voltaic and public resistance to chance for new technology	The barrier, affect the market projection negatively, cultural and religious faith Controversies towards economic development and sustainability
Institutional/Legal barriers	Institutional barriers, legal framework, regulatory issues, non-integration of energy mix, non-participation of private sector, poor research & development culture and stakeholder's noninterference	The barriers cause risk of uncertainty in support of solar energy, lobbies against RET, poor communication mechanism to reach the institutional policy makers for improvement and negative perception about the technology
Political/Policies Issues	Lack of long term policies, lack of political will to diversify into clean energy, constantly changing of	These barriers serve as a deterrent to future planning for solar and other renewable energy adoption and sustainability. There is the fear of uncertainty in government

	government and reshuffling of institutions.	
Market distortions issues	Trade barrier for new product, energy sector controlled, lack of access to diversified technology, lack of facilities and backup technology, non-market oriented research for solar energy technology and application	The barriers cause hindrance to market penetration and hence new technology failed at some point

Source: (ICGET, 2017)

2.13 Environmental impacts of heavy reliance on traditional biomass consumption

The utilization of the traditional fossil fuels can also be polluting sources that accelerate global warming, such as the increase of carbon dioxide and other greenhouse gases. The GHG emission from forest degradation due to heavy dependence on biomass energy sources in Ethiopia is expected to increase from 24 Mt CO_2 equivalent in 2017 E.C to 41 Mt CO_2 equivalent 2030 E.C if no action is taken (Gizachew *et al*., 2018).

The emitted gases due to fossil fuel combustion compromise air quality and do harms in human health (Hoekman *et al*., 2018). Scientists around the world have paid much attention to the balance between bioenergy production and environmental protection by considering multiple approaches, including the best management practices (Guo *et al*, 2018). In Ethiopia besides, the highly dependence on biomass energy is increasing the rate of deforestation and forest degradation in the country, due to much of the fuel wood comes from both natural forest and planted vegetation (Geda, 2021).

2.14 Health effect of heavy reliance on traditional biomass consumption

Direct burning of biomass in traditional and inefficient cook stoves results higher emissions of carbon monoxide, hydrocarbons and particulate matters. Since cooking is usually performed indoors without proper ventilation, this can and does result in severe health issues due to indoor air pollution (IAP). Exposure to particulate matter from biomass smoke is a risk through in utero exposure as well as direct inhalation during early life. Prenatal impacts occur as a result of the effect of pollution on the mother and the direct transfer of biomass toxins across the placenta which is known to reduce nutrient flows and disrupt the central nervous system of the fetus (Lafave *et al.*, 2019).

In Ethiopia, indoor air pollution is causing more than 50,000 deaths annually and causes nearly 5% of the burden of disease from indoor cooking and poor ventilation (Abadi *et al.*, 2017).

2.15 Social effects of heavy reliance on traditional biomass consumption

In developing countries, women and children are responsible for firewood and dung collection which are both time consuming and exhausting tasks. For example, women and children in some places travel more than 5 km (3 miles) and spend nearly 6 hours a day gathering biomass and cooking food (Topa , 2004 ,Liua , 2008). In addition to IAP, the labor is hard and can lead to back- and neck-pain as well as other physical ailments (Gautam , 2009). Because of these significant demands on time and labor, women and children are deprived of opportunities for education and other activities. Based on a case study conducted in Nepal, a household biogas plant saves about 2 h per day of a woman and child's time. Most of the saved time has been used in recreational activities, social work, income-generating labor and education (Katuwal , 2009).

From the literature review, it is clear that the pattern of traditional biomass fuel wood consumption presents had critical risk to forests, human health and biodiversity.

Chapter 3: Objectives

3.1 General objective

The main objective of this study is to assess the potential of biomass energy, its consumption pattern & challenges of adopting improved energy technologies in rural areas of Limmu Kossa woreda.

3.2 Specific objectives

1) To assess the potential of biomass energy resources.
2) To assess the status of biomass energy consumption pattern and available combustion technologies.
3) To assess the challenges related to improved energy technology adoption
4) To determine the benefit of adopting improved energy technology.

Chapter 4: Methods and Materials

4.1 Description of the Study area

The study was conducted at Limmu Kossa woreda, Jimma administrative zone, Oromia regional state, Southwest Ethiopia. It lies within Coordinates 07 57’32’’N and 36^0 53'11"E of the equator and altitude range from 1200 to 3020m above sea level. Limmu Kossa woreda contains 44 kebeles, including Chaffe Elfeta, Dengaja Sole, Yatu Tirgi and Kossa Geshe kebele. The administrative center of the woreda is Genet and is found 75 kilometers west of Jimma town and 426 kilometers southwest of Addis Ababa. There are 47,511 households and the total population of Limmu Kossa woreda is 228,054, of whom 112,887 are males and 115,167 females (Woreda administrative office report, 2020). Electric supply coverage of the woreda was 10.4% (Limmu Kossa Woreda Electric Utility Office report, 2020).

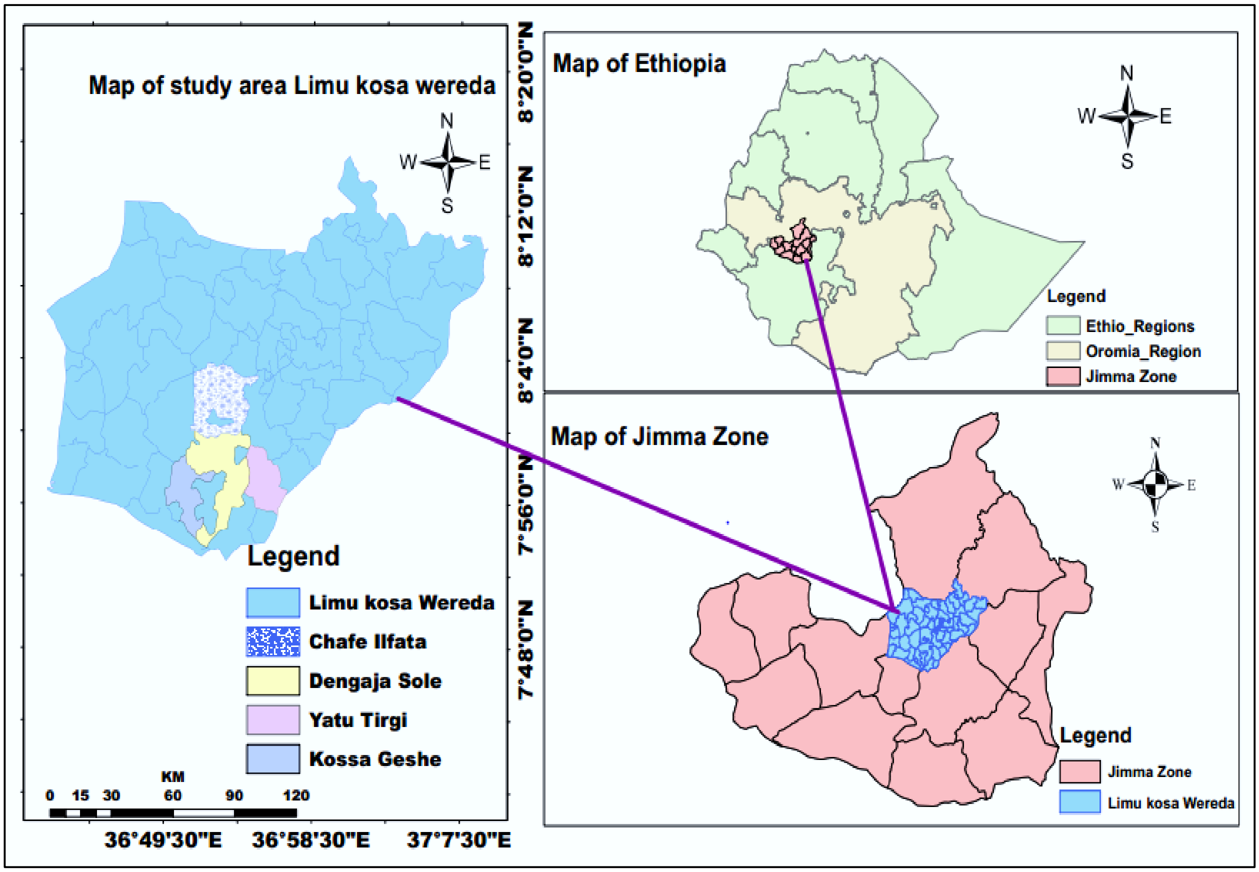

Figure 2: Map of The study area

4.2 Study design and period

A cross sectional study design was employed from June 13th - 24th 2021 in Limmu Kossa woreda to identify the potential of biomass energy, its consumption pattern and challenges faced to adopting improved energy technologies.

4.3 Population and data source

The source population for the study was the total number of households in Limmu kossa woreda which is about 47,511 households. For this study, both quantitative and qualitative data were collected. The quantitative data were employed in order to address research questions and objectives that could be better addressed quantitatively. The study population of this study were 411 randomly selected head of households and 32 purposely selected biogas users households, 14 key informants from woreda water & energy office head and renewable energy team expert, woreda Environmental protection, forest & climate change authority head and expert, woreda agriculture and rural development office head and natural resource management expert; health extension worker; development agents and 13 focus group discussion with biogas user household head, improved cook stoves adopter households, improved cook stoves producer target group and woreda water and energy office renewable energy team leader.

The secondary data were collected from different published and unpublished sources, including books, journal articles, office reports and records, magazines, and internet sources. The secondary data were used as a background information and bench mark to calculate available biomass energy potentials and triangulate statistical results and to support arguments of prior study.

Table 2: Summary of the total households in Limmu Kossa woreda

S. number	Name of Kebeles	Number of Households
1	Tencho	1,079
2	Gena Denbi	976
3	Denbi Gabena	930
4	Welensu	1,314
5	Chakewo	579
6	Limmu Genet 01	1,378
7	Limmu Genet 02	1,425
8	Debelo	1,083
9	Suntu	652
10	Mendera	654
11	Mito Gundib	795
12	Weleke	1,086
13	Dengaja Sole	1,741
14	Ambuye town	1,051
15	Chefe Elfeta	1,179
16	Dire Togo	1,047
17	Gena Dujuma	537
18	Kemise Babiya	1,328
19	Harewa Jimate	1,395
20	Harawa Keta	1,189
21	Harawa Gatira	2,010
22	Liban Gonde	1,164
23	Chukulu Dulecha	835
24	Wabe Sombo	769
25	Gobeze Wabe	923
26	Babu Town	1,036
27	Arengema	1,287

28	Acha	1,902
29	Kela Gebissa	1,669
30	Kechewo Tirtira	1,006
31	Kossa Geshe	985
32	Laku Chimme	963
33	Tenebo Lalo	991
34	Chancho Geshe	887
35	Gudo Bekere	893
36	Cheraki	905
37	Addis Limat	838
38	Burka Gudina	910
39	Gale Busase	865
40	Gale Jimate	981
41	Gale Kemise	888
42	Yatu Tirgi	877
43	Wirtu Sekore	981
44	Wabe Koticha	1,528
Total		**47,511**

Source: Limmu Kossa woreda administration office, 2020

4.4 Sample size determination

To determine sample size of households those to participate in the study, a sample technique which was developed by (Cochran 1977) to determine sample size (n) with the desired degree of precision (d) for general population, was used.

$$n = \frac{\left[Z_{\alpha/2}\sqrt{P\,(1-P))}\right]^2}{d^2}$$

Where: n = Sample size z = critical value 1.96 p = binomial parameter to estimate a population proportion is to be, 0.5 d = precision (marginal error) = 0.05 In calculating a sample size for a proportion, a value of 0.5 was used for the estimate of the population proportion; p=0.5 gives the largest sample size relative to any other value of p (unknown population proportion). As the sample size becomes larger, the value of marginal error is decreased. And, there is no previously done research in that particular study area. Due to these reasons the maximum value of binomial parameter, 0.5, is preferable. The sample size was determined by assuming the binomial parameter (a sample proportion to estimate a population proportion) to estimate a population proportion to be 0.5, giving any particular out come to be with 5% marginal error and 95% confidence interval. Based on this assumption, the actual sample size for the study was computed using single population proportion formula as indicated below.

Thus, the sample size is,

$$n = \frac{\left[Z_{\alpha/2} \sqrt{P\,(1-P))} \right]^2}{d^2} = \left[\frac{1.96}{0.05} \right]^2 0.5 \times 0.5 \approx 385$$

Adding 10% non-response rate, the sample size was about 424 households.

385*0.1=38.5

385+38.5= 423.5~424

For comparisons of socio demographic and economic characteristics of biogas users and non-users 32 biogas adopter households were purposely selected.

4.5 Sampling technique

Systematic random sampling and purposive sampling technique were employed for quantitative and qualitative data collection. First, Limmu Kossa woreda was deliberately chosen because it is a potential location for promoting improved energy technology. Second, out of 44 kebeles in the woreda only four kebeles were randomly selected for this study. Third, 424 households were selected randomly from the total of 4,782 households in the kebeles. According to Lewis (2015) random selection technique enables researchers to select a sample representative of the population, with all individuals having a legitimate chance of being selected. The lists of households were obtained from woreda administration office. The first house hold was selected by lottery method then the next household selected every x interval until the required sample size reached 424. Also all 32 biogas adopter households in the wereda were included in this study for comparison of socio-demographic and economic characteristics between biogas adopter and non-adopter.

Table 3: Sample size distribution in each sampled kebeles

Kebele	**Total households in sampled kebeles**	**Proportion of sampled households**
Chafe Elfata	1179	1179*424/4,782=105
Dengaja Sole	1741	1741*424/4,782=154
Yatu Tirgi	877	877*424/4,782=78
Kossa Geshe	985	985*424/4,782=87
Total	**4,782**	**424**

For the sake of understanding, number of the households was assigned from 1 to the maximum possible number of household, in each kebeles. In case of this, for households found in Chafe Elfata kebele have got 1-1179 and the sample proportion from this kebele was 105 households. The sampling fraction was: 105/1179 = 1/11. Hence, the sample interval was eleven. The number of the first household to be included in the sample was chosen randomly by blindly picking one out of 105 pieces of paper numbered 1 – 105. This implies that every eleven households were picked up to make the sample for this specific kebele. The same method and procedure was followed for the rest thee kebeles. For households located in Dengaja sole, 154/1741 =1/11. Hence, the sampling interval was every 11. Every eleven households were picked up to give 154 of sample households. By using the same methods; for households in Yatu tirgi; 78/877=1/11 i.e sampling interval was 11 and sample households was selected as every eleven households up to give 78 households. For households found in Kossa geshe; 87/985=11 and sampling interval was 11 and every eleven households were selected until it reach 87 households.

4.6 Study variables

4.6.1 Dependent variables

Potential of biomass for household energy
Energy consumption pattern
Challenges of adopting improved energy technology

4.6.2 Independent variables

Household income
Educational level of households heads
Household family size
Age of household heads
Number of cattle
Availability of firewood
Lack of Electric meter
House ownership
Access to credit
Land holding size
Gender of household heads
Adequacy of available water

4.7 Ethical consideration

Formal letter of permission was obtained from Ethical committee of Jimma University to communicate with local administrative bodies in the study site.

Letter of cooperation from kebele administrators was also obtained.

4.8 Method of data collection

The data collection questionnaire was developed that goes in line with the objective of the study. Both primary and secondary data were relevant for the study. Primary data was collected through questionnaires and interviews with household heads while secondary data was synthesized from existing literature relevant to the study.

To assess the potential of biomass energy, its consumption pattern and factors influencing adoption of improved energy technology, improved cook stoves and solar PV, household survey, focus group discussion and key informant interviews were carried out.

Data gathered from household survey, focus group discussion and key informant interview comprise socio-demographic and economic characteristics includes: household annual income, age, gender, educational level, access to water, number of cattle, number of family size, land holding size, energy sources of the households, frequency of firewood collection per week, distance to firewood collection and fetching water, energy end-uses, share of farm land by crop types, types of stoves used, household energy consumption by type, awareness about improved energy technology, reasons for adoption or the non-adoption of biogas technology, improved cook stoves and solar PV, financial sources and assistance for biogas construction, availability of biogas inputs, availability of spare parts at reasonable distances, after sale services, operational status and problems faced, impacts of the technology on energy use and challenges of improved energy technology adoption.

4.9 Data quality assurance

Questionnaire was primarily prepared in English and translated to Afaan Oromoo language and then back to English to check its consistency. In total, four data collectors, BSc and BA degree students from sociology, Statistics, Natural resource management and Chemistry departments' third year students collected the data. One-day training was given to the data collectors on the purpose, procedures, and data collection tools to ensure the quality of the data.

Appropriate key informants were selected for in-depth interview. For conformability, raw data was recorded during discussion with participants. Then, the questionnaire was pretested in two kebele on 21 households. During data collection, completeness and consistency of each questionnaire was checked by researcher on daily basis. Double data entry was done for validation using SPSS software version 23 and Microsoft excel.

4.10 Operational definitions

Injera: is the traditional food in major Ethiopian households.

Crop-residue: refers to the cereal crop-residue that can be used for bioenergy production.

The improved energy technology: the improved energy technology considered in this study are biogas, improved cook stoves (Mirt midija, electric mitad) and solar home systems.
Improved cook stoves: The improved cook stoves in this study includes electric injera mitad and mirt midija.

4.11 Data Analysis

Descriptive and inferential statistics were used for data analysis. The quantitative data were coded and fed to MS Excel and Statistical Package for Social Sciences (SPSS) version 23 and analyzed. The descriptive statistics included: frequency, averages, percentages, standard deviation and pie chart, minimum and maximum value. Inferential statistics encompassed multiple linear regression model to test the relationship between dependent variables (challenges of adopting improved energy technologies) and independent variables, which includes: family size, education level, time spent in fuel wood collection, distance walked to sources of fuel wood, annual income, land holding size, number of cattle, educational level, gender and access of credit service or subsidy.

The regression was tested at 5% level of probability. Human waste and animal livestock biogas energy potential was assessed based on average number of household's family size and number of live stocks per households and the potentials was quantified based on literatures values of daily production of human excreta, urine and animal manures per heads in developing countries. Agricultural crops residues biomass energy potentials were quantified depends up on existing literature of land size in hectares and crops product to residues ratios (PRR). The theoretical bioenergy potential defined as the energy associated to biomass that can be used for energy purposes were calculated according to the methodology described by (CSA, 2014).
The regression model performed to analyze the relation between dependent variables; Biogas adoption; improved cook stove adoption and solar adoption and socio-demographic and economic independent variables were as follows:

$$Y = \beta o + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + \beta 7X7 + \beta 8X8 + \varepsilon$$

Where, Y= Adoption of biogas technology; improved cook stoves and solar energy interchangeably.

B_0 = Constant

βi = Independent variable coefficients

X1 = Gender of households

X2 = Age of hh

X3 = Education Level

X4 = Household family size

X5 = Income

X6 = Number of animals

X7 = Availability of firewood

X8 = Access of credit

ε = Error term

4.12 Dissemination plan

The result of this study will be presented to the Department of Environmental Health science and Technology and then disseminated to: Jimma University Department of Environmental Health Science and Technology, Jimma zone water & energy office, Limmu kossa woreda administration office, Limmu kossa woreda water & energy office, Limmu Kossa woreda Environmental protection, forest and climate change authority office, Publication in national or international journals will also be considered.

Chapter 5: Results

5.1 Descriptive data analysis

5.1.1 Socio-demographic and economic characteristics of the respondents

Out of the 424 sampled respondents, this survey data was collected from the total of 411 (96.93%) response rate visited households from Kossa Geshe, Yatu Tirgi, Dengaja Sole and Chaffe Elfata kebeles. As suggested by Babbie (2011) a response rate of above 70% for paper based on questionnaires was very good. Socio-demographic and economic characteristics of biogas adopter and non-adopter in this study includes: household sex, educational level, household family size, age, annual income, number of animal per households and land holing size. Those socio demographic and socio economic variables were analyzed to study whether they had significance influence on improved energy technologies which includes biogas technology, improved cook stoves and solar adoption. The summary of socio-economic and demographic characteristics of improved energy technology adopter and non-adopter households also analyzed in this study.

Table 4: Socio demographic and economic characteristics of biogas adopter and non-adopter

Characteristics	Adopter of biogas		Non adopter of biogas	
Household gender	**Frequency**	**Percent**	**Frequency**	**Percent**
Male	32	100	387	95
Female	0	0	21	5
Educational level of Households				
Never to schooling/illiterate	5	15.6	180	44.1
Primary school	12	37.5	92	22.6
Secondary education	15	46.9	131	32.1
Post-secondary school	0	0	5	1.2
Household family size				
1-3	5	15.6	100	24.5
4-6	24	75	186	45.6
7-9	3	9.4	97	23.8
10-12	0	0	23	5.6

> 12	0	0	2	0.5
Age of households head				
15-24	0	0	0	0
25-34	4	12.5	70	17
35-44	22	68.8	101	24.8
45-54	5	15.6	110	27
55-64	1	3.1	69	17
>65	0	0	58	14.2
Number of cattle				
1-4	1	3	154	38
5-8	20	62.6	197	48
> 8	11	34.4	57	14
Land holding size (ha)				
< 0.25	0	0	26	6.4
0.25-0.5	0	0	94	23
0.6-1	0	0	120	29.4
1.1-1.5	2	6	71	17.4
1.6-2	13	41	53	13
> 2	17	53	44	10.8

The study revealed that all (100%) of biogas adopter households and (95%) of non-adopters in the study area were male headed households. The study further indicated that 15.6%, 46.9% and 37.5% of adopter household heads had attained never to schooling, primary and secondary education respectively. 75% of biogas adopter and 45.6% non-adopter households had family sizes of between 4-6 members. The average family size of biogas adopter and non-adopter households was 5.6 per household.

Most biogas adopter household heads (68.8%) were found to be in the age between 35-44 years. While 24.8% and 58.2%, of non-adopter households were found to be in the age between 35-44 and > 45 years respectively. The study revealed that, 62.6% of adopter and 48% of non- adopters' households had 5-8 cows. The majority (62%) of non-adopter of biogas have those households who have > 8 cows. Regarding to land holding size; in the ranges of < 0.25, 0.25-0.5 and 0.6-1ha, there is 0% of adopter and 6.4%, 23% and 29.4% were non-adopter of biogas respectively. 6% of adopters and 17.4% of non-adopters' of biogas were those who have land holding size of 1.1-1.5ha. 41% and 53% biogas adopter and 13% and 10.8% non-biogas adopters were those having land holding size of 1.6-2 ha and > 2 ha respectively.

5.1.2 Annual income and status of biogas adoption in the study area

The ranges of annual income were categorized into nine ranges, i.e. 10,000-20,000ETb, 20,001-30,000ETB, 30,001-40,000ETB, 40,001-50,000ETB, 50,001-60,000ETB, 60,001-70,000ETB, 70.001-80,000ETB, 80,001-90,000ETB, > 90,000ETB. From fig.3 below, 40.6% of biogas adopter and 9.6% of non-adopter household's annual income was >90,000 ETB. 25% of adopter and 6.8% of non-adopter household's annual income lies in the range of 80,001-90,000 ETB. 18.7% adopter and 11.7% non-adopter was those who can earn 70,001-80,000 ETB. 9.4% of adopter and 11% non-adopter households was those who can earn 60,001-70,000 ETB annually. 3% of adopter and 5%, 10.5% non-adopter households were those who earn 50,001-60,000 ETB and 40,001-50,000 ETB respectively.

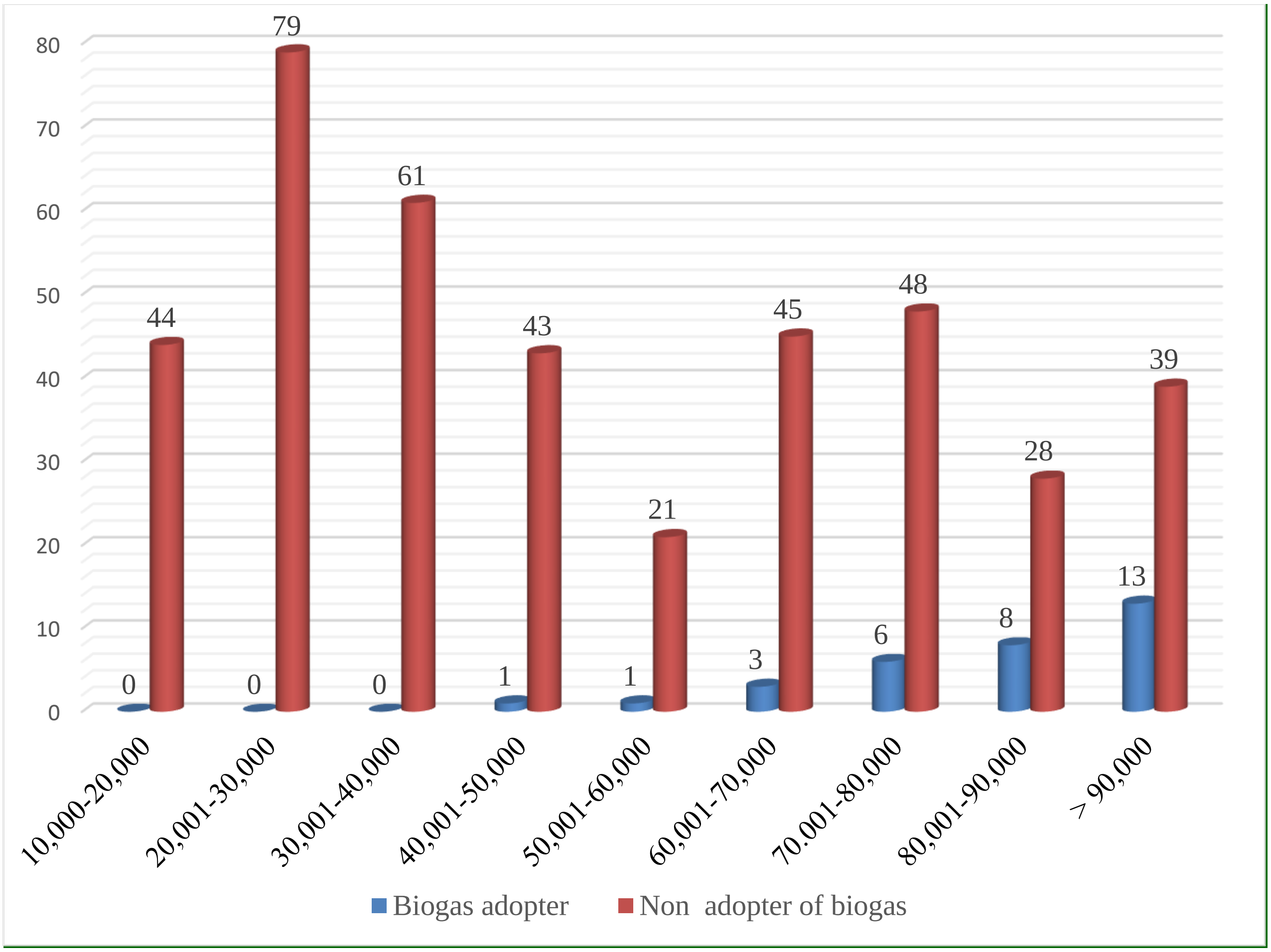

Figure 3: The annual income of biogas adopter and non-adopter households

5.1.3 Challenges of adopting biogas technology

Sampled households were asked whether they are aware of biogas as a source of household energy or not. As mentioned in table 5 below, 25.8% of households have prior information about biogas and its uses. But, they are non-adopter of biogas technology. Regarding to this, those households were asked about why not adopt biogas technology, 5.4% of them were prefer other renewable energy source like solar rather than biogas, 2.9% of them have lack of cattle, 6.8% were due to the high cost of installation of biogas, 8.3% of households were due to un functionality of neighbors' biogas. 74.2 % of the surveyed households have no prior information about the biogas technology and its benefits. Depending on the objectives of this study the interests of non-adopter households who have no prior information about biogas were identified. This study found that majority of them have interest to adopt biogas for renewable energy, among them 17.4% of households have interest to adopt biogas technology but the main problem is lack of accessible road to supply construction materials, 43% of those have lack of information about the procedures to construct biogas plant, 28.5% were due to high installation cost of biogas and 11.1% of them were due to lack of labor for daily operation.

Table 5: Challenges of adopting domestic biogas technology

Having information about benefits of biogas energy	**Frequency**	**Percent**
Yes	106	25.8
No	305	74.2
Households who have prior information about biogas but, reasons why not interested in biogas energy adoption		
Prefer other energy like solar rather than biogas	22	20.8
Lack of sufficient cattle	12	11.3
The cost of biogas installation is high	28	26.4
Un functional of neighbor installed biogas	34	32.1
Access of electric power	10	9.4
Households who haven't prior information, but now interested to install biogas and problems faced to adoption		
No accessible road to supply construction materials	53	17.4
Lack of information about the procedures	131	43
High installation cost	87	28.5
Lack of labor for daily operation/feeding	34	11.1

In addition to household survey; discussion with woreda water and energy office showed that the main challenges of adoption of biogas technology were lack of transportation facilities for promotion of the technologies, inadequacy of budget for material support for households, lack of after sale service for non-functional biogas maintenance. Non functionality of biogas has high influencing factor for adoption of biogas for non-adopter neighbors. The fluctuation of constructions materials cost also highly affect the adoption of biogas technology.

5.1.4 Status of installed biogas in the study area

Biogas user's households were asked about the current status of their biogas; whether it is functional or not, the causes of non-functionality, availability of maintenance service, availability of accessories, status of using byproducts of biogas as fertilizer. Their response showed that; 65.6% of installed biogas was functional and 34.4% was non-functional. Regarding to causes of non-functionality; 72.7% was due to lack of maintenance service and 27.3% was due to lack of accessories.

Regarding to bio slurry; field observation of this study shows that 25 (78.1%) of biogas user households does not use bio slurry as fertilizer. Only 7 (21.9%) of them used bio slurry as fertilizer. Regarding to the use of bio slurry as fertilizer; households also asked whether they have got technical support from agricultural development agent (DA) or not; 27 (84.4%) of them respond that they couldn't get technical support yet. Only 5 (15.6%) of biogas user households were get technical support from natural resource or agricultural experts. The result of this study revealed that the poor stakeholder cooperation was one of the serious problem of biogas technology dissemination and sustainability.

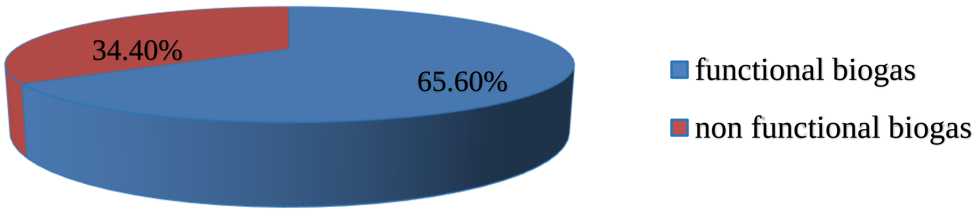

Figure 4: Current status of biogas

5.1.5 Current status of ICSs adoption and characteristics of adopter and non-adopter

From the total of 411 respondents, 48 (11.4 %) were found adopter of Mirt improved cook stoves and electric injera mitad. Regarding to educational status of improved cook stoves adopters 22 (45.8%) were attend secondary school and 23 (47.9%) of adopter households were attend post-secondary school. Few of them 3 (6.25%) of adopter households were attend primary school. Most of adopter households 45 (93.7%) of them were attend secondary and post-secondary education and 169 (46.5%) of non-adopter of improved cook stoves households were never to schooling, 129 (35.5%) of non-adopter were attend primary school and the remaining 89 (24.5%), 3 (0.8%) of non-adopter of improved cook stoves were attend secondary and post-secondary school respectively.

Regarding the annual income and improved cook stove adoption 34 (70.8%) improved cook stoves adopter households were those who can earn 50,001-60,000 ETB, 8 (16.7%) of them are those who can earn annual income between 40,001-50,000 ETB and 6 (12.5%) of them are in the income range of 30,001-40,000ETB.

From interview with woreda water and energy office head and renewable energy team leader, the main barriers for adoption of improved cook stoves were lack of awareness on improved cook stove, lack of improved cook stove mold in nearby place, availability or supply and unwillingness of individuals' target group to produce ICSs.

Woreda Environment, Forest and Climate Change Authority interview and discussion, it was shown that, the current highly reliance on firewood and charcoal consumption by traditional and inefficient ways have significant effect on climate change and Environmental degradation. From field observation during data collection of this study, the woreda office of EFCCA was decided to control the firewood and charcoal market in woreda city. Figure 5 below show that firewood and charcoal which pinched by woreda office of EFCCA due to the high environmental degradation of firewood and charcoal consumption.

Figure 5: Charcoal and firewood pinched by woreda EFCCA due to environmental degradation and high consumption

5.1.6 Types of household's energy usage pattern and cooking appliances in the study area

Households were asked types of fuel source for baking injera and wet. The dominant source of energy used for baking injera was fire wood which account 85.4%. Only 11.2% use firewood and crop residue and 3.4% were use electric power. Only few households solely depend on electricity for their cooking. The study also found that majority of households 87% use firewood and crop residue for making wet and coffee. The remaining 9.8% and 2.5% households use charcoal and electric power respectively. Regarding to types of cook stoves majority of the respondents 363 (88.3%) of them use three stone stove and a few of them 48 (11.7%) used improved cook stoves. For lighting purpose 283 (68.9%) of them use solar energy, 98 (23.8%) of them use kerosene and the remaining 24 (5.84%), 3 (0.73%) and 3 (0.73%) of the respondents used electric power & candle, firewood and biogas for lighting respectively. From this survey data; majority of respondents still now rely on traditional (three stone stove) in percent 363 (88.3%) use three stone stove for cooking and only 48 (11.7%) of them use improved cook stoves and electric stove for cooking purpose.

Table 6: Types of fuel used for cooking, lighting and types of cook stoves

Types of Energy used for baking Injera	**Frequency**	**Percent**
Firewood and crop residue	397	96.6
Electric power and firewood	14	3.4
Types of Energy used for cooking wet and making coffee		
Firewood and crop residue	358	87
Biogas	3	0.73
Charcoal	40	9.77
Electric power	10	2.5
Types of energy for lighting		
Solar	283	68.9
Kerosene	98	23.8
Electric power	24	5.84
Firewood	3	0.73
Biogas	3	0.73
Types of cooking stoves		
Three stone stove	363	88.3
Improved cook stoves (mirt mitad) and electric mitad	48	11.7

5.1.7 Status of solar energy adoption in the study area

Households were asked whether they are adopter of solar energy or not. As shown below in fig. 6, from the total of 411 respondents, 283 (68.9%) were found adopters of solar PV while; 128 respondents (31.1%) are non-adopters. This implies, the majority of the households were found to be adopters of solar PV.

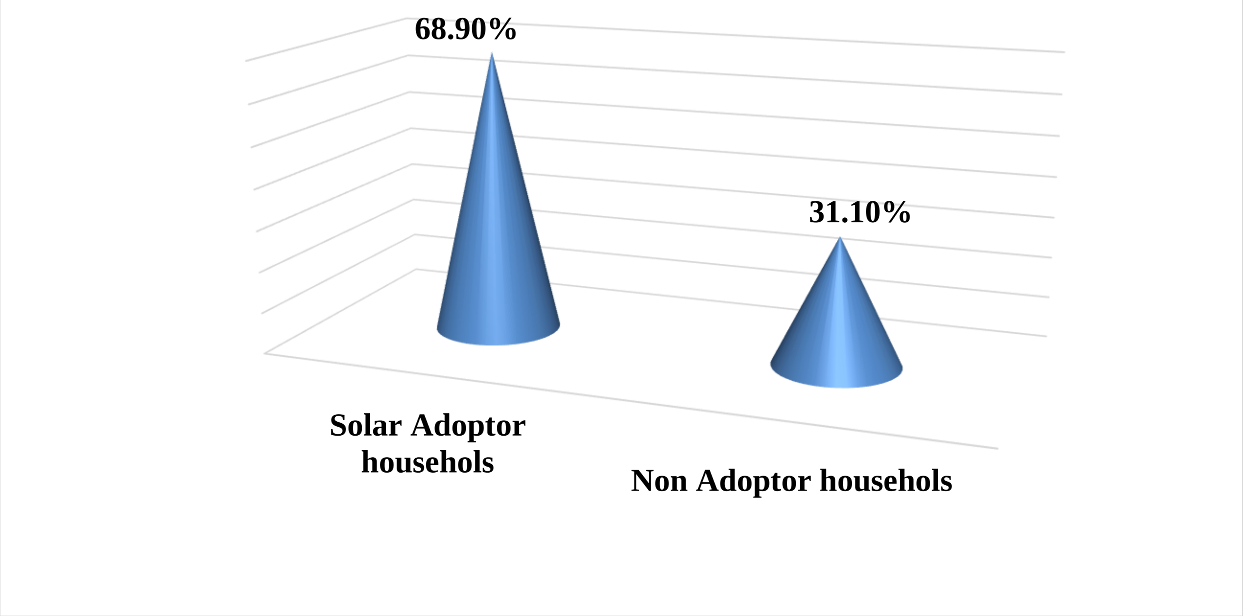

Figure 6: Current status of solar PV adoption

From woreda water and energy office renewable energy team leader discussion, the main challenges for adoption of solar energy technology, lack of after sell service, poor product quality; lack of subsidy and unwillingness of target group to maintain and produce solar energy technology were observed as challenges.

5.1.8 Household annual energy consumption in the study area

Households were asked that, their frequency to firewood collection per week and their response shows that, in average they collect firewood 2.25 times per week. This implies that 2.25 loads of firewood were consumed per households per week in the study area. According to Duguma (2014), OECD/IEA (2006) and UNDP (2010), the weights of one load of firewood was varies between 20-30kg. By considering 25kg weight for one load of firewood, about 56 Kg of firewood was consumed per week at household level in the stuy area. From table 7 below, on average about 2,952 kg of biomass (firewood, crop residue, charcoal and animal dung), 18.2L of kerosene and 18.2KWh of electricity was consumed at household level. The annual consumption of biomass, kerosene and electricity at sample households were 1,213ton, 5,984Liter, 7,480 MWh respectively. Generally, 14,113ton of biomass, 69,624Liter of kerosene and 87MWh of electricity consumed at selected four kebeles.

Table 7: Summary of energy types weekly and annual consumption in the study area

Sources of energy	**Daily Consumption/hh**	**Weekly consumption/hh**	**Annual consumption/hh**
Firewood (Kg)	8	56	2,912
Crop residue (Kg)	0.08	0.56	29.12
Charcoal (Kg)	0.02	0.14	7.28
Animal dung (Kg)	0.01	0.07	3.64
Kerosene (L)	0.04	0.28	14.56
Electricity (KWh)	0.05	0.35	18.2

5.1.9 Sources and distance travelled for collecting firewood

From table 8 distances of households travelled to firewood collection in one-way trip showed that 26.5% of households travelled < 2km and majority of households (66.6%) travelled 2-4km and few of them (6.8%) households have travelled greater than 4km. Households were asked about the sources of biomass fuel from where they get for domestic consumption. The finding of this study has been indicated that trees on farm land were the dominant sources of firewood which covers about 51.1%, 25.1% of the respondents were collect firewood from public forests, 0.7% from planted trees, 3.6% from virgin lands and 2.7% and 13.9% of the respondents were collect firewood from private forest and common farm land respectively. About 2.9% respondents fulfill their energy demand from market by purchasing.

Table 8: Distance travelled to firewood collection for one-way trip and sources of firewood

Distance travelled for firewood collection	Frequency	Percent
< = 2Km	109	26.5
2.1-3Km	137	33.3
3.1-4Km	137	33.3
> 4Km	28	6.8
Sources of firewood		
Public forest	103	25.1
Planted tree	3	0.7
Virgin land	15	3.6
Trees on farmland	210	51.1
Private forest	11	2.7
Common farmland	57	13.9
From market	12	2.9

5.1.10 Biogas energy potential of the study area

5.1.10.1 Biogas potential of animal dung`

The livestock number of cows, goats, sheep's and chickens were collected from the household survey data. The average number of cows, goats, sheep's and chickens per households in the study area were 5.3, 0.24, 2.7 and 4.4 respectively (table 9). The total dung produced annually was calculated by multiplication of the animal dung production per year and the number of heads of different animals taking the lower and higher dung yield.

According to Sameer (2009), NBPE (2008) and Sasse (1988), the average fresh manure obtained from, cattle is 4.5kg/day/cattle, sheep and goat 1kg/day/head and chicken is 0.08kg/day/head. By taking this into account the daily and annual dung production of biogas potential in the study area was calculated.

Table 9 : Animal manure biogas potential in the study area

Animal livestock	Kossa Geshe kebele	Dengaja sole kebele	Yatu Tirgi kebele	Chaffe Elfata kebele	Ave.no of animals/ households	Total livestock in sampled hh	Ave.Fresh manure kg/day/ animal	Total Fresh manure (t/day)	Total fresh manure (t/year)
Cows	448	793	402	541	5.3	2,184	4.5	9.83	3,588
Goats	21	37	19	25	0.24	102	1	1.12	409
Sheeps	231	408	206	278	2.7	1,123	1	0.10	36
Chickens	371	656	332	447	4.4	1,806	0.08	0.14	51
Total	1,071	1,894	959	1,291	12.7	5,215	6.58	11.2	4,084

The average biogas yield of cattle, is 0.24m^3/kg DM, sheep and goat is 0.37m^3/kg DM where as chicken is 0.4m^3/kg of DM and the dry matter content of cattles manure was 16.7%/kg and 30.7%/kg for sheeps, goats and chickens (Jørgensen, 2009, Teodorita Al Seadi, 2008, (Nicholson *et al*., 1999), Anelia, 2009). To calculate the biogas energy potential of the study area; the following formula was employed.

Total Fresh manure potential of the study area (tone/day) = Average Fresh manure (kg/day/animal) * total no. of livestock in the study area.

Total dry mater (DM) from fresh manure = DM % of Fresh manure * Total Fresh manure potential of the study area (t/day).

Total electricity production in kWh/day= electricity production by biogas generator from 1 m^3 biogas in kWh * total biogas production in m^3/day. According to Sameer (2009) by using biogas generator, it is possible to generate 1kWh electricity from 0.7m^3 biogas. The available potential of livestock's and energy resources of the study area were computed as table 10 below.

Table 10: Summary of expected manure potential for biogas energy from animal livestock

Animal livestock	Ave. Fresh manure kg/d/animal	Total no. of livestock	Total Fresh manure (t/d)	Total DM (kg/d)	Biogas (m^3/kg) DM	Total biogas (m^3/d)	Total biogas (m^3/y)	Electricity production (kWh/d)	Electricity production (kWh/y)
Cattles	4.5	2,184	9.83	1,642	0.24	394	143,810	563	205,443
Sheep's	1	1,123	1.12	343	0.37	127	46,355	181	66,065
Goats	1	102	0.10	31	0.37	11.5	4,197	16	5,840
Chickens	0.08	1,806	0.14	43	0.4	17	6,205	24	8,760

Kg = kilogram, d = day,y = year, t = ton, KWh = kilowatt hour, DM = Dry mass; Source: survey data (2021) based on Jørgensen (2009), Teodorita Al Seadi (2008), Anelia (2009), Nicholson (1999)

The expected biogas potential from animal livestock manure was 11.2 ton/day and its biogas production capacity is 549m^3/day. This implies that, the available livestock's manure potential can generate 1.3m^3 of biogas per day at each household level.

According to Mark Powell (2008) the collection efficiency of animal manures varies from 50%-100%. By considering the collection efficiency of 80% for cattle and 50% for chicken, goat and sheep manure. The collectible biomass energy potential of the study area was computed as follow table.

Table 11: Collectable biomass energy potential from livestock manure in the study area

Animal livestock	Ave. Fresh manure (kg/d/animal)	Total No.of livestock	Total collectable manure (t/d)	Total collectable DM (kg/d)	Biogas(m^3/kg) of DM	Total biogas (m^3/d)	Total biogas (m^3/y)	Electricity production (kWh/d)	Electricity production (KWh/y)
Cattles	4.5	2,184	7.86	1,314	0.24	315	114,975	450	164,354
Sheep	1	1,123	0.56	172	0.37	64	23,360	90.5	33,032
Goats	1	102	0.05	15	0.37	5.6	2,044	8	2,920
Chickens	0.08	1,806	0.07	21.5	0.4	8.6	3,139	12	4,380

The results in table 11 above indicates that, the available and collectable livestock manure was 8.54ton/day and can generate about 393m^3 biogas energy potential per day. From this it can be conclude that, the available livestock biogas energy potential in the study area can generate 0.96m^3/hh/day.

5.1.10.2 Urine and faeces potential of biogas from human waste

The human waste and other form of waste can be recycled as a source of energy through anaerobic digestion. The quantities of human excreta per capital as reported in the different literatures vary widely. The mean of wet faeces weight (g/cap/day) of low income countries was 250 g/cap/day. Whereas 126 g/cap/day of wet faeces for high income countries. The faeces and urine generation of low income countries 250 g/cap/day and 1.5 lit./person/day standards was considerable for this study. Biogas energy potential of human faeces and urine at household level can be calculated depends up on the average family members in the study area. The average number of family size in the study area was 5.6 families per households. One person produces on average 0.25Kg of faeces per day, the dry matter content of which is about 25% and its biogas yield of about 0.2m^3/kg (Rose, Parker, Jefferson & Cartmell, 2015).

Table 12: Total population and average family size in selected kebeles

Population number of the study area	Kossa Geshe	Dengaja sole	Yatu Tirgi	Chaffe Elfata
No of sample households in each kebele	84	150	75	102
Average family size of sampled household	5.6	5.6	5.6	5.6
Total population number of sample households	470	840	420	571

Table 13: Summary of energy potential from human manure (feces) in the study area

Types of livestock	Fresh. Faeces (kg/d/person)	Total no. of population	Total fresh faeces potential (t/d)	Total DM (kg/day)	Biogas (m^3/kg) DM	Total biogas (m^3/d)	Production capacity of electricity (kWh/d)
Human	0.25	2,301	0.58	144	0.2	29	41

Calculation based on Rose, Parker, Jefferson & Cartmell (2015)

The expected biomass energy potential from human faeces of sample households was 0.58 ton/day and its biogas production capacity is 29m^3/day. This implies that the expected human faeces biogas potential of the study area was 0.07m^3/day.

But, due to the movements of peoples from place to place; the collection of human waste for energy source was difficult. By considering 60% of the collection efficiency of human faeces and urine; the total collectable fresh manure (faeces) biogas energy potential of the study area from human is estimated to 0.042m^3. In average 1.5L of urine can be generated per person per day in developing countries. This indicates that about 3,452L/day or 3.4m^3/day of urine which used to dilute fresh dung for biogas can be generated per day in the study area. The same to faeces potential; the collection efficiency of urine for energy potential was consider 60% for this study. This implies that from expected urine generated 3.4m^3/day only 2.04m^3/day was collectible to use as a source of biogas energy potentials for diluting fresh manures.

5.1.10.3 Water Sources and distance travelled in fetching water

The study found that the dominant source of water about 89.8% of sample households was spring. The remaining 9%, 0.7% and 0.5% of HHs water source were pipe line, bore hole and river respectively. 89.8 % of the sample households were fetch water from water sources and the mean distance travelled to fetch water was about 0.94km.

Table 14 : Summary of sources of water and distance to fetch one-way trip

Sources of water for domestic	**Frequency**	**Percent**
Spring	369	89.8
Pipe	37	9.0
Bore hole (biri)	3	0.7
River	2	0.5
Distance travelled to fetch water		
< = 0.1 km	35	8.5
0.1 km - 0.5 km	112	27.3
0.6 km – 1 km	135	32.8
1.1 km - 1.5 km	116	28.2
1.6 km – 2 km	13	3.2

5.1.10.4 Farmland holding size

Regarding the land issues, land ownership and land size are the major points to be focused. The size of land holding of the household was asked by local language “fecasa” and four fecasa of land is equal to one hectare. After the size of land ownership data collected in fecasa then it was changed into hectare. Concerning the land size, it was categorized in six ranges; less than 0.25 hectare, 0.25-0.5 hectare, 0.6-1 hectare, 1.1 – 1.5 hectare, 1.6-2 hectare and above 2 hectares. The mean of land size was about 1.63 hectare. In percent 4.6% of the respondents have less than 0.25 hectare, 18.6% have 0.25-0.5-hectare land, 26% of them have 0.6-1 hectare, 15% have 1.1-1.5 hectare and the remaining 15.6% and 20% of them have 1.6-2 hectare and above 2 hectares respectively. The mean of land holding size was 1.63 hectare per households.

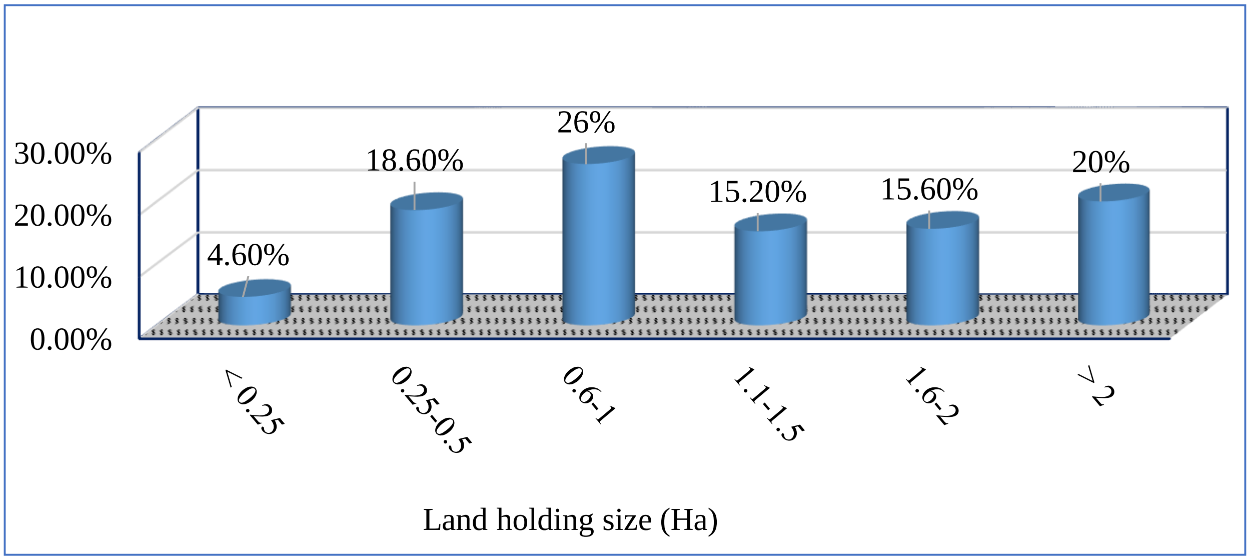

Figure 7: Land possession in (ha) per households, Ha=hectare

5.1.11 Crop residue energy potential in the study area

The available energy potentials of crops residues were calculated by multiplying the average farmland size (ha) by average crops yield (t/ha), residue to product ratio (RPR) of specific crops and availability coefficient (%).

The theoretical potential of residue assumes a 100% availability of all residues considered and was calculated using residue to product ratios (RPRs) obtained from the field data and literature. The technical potential of residue assumes a recoverability fraction. Average land size per households and share of crops in percent were obtained from woreda agricultural and rural development office. The average farmland size of the woreda per household was 2 hectares. From household survey the average farmland size was 1.63 hectares per households. The average value of 1.8 hectare per household was considered for this study. The estimation of crop residue for energy source was quantified by assuming 40% of collection efficiency. From table 15 below the collectable (technical) crop residues biomass energy potential was 1,146t. This implies that annually 2.7t of technical biomass energy was generated from crops energy residues.

Table 15: Annual cereals crops residues potentials in the study woreda

Types of crops	Land size (ha)	Share of land coverage (%)	Crop yield (t/ha)	RPR	Theoretical residues (t/ha)	Collectable crop residues (t/ha)	Collectable crop residue (t)
Maize	459	62	3	1.4	4.2	1.7	780
Sorghum	229	31	2.1	1.5	3.2	1.3	298
Teff	30	4	1.8	2.3	4.1	1.6	48
Wheat	7.4	1	2.1	1.3	2.7	1	7.4
Barley	7.4	1	1.8	1.3	2.3	0.9	6.7
Other	7.4	1	1.5	1.3	2	0.8	5.92
Total/Av	740	100	2	1.5	3	1.2	1,146

Calculation based on (CSA, 2014); t = ton, ha = hectare, RPR=residue to product ratio

5.1.12 Current status of planting trees for fuel source

Households were asked whether they are planting trees or not for fuel sources and it was found that, 99.3% of the respondents were not purposely plant trees for fuel sources. Only about 0.7% of respondents planted trees for their fuel sources. Regarding to this factors affecting planting trees for energy source were conducted. This study found that about 82.2% of their response showed that due to lack of awareness, 8% of them were due to lack of lands for cattle production and the remaining 6.1% and 3.6% of the respondents due to accessibility of firewood in nearby place and accessibility of electric grid for energy demand respectively. Summary of status of planting tree for fuel source and factors affecting to planting tree were summarized in table 16 below.

Table 16: Current status of planting trees for energy source and reasons why not plant trees

Planting tree for fuel sources	**Frequency**	**Percent**
No	408	99.3
Yes	3	0.7
Challenge faced to plant trees for fuel source		
Lack of awareness	293	71.3
Lack of having enough land	79	19.2
Availability of firewood in nearby place	24	5.8
Having Electric power	15	3.6

5.2 Multi-linear regression results

5.2.1 Main challenges to adopt biogas technology

The study had an objective of establishing the factors influencing adoption of biogas by households in rural areas of Limmu Kossa woreda**.** Multiple linear regression was performed with the following social-economic factors considered; household family size, gender, educational level of household, income of household, availability of firewood, number of cattle, land size and age of household. The results are presented in below Tables 17, 18 and 19. Results in Table 17 indicate that the r squared was 0.541 or 54.1% indicating that the factors included in the model (household family size, gender, educational level of household, annual income of households, distance travelled to firewood collection, number of cattle, land holding size and age of household) can explain 54.1% of the variation in biogas adoption.

From the analysis of variation (ANOVA) results in Table 18 indicates that significant differences in the contribution of the eight factors to the variability in biogas technology adoption. (p = 0.000). This indicates that the model used to establish the factors affecting adoption of biogas was adequate and could provide predictive ability of the relation between dependent and independent variables.

Table 17 : Analysis of variance (ANOVA)

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	15.874	8	1.984	55.169	0.000^b
Residual	13.452	374	0.036		
Total	29.326	382			

a) Dependent Variable: Biogas adoption

b) Predictors: household family size, gender, educational level of household, income of household, availability of firewood, number of cattle, land size, age of household

From multi linear regression of table 19 the factors that had a significant influence on biogas adoption were: gender (p=0.019), education level (p = .006), household income (p = 0.000), availability of firewood in nearby place (p = 0.007) and age of household (p = 0.047).

Household family size, number of cattle and land holding size did not have a significant contribution to adoption of biogas at 5% confidence level. Socio-economic factors such as gender of household heads, educational level of household head, income of households and availability of firewood significantly influenced adoption of biogas technology. The relative contribution of these factors on adoption of biogas technology was discussed in the chapter six.

Table 18: Model Summary

Model	R	R Squared	Adjusted R Square	Std. Error of the Estimate
1	0.736^a	0.541	0.531	0.18965

a. Predictors: age of households, gender, number of cattle in range, availability of firewood, land Size, household Family size , educational level of household, Income of households

Table 19: Multiple linear regression analysis of factors influencing adoption of biogas

Variables	Unstandardized Coefficients		Standardized Coefficients	T-test	Sig.
	B	Std. Error	Beta		
Households Family size	0.120	0.014	0.034	0.859	0.391
Gender	0.189	0.068	0.046	1.307	0.019
Educational level of households	0.257	0.014	0.172	1.779	0.006
Income of households	0.310	0.005	0.298	6.269	0.000
Availability of firewood	0.371	0.013	0.099	2.722	0.007
Number of cattle	0.080	0.16	0.176	4.707	0.214
Land Size	0.190	0.007	0.535	14.199	0.146
Age of households	0.018	0.009	0.101	1.994	0.047

Dependent Variable: Biogas technology adoption

5.2.2 Factors affecting improved cook stoves adoption

Multi linear regression (table 20 below) show the relative contribution of different factors to the adoption of improved cook stoves. The factors that had significant influence on ICSs adoption were annual income (p=0.0000), availability of firewood (p=0.000), gender of household's head (p=0.045 and the cost of ICSs. Age, household's family size and educational level of households did not have significant contribution to adoption of improved cook stoves at 5% significant level since, p>0.05.

Table 20 : Results of multiple linear regression analysis of factors influencing adopting of improved cook stoves

	Unstandardized Coefficients		Standardized Coefficients		
Variables	B	Std. Error	Beta	T	Sig.
Age of households	0.18	0.012	0.088	1.539	0.125
Income of households	0.56	0.006	0.487	9.413	0.000
Family size	0.24	0.018	0.059	1.332	0.184
Availability of firewood	0.452	0.095	0.206	4.784	0.000
Gender	0.70	0.035	0.079	2.010	0.045
Educational level of households	0.012	0.020	0.031	0.609	0.543
The cost of ICSs	0.181	0.038	0.199	4.736	0.000

Dependent Variable: Improved cook stoves adoption

5.2.3 Challenges of adopting solar PV

Multi linear regression (table 21 below) show the relative contribution of different factors to the adoption of solar PV. The factors that had significant influence on solar PV adoption were: age of households (p=0.000), income of household heads (p=0.010), household's family size (0.000) and educational level of household's head. Gender of household's head (p=0.879) did not have significant contribution to adoption of solar PV at 5% significant level since, p>0.05.

Table 21 : Multiple linear regression analysis of factors influencing adoption of solar PV

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	T	Sig.
Age of HH	-0.188	0.012	-0.578	-5.053	0.000
Income of HH	0.163	0.006	0.091	2.574	0.010
HH Family size	-0.983	0.019	-0.155	-5.197	0.000
Gender	0.060	0.037	0.004	0.153	0.879
Educational level of HH	0.118	0.020	0.200	5.827	0.000

a. Dependent Variable: Adoption of Solar energy

Chapter 6: Discussion

6.1 Factors influencing adoption of biogas technology in the study area.

The relation between household's family size and biogas adoption in table 4 show that majority of adopters and non-adopter households (75% and 45.6% respectively had family sizes of between 4-6 members. Household's family size had implication on labor provision since biogas requires regular feeding and collection of dung. However, as shown in table 19 household family size did not have significant effect on biogas adoption in this study since p=0.391. This might be due to many households' family members stay long time in schooling and households adopt biogas technology regardless of their household's family size. The finding of this study was supported by Mwirigi *et al* (2018) which nowadays people in many parts of the world hire labor and no longer entirely depend on their children to perform household tasks.

From table 4, the relationship between gender of household head and biogas adoption in this study is viewed the influence and responsibility of male gender on household energy choose. The study revealed that all (100%) of biogas adopter households and (95%) of non-adopters in the study area were male headed households. Gender in this study had the implication on household decision making system and the influence between male and female gender in adoption of the technology. From multi linear regression analysis of table 19 the relation between gender of household's head and biogas were statistically significant (p=0.019).

The relationship between education level of household's head and biogas adoption was shown in Table 4. The study further indicated 46.9% biogas adopter attained primary education, 37.5% of adopter households were attend secondary school and 15.6% adopter households were never to schooling. This implies households who can read and write were more adopter of biogas technology than those who cannot read and write. Table 19 also shows that education level had significant influence on biogas adoption (p = 0.006). The result of this study was agreed with the finding of Omer & Fadalla (2003), Mwirigi *et al* (2018) which education increases information acquisition ability thereby providing awareness and knowledge to new technologies.

The relation between households head annual income and adoption of biogas technology in Fig. 3 indicated that; high income earner households were more adopter than those who earn less income earner. This implies that annual income of households has an implication of biogas technology adoption.

As indicated in Table 19, household's annual income had significant effect on biogas adoption (since p=0.000). The results of this study is supported by Mwirigi *et al* (2018), Geddafa *et al* (2021), Mukumba *et al* (2016), Marfo *et al* (2018 and Rupf *et al* (2015) which indicated the high initial cost of installing digesters as the major constraint to the adoption of biogas in Africa. As income of household's head increases capacity to cover the cost to install biogas also increase and consequently the decision to adopt biogas technology also increase. This will require a subsidy, grants, or long-term repayment loans from governmental and non-governmental financial institution motivate households to adopt biogas technology in the study area.

As shown in Table 19, the availability of firewood in nearby place had significant effect on biogas technology adoption (p=0.007). This implies that households who have the possibility to collect firewood from their nearby place and cost free were less biogas adopter than those of households cannot afford firewood from their nearby place and without charges. The results of this study was in line with the finding of Wawa (2020), Geddafa *et al* (2021) which biogas adopter households had scarcity of fuel wood than non-adopters.

As shown in table 4 the study reveals that 62.6% and 48% of biogas adopters and non-adopters' households respectively had between 5-8 cows. 62% of non-adopter of biogas have those households who have > 8 cows. From Table 19, number of cattle did not have significant influence on biogas adoption. This is due to; having 4 cows can provide enough dung for daily feeding of biogas operation.

Regarding to land holding size, as shown in table 4 majority of biogas adopter households (41% and 53%) and (13% and 10.8%) non-adopter households were those having land holding size of 1.6-2ha and > 2ha respectively. This indicated that those who have large land holding households were more adopter than those of small land holding size. This is due to large land size holder have the possibility to have high cattle production, since cattle manure was the limiting factor of biogas adoption. But, the results in table 19 shows (p = 0.146) indicated that, land holding size does not have significant effect on biogas adoption. This might be due to the production of 4 cows on small land size can fulfill the daily required dungs for biogas operation.

6.2 Factors influencing adoption of ICSs in the study area.

Table 20 showed that age of household's head, family size and educational level did not have significant contribution to adoption of improved cook stoves at 5% significant level since, $p>0.05$.

6.2.1 Annual income and ICS adoption

The relation between annual income of households and improved cook stoves adoption was statistically significant ($p=0.000$). Income of households had significant indication of the use of improved cooking appliances. This indicated that high income earner households were more adopter of improved cook stoves than those earn low income. A similar study by Mwirigi *et al* (2018), Gelaw (2020) and Malla *et al* (2014) illustrates that as income of households increase most families receive cleaner business energizes to improve their day to day environments.

6.2.2 Availability of firewood and improved cook stoves adoption

From the results in table 20, the relation between availability of firewood and improved cook stoves adoption were statistically significant since $p < 0.05$. This implied that; access of firewood from nearby place and without charge have negative influences on improved cook stoves adoption. As households get firewood free of charge, fuel wood saving cannot be the concern of the particular household and the adoption of improved cook stoves as incurs a cost, the household prefers to stay in the business as a usual practice to avoid additional costs. This result was supported by the work of Bogale (2020) and Geddafa *et al* (2021) which the possibility to adopt renewable energy technology can be influenced by the scarcity of firewood.

6.2.3 Relation between gender, cost and improved cook stoves adoption in the study area

Table 20 show that, gender of the household's head had significant effect on the adoption of improved cook stoves at 5% confidence level since $p=0.045$. Gender in this study had the implication on household decision making system and the influence between male and female gender in adoption of improved cook stoves. This might be the decision to adopt or not was made by husband rather than wife. This is in line with the study conducted by Bogale (2020) in Debre Elias district, which suggested that male headed households were more adopter than female headed households and oppose the finding of Mwirigi *et al* (2018) which illustrate that the decision to adopt renewable energy technology or not was made jointly by both husband and wife.

As it was expected from table 20 the price/cost of improved cookstoves had significaant effect on improved cook stoves adoption since p-value was 0.000. This finding can confirms that, household energy ladder theory which suggested that household's socio economic status ability to pay for improved energy technology determines the adoption decision. This study came up with different findings of worabo (2020), Puzzolo *et al* (2013) and Tigabu (2014) found price as one determinant factor that affects improved cook stoves adoption decision.

6.3 Challenge influencing adoption of solar PV

From table 21 it was observed that, age of households had the smallest impact which is negative (-0.578), this indicate that elder in age will decrease the likelihood of using solar as energy source. This indicates that younger households were more willing to adopt when compared to the older ones. The willingness to adopt solar energy decreased with increase in age of the households and vice versa. This is supported by result of research done in Ambo by Warkaw *et al* (2016) shows that the probability of household adoption of renewable energy sources increases with a decreasing age of household head. The results in table 21 also show that the relation between adoption of solar and annual income of households statistically significant since $p< 0.05$, this implies high income earner more adopter of solar than that of low income earner. This result was in line with the finding of Anteneh (2019) household with more annual income earner is more likely to adopt solar technology than that of low income earner.

Household size and the wish to adopt solar energy had a negative relation. This indicates that when household size increased the wish to adopt the solar energy technology decreased. The result of this study was agreed with the finding of Isaac (2014), Anteneh (2019) which indicated that household size had a negative but significant influence on the adoption of solar energy.

Gender in this study is not significant factor in solar adoption and use; since both gender adopt solar PV. According to Worabo (2020) education is very important for the household to interpret the information coming to them from any direction. A better educated person can easily understand and interpret the information transferred to them energy sector. From table 21 the relation between solar adoption and educational level of households was statistically significant ($p=0.000$) and it can be generalized that there is significant relationship between educational status and the probability of solar PV adoption decision. From this finding one can realize that educated households are found to be more solar adopter than those of less educated as well as illiterate households as compared. This result was agreeing with the work of Anteneh (2019).

6.4 Status of biogas technology and its role in attainment of SDG

From the analysis of status of biogas adoption; the available biogas energy potential and current use of biogas as energy generator was quite different. Among 47,511 households in the woreda this study reveals that only 32 households or 0.06% was the adopter of biogas as energy generator; the results of this study is a little bit less than the same study conducted in Gomma woreda by Mechal (2016) found that among total households in the wereda only 0.12% was biogas user. This might be due to the availability of sand in their nearby place and better promotion of the technology. Regarding to functionality rate of constructed biogas in the woreda; from 32 constructed biogas in the wereda currently 21 (65.6%) was functional and 11 (34.4%) non-functional.

As Winoto (2012) 1m^3 of biogas is equivalent to 60-100-watt bulb for 6 hours for lighting, can cook 3 times meals for a family of 5 – 6, fuel replacement 0.7 kg of petroleum, shaft power which can run a one horse power motor for 2 hours and electricity generation capacity of 1.25kWh. Since the available biogas energy potential from animals and human manures in the woreda of this study was 1m^3; this is equivalent to about 60-100-watt bulb for 6 hours for lighting, can cook 3 times meals for a family of 5 – 6, fuel replacement 0.7 kg of petroleum, shaft power which can run a one horse power motor for 2 hours and electricity generation capacity of 1.25kWh per household per day.

According to (SNV, 2009), 1m^3 of biogas is equivalent to 5.56 kg of firewood; therefore, it is assumed that annually 2,029kg of firewood can be saved at each household level. This indicates that by using the available biogas potential at household level; from the annual average biomass energy consumption of 2,952 kg/year/household in the study area it can be save 69% of consumption. Generally, if the whole available biogas energy potential of the study area can be converted to biogas energy it can be saved that annually about 9,599ton of firewood in the study area. This indicated that biogas also reduce the possible deforestation created by firewood consumption. Therefore, such using the existing resource for biogas energy reduced 69% of end uses emission and deforestation from annual firewood consumption in the woreda.

The adoption of biogas technology at households would directly contribute to the attainment of SDG. Contribute to SDG 2 by nutrient (available cattle dung and human excreta) recycling it can be restoring soil nutrient through the use of digestion as organic fertilizer or the effluent serves as soil ameliorator. This will give good crop yields and savings households from the purchase of inorganic fertilizers can be used to soar the family income for other business ventures. This will improve food production, reduce hunger and malnutrition, and enhance sustainable agricultural practices. To SDG 3, the substitution of biogas by firewood can reduces IAP and improves health, especially women and children who spent long time in kitchen reduce burden on women and children in gathering firewood. To SDG 6, anaerobic digestion can eliminate pathogens waste. This can reduce the pollution burden of raw wastewater discharged into water bodies and ensures water availability for other uses. To SDG 7, biogas technology can reduce the heavy dependence of households on biomass based energy sources by providing readily available gas which can be used for cooking, lighting and powering of other electric gargets with minimal emission. To SDG 15, the use of biodegradable waste as biogas energy source reduces the amount of nutrients that would have caused environmental challenges to water bodies like eutrophication and algal blooms which can lead environmental pollution.

6.5 Role of improved cook stoves on Environmental sustainability and human health

Highly reliance on biomass energy consumption in inefficient cooking appliances and unsustainable cooking and lighting practices can have serious impacts on the environment, such as land degradation, indoor and outdoor air pollution. Firewood and charcoal takes 100% for baking injera and 96.77% use for making wot and coffee in the study area. In view of cooking stoves, 88.3% of households were used traditional three stone stoves for baking injera and making wot. This indicates that among annual consumption of biomass of 1,213tons, 88.3% of it was consumed by using this inefficient stoves. Improved injera baking Mirt stoves had saved firewood by 40% (Fekadu *et al*., 2021). By considering this, it is assumed that if the whole households in the study area shifted to the improved mirt stoves it can be save about 5,647 tons of firewood when compared to the traditional three stone stoves from the current annual biomass consumption. Then, improved stoves also reduce the possible deforestation created by open three point stoves. Therefore, such improved cooking stoves reduced end uses emission and deforestation from 40%

of the one created by traditional open three stone stoves. Therefore, adopting and using ICSs would also contribute to the achievements of SDG 3, SDG 7 and SDG 13.

6.6 Biomass energy potential and its consumption pattern in Limmu Kossa woreda

Regarding to biogas energy potentials; the available and collectable livestock manure at survey households was 8.54t/day and can generate about 419m^3 biogas energy potential per day. This indicates that the available animal livestock energy potential in the study area can generate 0.96m^{3}of biogas per households per day. Human excreta and urines potential was considerable for biogas energy and the estimated biomass energy potential from human feces of sample households was 0.57 ton/day and its biogas production capacity is 28.7m^3/day and 0.07m^3/households/day. The daily biogas potential of mix of animals' livestock manure and human excreta is about 1m^3.

The other concern of this study is estimation of crop residue from cereals crops and others. Annually about 1,146 t of collectible crops residue was generated in the study area. Distance that household members travel for fetching water was one of the key areas of inquiry in the survey and the mean distance travelled in two way trip to fetch water was about 0.94km.

As suggested out by Eshete and Kidane (2008) fetching water required to mix with the daily input of 20 kg fresh dung in a 1:1 ratio should not take more than 15 to 30 minutes for two-way trip. The results of this study shows that, the availability of water for use of biogas as energy generator at households in this study fulfills the minimum requirements of water availability which not more than 500m travelled to one-way trip and can adopt biogas at household level as standard of national biogas program of Ethiopia. Hence, there is enough access of water to adopt biogas as energy source in Limmu Kossa woreda.

In view of the source and types of fuels; the dominant source of energy used for baking injera was fire wood, which account 85.4%, 11.2% used firewood and crop residue and 3.4% were use electric power. 88.3% households use three stone stove and 11.7% use improved cook stoves and electric midija and mitad. For lighting purpose 68.9% use solar energy 23.8% use kerosene and the remaining 24 5.84%, 0.73%) and 0.73% of the respondents used electric power and candle, firewood and biogas for lighting respectively. Annually 2,952 kg of mix biomass, 18.2L of kerosene and 18.2KWh of electricity was consumed at household level. The annual consumption of biomass, kerosene and electricity at sample households were 1,213t, 5,984L, 7,480 MWh respectively. Prior studies regarding to hh energy consumption in different places found that the patterns of house hold energy consumption in Ethiopia (Ferede, 2020; Ejigu, 2020; Debebe 2017; Mequannt, 2020; Alemu & Köhlin, 2008; Gebreegziabher, 2004; Gebreegziabher, 2007; Kebede *et al*, 2002; Samuel, 2002).

The result of this is study was higher than what have been found in Holleta Debebe (2017; in South-Eastern Oromia Region Challa et.al 2019; Woreta town Asres (2012) and Addis Ababa Asfaw & Demissie (2012). This difference may be due to the availability of firewood in the study area and the highly dependence on use of three stone stoves.

Chapter 7: Conclusion and recommendation

7.1 Conclusions

There is about 1m^3 of biogas energy potential at household level in the study area. Although adoption level was quite low and out of 47,511 households in the woreda, only 32 households had installed biogas digester. 90% of households use biomass energy by using inefficient cooking stoves. Annually 2,952kg of biomass energy consumed at household. This high reliance on firewood biomass consumption in inefficient practice was dissipated resources and causes indoor and outdoor air pollution and deforestation.

Biogas, improved cook stoves and solar energy technology had significant impact on sustainable environmental management and healthy lives among the adopters. Socio economic like, income, educational level, subsidy, awareness, stakeholder engagement and technical service were found to be the major accelerator of rapid adoption.

7.2 Recommendations

Challenges faced to adopt biogas energy technology, improved cook stoves and solar energy needs more attention while policy making. Disseminating initiatives, programs or projects should be target on localities that highly depends on fuel-wood consumption as their basic fuel needs.

Promotion enhancing to efficient energy technology adoption should be strengthened and targeted on religious places, schools, kebele, natural resource and water shade management works, public meeting and market places through rural energy experts, women and child affairs experts, health extension workers, natural resource management expert's Environmental protection forest and climate change.

Determinants of efficient and improved energy technology and cooking stoves adoption can provide information that policy makers can use to reduce the burdens on biomass resources and reduce the human health effects of household energy consumption.

The current non-functional biogas installed needs high priority and attentions to maintain, since non functionality make wrong promotion of technology.

The distribution of low quality product and way of distribution of solar PV needs governmental attention regarding to legal framework.

7.2.1 Areas of future studies

Further studies should conduct baseline issues to examine these aspects in order to achieve a better understanding of the dynamics and spatial heterogeneities of rural renewable energy potential, demand and consumption.

Further investigation is needed on: the amount of biomass energy resource that can be saved by use of biogas and improved cook stoves locally & its health implication, Available potential of mini hydroelectric power generation and potential of jatropha biofuel needs further investigation.

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Appendix

Self-introduction

Hallo. My name is **Ashenafi Getaneh** from Jimma University. I am doing research for my Master thesis on the, **<u>Assessment of potential of biomass energy, its consumption pattern and challenges of adopting household improved energy technologies in rural areas of households in Limmu kossa woreda (Kossa geshe, Yatu tirgi, Dengaja sole and Chafe ilfata kebeles)</u>**

This will help me to understand more about the biomass potential, its consumption and factors influencing adaptation of efficient and improved energy technology. The information you give me will be confidential and will be used solely for my Master thesis and not for any other purposes. Your household was selected randomly from all the households in this kebele. I would like to ask you about the potential of biomass, consumption and condition available for house hold biogas use. Your participation in the research is voluntary and you can withdraw at any point, including the information you have given. If you would like to ask me any questions regarding this survey, please feel free to do so. Thank you.

Household survey questionnaire

Name of data collector ___________________________signature ___________date _________

Part I: Demographic and Socio-economic information

1) Name of household head (optional) ___________
2) Age of the household head (years) ________
3) Sex A. Male B. Female
4) House ownership A. Private B. Rented
5) Household family size A. 1 B. 2 C. 3 D. 4 E. 5 F. 6 G. 7 I. 8 H.9
6) Household family composition: Number of male ______ Number of female______
7) Level of education of household head A. Never to schooling B. Primary School C. Secondary school D. College Diploma E. First degree F. others, specify______
8) Occupation A. Unemployed B. Daily laborer C. Employed D. Merchant E. Others, specify_____
9) Estimated monthly income of the household (HH) in birr____________
10) Religion: A. Orthodox B. Protestants C. Muslim D. others, _____ used for cooking

Part II: Energy use pattern

11) What is the type of food you usually cook? A. Injera & Wet B. others (please specify),
12) How many times do you cook Injera per week? A. 3 times B.4 times C. 5 times
13) Please specify your reason for question no.12 above A. fuel is expensive C. due to the size of your family B. fuel has scarcity of supply D. Income E. nature and time of my job
14) At what time do you cook Injera? A. morning B. Afternoon C. evening
15) Please specify the reason_____________________________
16) What type of energy source do you use for baking injera? A. Fire wood B. Agricultural residue C. Electricity D. cow dung E. Sawdust
17) How many times do you cook wet per day? A. 1 B. 2 C. 3 D. do not cook
18) Please specify the reason for question no.17 above. _____________ A. Fuel is expensive C. due to the size of your family B. Scarcity of Fuel D. In come E. habit of my job and time
19) At what time do you cook wet? A. morning B. Afternoon C. evening
20) Please specify the reason_____________________

21) What type energy source do you use for making Wet? A. Fire wood C. Agricultural residue E. Biogas G. LPG B. Charcoal D. Kerosene F. Electricity
22) Do you make coffee and tea? A. Yes B. No
23) How many times do you make coffee per day? A.1 B. 3 C. more than 3 D. do not make
24) Please specify the reason for question no.23 A. Fuel is expensive C. due to the size of your family B. scarcity of Fuel D. Income E. nature of my job and time
25) At what time do you prepare tea or coffee? A. morning B. Afternoon C. evening
26) Please specify the reason__________________________
27) What types of energy sources do you use for making Coffee and tea? A. Fire wood C. Agricultural residue E. Biogas B. Charcoal D. Kerosene F. Electricity
28) Do you buy or collect fire wood? A. buy B. Collect C. Both
29) How much a bundle of firewood costs if you buy it? ________
30) How money time do you collect firewood per week? A.1 B.2 C.3 D.4 E. other…………….
31) How much a bundle of firewood weighs? ________
32) If you collect the firewood, from where? A. from forest B. from own farm land C. others (specify),
33) The fire wood is collected by A. Mother B. Sister C. Servant (female) D. Father
34) How much does it take to get the firewood? A. In Kilometer______ B. In Hours____
35) What do you think about the trips to get the firewood from the forest? A. It is the same as in the past B. It is increasing from year to year
36) Do you have a separate kitchen? A. Yes B. No
37) Are the family member stays with you during cooking? A. Yes B. No
38) If you choose Yes ‘, who are they? A. Small children B. the whole family C. Elders D. other females
39) How long do you stay in kitchen per day? A. 1-3 hrs. B. 5-6 hrs. C. others, __
40) How ventilate is it in square meter? A. Less than 5 B. 6-10 C. 10-15 D. Above 15
41) What kinds of stoves do you use for firewood? A. Open traditional three stone stoves B. Improved stoves
42) How much bundle of firewood do you use with your stove per day?
43) Do you have an electric meter (Qoxari)? A. Yes B. No

44) If you choose No ‘for Q. no. 43, please specify the reason____________________

45) Do you use electricity for cooking? A. Yes B. No

46) If you choose yes ‘, for making what? A. cooking wet B. Cooking Injera C. re-heating cooked wet D. Preparing coffee

47) If you choose No ‘for question no.44, why? A. not convenient B. not reliable C. do not have electric stove

48) Do you use agricultural waste for cooking? A. Yes B. No

49) If you choose yes ‘, what are they? A. Maize straw B. Sorghum straw C. others,

50) How much bundle of the agricultural waste do you use to cook the food per day? A. 1- 3 B. 4 -7

51) How many times do you collect firewood per week? _____________

52) How much a bundle weighs, in kilogram? ____

53) From where do you get the agricultural wastes? A. buy B. collect

54) How much a bundle of agricultural wastes costs if you buy it? _____

55) Does the agricultural waste convenient to use? A. Yes B. No

56) If you choose Yes ‘, for what kind of food? _____________

57) If you choose No ‘, please specify the reason A. Not available B. Bulk to collect C. Others___

58) What other options do you use for cooking? A. Kerosene B. Biogas

59) If kerosene, how much per week in liter? A.1- 2L B.3- 4L C. 5-8L

60) How much a liter of kerosene costs you? _________________

61) What kind of food do you cook with kerosene? _________________

62) What kind of kerosene stoves do you use? A. Wick type B. Pressure

63) Why do you use to cook with kerosene? ______________________________

64) Do you use charcoal for cooking? A. Yes B. No

65) If you choose yes ‘, from where do you get the charcoal? A. I buy it B. I prepare it

66) If you choose yes ‘, how much charcoal do you buy per week in sacks? A. 1 B. 2 and above

67) If you choose No ‘question no 65, please specify the reason_________________

68) How much does it cost you for a (Kg /sack) of Charcoal? _______

69) For what purpose do you use charcoal? _____________

70) 258. For what kind of food does using charcoal is convenient? A. cooking wet B. making coffee and tea C. others, _____

71) What type of stoves do you use to cook with charcoal? A. ordinary charcoal stoves B. improved charcoal stoves

72) What is the other use of kerosene? A. lighting B. to ignite fire C. others, _____

Part III: Questions related on lighting energy

1) What do you use for lighting? A. Fire wood B. Kerosene C. Electricity D. Candle E. Solar
2) Do you have wick lamp? A. Yes B. No
3) How many wick lamps (Fanos, Kuraz) do you have? A. 1 B. 2 C. 3
4) For how long per day (in hour) do you use) wick lamps? A. 1- 3 hours B. 4-5 hours
5) For what purpose do you use wick lamps (Fanos, Kuraz)? A. As of electricity failure B. to start the fire to cook C. Others (specify) __
6) If you choose electricity for no.1, how many bulbs do you have? A. 2 B. 3 C. 4 D. 5
7) Which type of an electric bulb you have? A. compact fluorescent B. incandescent
8) Please specify the reason for your choice ______________________
9) How long do you use per day (in hours)?
10) What type of fuel do you use when there is failure of electricity? A. Candle B. Kerosene C. Firewood
11) Please specify the reason for your choice ______________________
12) How much do you pay per month for electric energy? In KWh_____, In Birr______
13) . Do you have a refrigerator? A. Yes B. No

Part IV Questions related to solar adoption and use

1) Do you know about solar energy system? (yes/no) If yes, do you have any in your house?
2) Do know any other person that are using solar energy system? (yes/no)
3) Why you are not using solar PV system for you home? A. due to high cost B. Technical issues for maintains C. Market problem D. Distance from source
4) Are you interested to use solar energy system? (Yes/No)

5) What are main constraints/challenges that can prevent solar energy use? A. Durability of materials B. Cost to buy C. Lack of spare part D. Maintains cost E. Cos and benefits are not balanced

Part V- The types of cooking stoves and appliances they use

1) Which type of appliances you are using for cooking Injera? A. Three stones open fire B. Mirt Mitad/Midija C. Electric stoves/mitad
2) Please specify the reason for your choice __________________________
3) If you failed to choose Mirt Mitad/Midija& Electric stoves/mitad, why? A. I can 't affords B. not friendly and not easily utilized C. Not recognized well
4) Which type of utensils you are using for making wet? A. Shekla Dist B. Biret Dist
5) Please specify the reason for your choice ____________
6) Which type of stoves you are using for making Wet? A. Three stones open fire B. Kerosene stove (Buta gas C. Charcoal stove (Kesel mandeja) D. Electric stove
7) Please specify the reason for your choice __________________________

Part V: Checklist of Key Informant Interview

1. How do you evaluate the current wood fuel availability (scarcity) of the area?
2. How do you see the Environmental, health and economic impacts of reliance on inefficient way of biomass energy consumption?
3. What institutional measures are being to minimize the problem of domestic energy in the area?
4. How do you evaluate the grazing habits of the people in the area?
5. How do you evaluate of people's habit of utilizing manure for fertilizer?
6. Are there extension services related to domestic energy?
7. How do you see the expansion of biogas installations in your locality?
8. What favorable and constraining factors are there to further promote biogas technology, improved cook stoves and solar PV in the area?
9. Do you have any involvement in the biogas technology, improved cook stoves and solar PV dissemination?
10. Are there extension services related to management and use of bio-slurry that specifically targeted the biogas user households?

11. How do you evaluate the current wood fuel availability (scarcity) in the woreda?
12. How do you evaluate the overall tree planting activities of the people in the area? What favorable and constraining factors are there to further promote tree planting activities?
13. What institutional measures are being taken to minimize the problem of domestic energy in the woreda?
14. What alternative sources of energy are there to the rural community?

a) Distribution of photovoltaic?
b) Distribution of improved stoves
c) On/off-grid hydroelectricity
14 Are there plans to further promote alternative energy?

VI: Checklist for focus group discussions

1. How do you evaluate the current scarcity of wood fuel in your locality and its usage?
2. What problems do you experience in association with wood-fuel scarcity?
3. What are the measures being taken against the problem of wood-fuel scarcity in your locality?
4. How do you evaluate the benefits of biogas technology dissemination to the community?
5. With increased dissemination of biogas technologies, among the community and Household members, who do you think getting more benefits?
6. What are the barriers for further adoption and dissemination of biogas technology, improved cook stoves and solar energy in your locality?
7. What opportunities are there for further dissemination of the biogas technology in your locality?
8. What weaknesses do you observe with the implementation of the biogas program or biogas program implementing office?
9. What do you suggest for further promotion of biogas technology in your locality?
10. What do you suggest as lasting solutions for the problems of domestic energy in your locality?

Part VII: Questionnaire related biogas potential assessment

1) Number of household members: Adults……………. Children………………
2) Number of livestock: Cattle: Mature……......young……..…. Total……...….
   Goats: Mature……......young……..…Total……...….
   Sheep: Mature……......young……..…. Total……...…
   Poultry: Mature……......young……..…. Total……...….
   Others (specify)........................... Mature……......young……..…. Total……...….
3) Daily dung collected in Kg-----------/ Jerican………………………
4) Responsibility of collection a. spouse b. daughter c. son d. husband e. servant
5) Have you ever heard of a biogas digester? (Yes/No)
6) What agricultural activities do you practice on the farm? (……………………………...)
7) Land size (a) Under 1 hectare..................... (b) 1-5 hectare..................... (c) 5-10 hectare..................... (d) 10 -15 hectare..................... (e) Other (specify).....................
8) Availability construction materials for biogas in nearby place A. yes B. No
9) Accessibility of roads for transportation of construction materials.

10) Gross household income per/year, month (birr): (a) under 5,000..................... (b) 5,000 - 10,000..................... (c) 10,000 - 15,000..................... (d) 15,000 - 20,000..................... (e) Other (specify).........................
11) Source(s) of water for domestic/farm use…………………….
A. Piped…………………...
B. Obtained from bore hole…………………...
C. Obtained from the river/dam…………………...
D. Rain water harvested in a tank…………….
E. Other (specify)..
6 Distance to the water source in
(a) Kilo meter.............
(b) Meter................

Part VIII: Questionnaire for biogas energy adopter households

1. Name of the respondent ……… Date of interview ………
2. Village…………………Sub-Location………………Loc……………
3. Mobile phone ……………………………………………………………..

4. Gender…………………
5. Age
6. Education Level
7. Household size
8. What is your annual income………………………………………
9. Number of cattles……………………….
10. Is it your biogas is currently functional? (Yes, No)
11. If your answer for question no 10 is no why?...
12. Frequency of firewood collection per week…………………………..
13. Monthly Kerosene consumption in liter-------------------------------
14. Charcoal consumption per week…………………sack
15. Are you spending more, less, or the same amount of time with the use of biogas? …………………………….
16. If saving time, how much time on average do you save in a week (hours)? …………………
17. How do you spend your saved time and income (if any)………………………………....?
18. Distance to firewood collection in Km……………………….
19. Distance to fetching water in Km……………………….
20. Sources of finance for biogas installation………………………………
21. Access maintenance service, yes/no

Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for this thesis have been acknowledged

Name of student ________________________signature___________

We confirm that the work reported in this thesis was carried out by the candidate under our supervision as the supervisors.

Name of Advisors________________signature _____________Date____________

Name of Co-Adviser_______________________ signature, Date_______________