SOCIO-ECONOMIC AND ENVIRONMENTAL CONTRIBUTION OF BIOGAS TECHNOLOGY ADOPTION AND ITS DETERMINANTS IN ARBAMINCH ZURIA WOREDA, GAMO ZONE OF SOUTHERN ETHIOPIA

M.Sc. THESIS

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

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APPROVAL SHEET I

This is to certify that the thesis entitled **''Socio-economic and Environmental Contribution of Biogas Technology Adoption and its Determinants in Arbaminch Zuria Woreda, Gamo Zone of Southern Ethiopia''** is submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Renewable Energy Utilization and Management, the Graduate Program of Environmental Science and, has been carried out by **Daniel Demeke** Id. No MSc/REUM/R005/10, under my supervision. Therefore I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department

Yoseph Melka (Ph.D.)		09 November 2019
Name of Major Advisor	Signature	Date

APPROVAL SHEET II

We, the undersigned, members of the board of examiners of the final open defense by *Daniel Demeke* have read and evaluated his thesis entitled *''Socio-economic and Environmental Contribution of Biogas Technology Adoption and its Determinants in Arbaminch Zuria Woreda, Gamo Zone of Southern Ethiopia''*, and examined the candidate. This is, therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of masters of Science in Renewable Energy Utilization and Management.

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DECLARATION

I, Daniel Demeke W/Hana, hereby declare that this thesis is my original work and has not been presented for a degree in any other University. Again, all the materials used in the thesis have been indicated and acknowledged duly with references.

Name of student	Signature	Date
Daniel Demeke	…………………	……………….

LIST OF ACRONYMS AND ABBRVIATIONS

Btu	British thermal units
CO_2e	Carbon dioxide equivalent
EFAP	Ethiopian Forestry Action Programme
EIA	Energy Information Administration
EREDPC	Ethiopian Rural Energy Development and Promotion Center
ETB	Ethiopian Birr
FAO	Food and Agricultural Organization
FGDs	Focus Group Discussions
GHG	Greenhouse gas
Gt	Giga-tonne
GTP	Growth Transformation Plan
GWP	Global Warming Potential
IGAD	Inter- Government Authority on Development
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MoWIE	Ministry of Water, Irrigation and Electricity
NBPE	National Biogas Program of Ethiopia
NEMA	National Environmental Management Authority
OECD	Organization for Economic Cooperation and Development
PID	Programme Implementation Document
SNNPR	South Nations Nationalities Peoples Region
SNV	Netherlands Development Organization

Toe	Tonnes of oil equivalent
TWh	Terawatt-hour
UNEP	United Nations Environment Program
UNFCC	United Nations Funds on Climate Change
WHO	World Health Organization
WBISPP	Woody Biomass Inventory and Strategic Planning Projec

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Socio-economic and Environmental Contribution of Biogas Technology Adoption and its Determinants in Arbaminch Zuria Woreda, Gamo Zone of Southern Ethiopia

ABSTRACT

Ethiopia has been disseminating biogas technology as an alternative renewable energy source to reduce excessive dependence on traditional biomass. Despite its potential, only a small percentage of (0.8%) of the potential households are benefiting from domestic biogas. There are limited empirical evidences concerning to both its adoption and the overall contribution of the technology in Arbaminch Zuria Woreda. This study was conducted with the objectives of quantifying the socio-economic contribution of biogas technology adoption, measuring the environmental benefits of adopting biogas technology and examining factors affecting households' decisions of biogas technology adoption in the study area. A total of 217 sample households were selected following stratified random sampling approach. Structured and Semi-structured survey, measurement of fuel masses, FGDs and key informants interview were used as data collection instruments. Descriptive statistics, independent sample t-test, dependent sample t-test and binary logistic regression model were used to analyze the collected data. Results showed that the use of biogas technology has significant contributions in improving the livelihood of the rural people. It helps to reduce energy consumption by 30,494.58 MJ per year per household. It substantiated households' income by reducing the costs to be incurred for fuel-wood, charcoal and kerosene consumptions by saving ETB 3,337.46 annually. It also minimizes the household workloads on average by 2.42 hours per week. Traditional biomass substitutions with biogas reduce greenhouse gas (GHG) emission on average by about 2.4t of carbon dioxide equivalent (CO_2e) per digester per year. The regression result revealed that education level of the head of household, family size, availability of fuel-wood, awareness, and access to credit were found to be the most important factors that affect adoption of biogas technology. The study recommends that, the County government should employ strategies such as education, awareness, provision of credit and exploiting the existing carbon market may go a long way in encouraging households to adopt biogas technology.

Key words: Adoption, Arbaminch Zuria Woreda, Biogas technology, GHG, Kerosene, Traditional-biomass

1. INTRODUCTION

1.1 Background of the Study

Energy is absolute necessity of everyday life. It provides essential services for cooking and heating, lighting, food production and storage, education and health services, industrial production, and transportation. The energy supply and use system has also many implications in the household economy, the indoor environment, women's activities, child safety, family nourishment and other aspects including local and global climate. Around 3 billion people still cook using solid fuels (such as wood, crop residues, charcoal and dung) and kerosene in open fires and inefficient stoves (WHO, 2018). Sub Saharan Africa is the region showing the least progress on clean cooking, almost 80% of the population cook with solid biomass (IEA, 2017).

Continued over dependence on unsustainable fuel-wood and other forms of traditional biomass as primary sources of energy to meet household energy needs has contributed to negative impacts on the environment and economy (Johnson *et al.,* 2017). It further causes high levels household air pollution with a range of health-damaging pollutants, including small soot particles that penetrate deep into the lungs. Exposure is particularly high among women and young children, who spend the most time near the domestic hearth (WHO, 2018). In developing countries, access to energy is a major challenge; the rural poor are seriously affected by the depletion of their energy resources, especially fuel-wood. This has put pressure on women and children and further heightens their vulnerability to falls and attacks during fuel-wood collection.

As distance become longer due to deforestation, fuel-wood collection has become a time and energy consuming activity for the average rural woman. These results in less time spent on income generating activities and education. Issues related to the use of traditional biomass energy are for example, high costs and absence of constant supply (NAMA, 2016). Purchase of traditional biomass energy claim a substantial portion of poor people's budget.

Energy-related greenhouse gas emissions are also the main drivers of anthropogenic climate change, exacerbating patterns of global warming and environmental degradation. Fire emits a significant amount of carbon from the biosphere into the atmosphere. It is estimated that global carbon emissions from fires are between 2-4 Gt per year (Seiler and Crutzen 1980, van der Werf *et al.,* 2010). It contains mixture of gases, but carbon dioxide (CO_2) is the most abundant, along with carbon monoxide (CO) and methane (CH_4).

Ethiopia, located in the horn of Africa, is a country potentially gifted with huge amount of hydro, wind, geothermal and solar power potentials. However, only a small portion of these resources has been utilized so far. Traditional biomass fuels accounted for 92% of the total energy consumption whereas modern fuels constituted the remaining 8% (MoWIE, 2012). According to IEA (2015), in 2013, the per capita total primary energy supply in Ethiopia was merely 0.51 toe while it was 0.67 toe, 4.2 toe, and 1.9 toe for Africa, OECD countries and the world average, respectively. Thus, in conditions of unaffordable and escalating prices of imported oil, inaccessibility of electricity and increasing scarcity of fuel-wood, the option for the majority of the population would be increasing use of animal dung and crop residues for fuel.

Biogas provides an attractive option to replace unsustainable utilization of traditional biomass fuels. It complies with the principles put forward in the country's Energy Policy and Environmental Protection Strategy, Promoting improved bio-energy conversion technologies. It is a local, renewable resource that addresses the basic needs of rural households amongst which energy; it supports decentralized access to household energy; its by-product enhances agricultural productivity and promotes organic farming, thus offering opportunities for niche markets and export (MoWIE, - 2012). It saves the household economy by reducing fuel-wood, charcoal and kerosene expenses (Yitayal 2011). Biogas reduces greenhouse gas emissions by reducing the smoke from traditional energy sources (Pathak *et al.*, 2009).

Biogas was introduced in Ethiopia around 1957 Ambo Agricultural College (Amera, 2010). To promote the uptake of domestic biogas, the first phase of national biogas programme was established in Oromia, Amhara, SNNP and Tigray regional states. However, the rate of dissemination was very slow, even if Ethiopia has a technical potential of 1.1 million domestic biogas digester construction (Eshete and Kidane, 2008), the number of digesters disseminated up to the end of 2013 is about 9,000; 1000 digesters and 8,000 digesters before and after 2008, respectively. Situation in SNNPR is also similar even if the first biogas digester was installed as early as 1976 in Agricultural College‘s compound of Woliyta Soddo town. Despite the numerous benefits of the technology, its dissemination remains low and its potential has not been well defined (Desalegn, 2014).

Therefore, this study attempted to investigate socio-economic and environmental contribution of biogas technology adoption and its determinants in Arbaminch Zuria Woreda, Gamo Zone of southern Ethiopia.

1.2 Statement of the Problem

More than one-third of people in the world start life without access to electricity and clean fuels for cooking, heating and lighting. Bioenergy accounts for roughly 9% of world total primary energy supply today. Over half of this related to the traditional use of biomass in developing countries for cooking and heating, using inefficient open fires or simple cookstoves (IEA, 2017).

Traditional biomass fuels consumption in Ethiopia is one of the highest in the world. It contributes 92% of total energy consumption in the country (MoWIE, 2012). The situation in SNNPR is much worse than the country's profile. Regionally, traditional fuels provide 99.8% of the total (rural and urban) domestic energy supply, with 88% derived from woody biomass, 10% from crop residues, 1% from dung and 0.1% from charcoal (Eshete and Kidane 2008).

Consumption of biomass fuel is not by itself an issue but once the resources are reaped unsustainably; there are severe adverse effects on the environment and economic development. Household productivity is being affected by the reallocation of time and labor from yield bearing activities to the collection of biomass energy, which have led to reduced rural economy (Amare, 2015). The cost of purchasing fuels adds financial burden to poor households with scarce income. Deforestation increased as a result of fuel-wood extraction to meet the energy demand for the rural and urban residents, also fuel-wood contributes to

GHG emissions through unsustainable harvests and incomplete combustion of biomass. A potential option towards reducing both urban and rural demand for fuel-wood, crop residue, charcoal and kerosene is through switching to use renewable energies.

Ethiopia has been disseminating biogas technology as an alternative renewable energy source to reduce excessive dependence on fuel-wood and other forms of biomass. However, with a technical potential of 1.1 million of rural households, only a small percentage of (0.8%) of the potential households are benefiting from domestic biogas (PID, 2014). According to Eshete and Kidane (2008), SNNPR state would have the technical potential of constructing about 152,000 household biogas plant installations. However, only 4343 biogas plants have so far been established by governmental bodies and different NGOs (The regional WIEB performance report, 2019). In Arbaminch zuria woreda, only 173 household installed biogas technologies (The woreda Sector performance report, 2016). Eventhough these efforts, it is not clear why some households in the study area adopt the technology while many others do not adopt. It is also not examined how biogas contributes for the socio-economic status of biogas user environmental sustainability.

Therefore, thorough understanding factors affecting households' decisions of biogas technology adoption in rural Ethiopia, and to what extent the biogas installations, which have been built up to now, have contributed to the sustainable rural livelihood and environment are relatively important for the next successful plans and dissemination action. Limited studies have been done on biogas technology in Ethiopia (Nigussie *et al.,* 2016; Abayneh and Tasew 2017; Kamp and Forn 2016; Kelebe *et al., 2*017; Desalegn 2014). However, none of these studies provided due attention to the socio-economic and environmental contribution of dissemination of domestic biogas, and factors affecting households' decisions of biogas technology adoption in the study area.

Therefore, this study has attempted to examine factors affecting households' decisions on adoption of biogas technology, and socio-economic and environmental contributions of biogas technology in Arbaminch Zuria woreda, southern Ethiopia.

1.3 Objectives

1.3.1 General objective

To investigate the socio-economic and environmental contribution of biogas technology adoption and its determinants in Arbaminch Zuria Woreda, Gamo Zone of southern Ethiopia.

1.3.2 Specific objectives

- To quantify the contribution of adoption of biogas technology on the socio-economic status of the biogas users.
- To measure the environmental benefits of adoption of biogas technology.
- To examine factors affecting households' decisions of biogas technology adoption.

1.4 Research Questions

1. What are the socio-economic contributions of biogas technology on user households?
2 To what extent does biogas technology reduce GHG emissions?
3 What are the major factors influencing households' decisions on adoption of biogas technology?

1.5 Significance of the Study

Ethiopia have a potential to use as a feedstock for biogas production and reduce the over dependency of fuel-wood and other forms of biomass help to reduce the greenhouse gas emissions which may be affecting the climate change, but so far the technology not adapted to the expected level. Large-scale investment in biogas energy technology requires first an assessment of its socio-economic and environmental impact as an alternative source of energy.

The finding of the study may be used as inputs for decision-making by the policy makers, planners, non-governmental organizations and implementers of bio-energy technologies and other projects of similar nature. In addition the study may bring in to light more evidence and add to the excising knowledge of biogas technology to other researchers and donor agencies.

1.6 Scope and Limitation of the Study

Conceptually, this research was limited to quantifying socio-economic contributions of biogas technology on user households, measuring environmental benefits of adoption of biogas technology and examining factors affecting adoption of biogas in Arbaminch Zuria Woreda, Gamo Zone of Southern Ethiopia. The economic benefits of biogas technology such as Cost of biogas investment include installation, operational and maintenance costs, employment generation have not been considered. To analyze the Environmental Benefits of adoption of Biogas technology in reducing GHG emission only three most potent GHGs namely, CO_2, CH_4 and N_2O were considered.

2 LITERATURE REVIEW

2.1 Definition and Concept

Fuel-wood is part of a tree or shrub which is ready to be used as fuel (Mulu, 2016). Traditional biomass fuels are types of energy sources that are locally available and produced, and require no high level of conversion. They include fuel-wood, charcoal, cow dung and crop residues. They may simply be called traditional fuels or biomass fuels.

Biogas is a combination of two word; bio meaning living matters and gas the product as a result of the decomposition of the biodegradable materials. It comprises 50 to 70 % of methane (combustible gas); 30 to 40 % carbon dioxide; 5 to 10 % hydrogen; 1 to 2% nitrogen; 0.3 % water vapour, hydrogen sulfide, and other trace gases by volume (Lam *et al.*, 2009).

Slurry: These are the remains in the digester after anaerobic process and can be used as manure in agriculture.

Technology adoption as stated in Rogers (1995) is a process in the mind that ranges from hearing and gathering information of technology, developing interest, evaluating its attributes, to making eventual decision of either acquiring for use or rejecting it out rightly.

2.2 Overview of Global Energy Consumption and Sources of Energy

World energy consumption is projected to grow by 56% between 2010 and 2040, from 524 quadrillion British thermal units (Btu) to 820 quadrillion Btu. Most of this growth will come from non-OECD (non-Organization for Economic Cooperation and Development) countries, where demand is driven by strong economic growth (EIA, 2013).

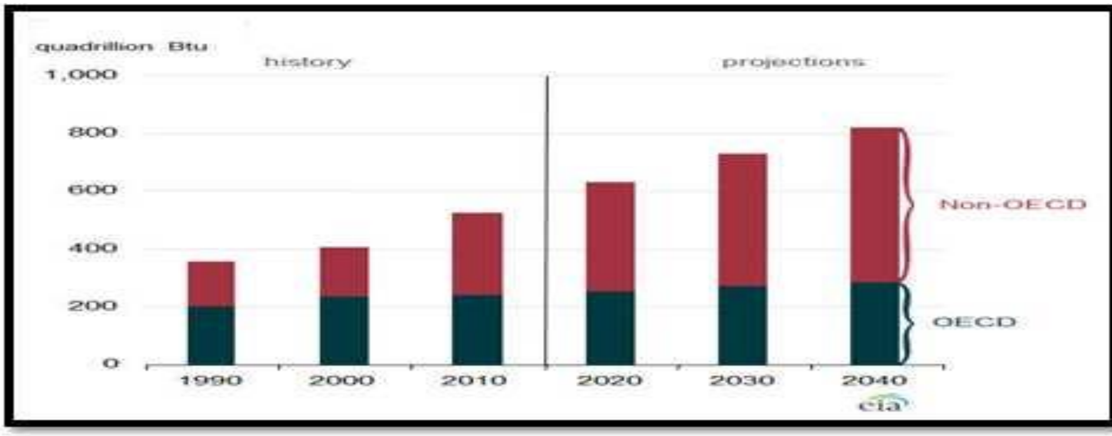

Figure 1: World total energy consumption 1990-2040
Retrieved from: www.iea.org.

About 2.4 billion people have no access to electricity and rely heavily on unsustainable biomass energy to meet their energy needs (IEA, 2008). The situation is not different in Africa, where figures for Eastern and Southern African countries indicate that a high proportion of total national energy supply is derived from the diminishing biomass energy (Karekezi, 2002). Biomass energy, such as wood, charcoal, agricultural residues and animal waste, is often used in its traditional and unprocessed form. According to the IEA (2008), even oil rich African countries like Nigeria continue to rely on 97 percent biomass energy to meet their bulk household energy requirements.

The demand for biomass energy has increased due to increasing population, such over-reliance on primary biomass energy led to widespread exploitation of forest resources with adverse impacts on the environment and economy (Kirai, 2009). Globally, 55% of the wood extracted from forests is for fuel, and fuel-wood is responsible for 5% of global deforestation (UNFCC, 2010). Statistics suggest that some 1.86 billion m^3 of wood is extracted from forests for fuel-wood and conversion to charcoal. Of this total, roughly one-half comes from Asia, 28% from Africa, 10% from South America, 8% from North and Central America and 4% from Europe.

Also, the WHO (2018) highlight that, 4 million deaths annually are associated with household air pollution from inefficient cooking practices using polluting stoves paired with solid fuels and kerosene. In addition, burning of biomass discharges carbon dioxide, methane and other greenhouse gases leading to global warming hence climate change (WHO, 2009). Therefore, the energy sector has a significant part to play in reducing the environmental damage and harmful effects by introducing renewable and green energy sources to supply modern cooking fuels.

Energy policies in developing countries have traditionally focused on large capital investments and urban populations, whilst rural populations and their energy requirements are frequently overlooked (World Bank, 2007). Nevertheless, many rural areas do have local access to other sources of energy, such as solar energy and biogas technology. There are opportunities for these resources to be tapped using existing technologies and thereby release a range of useful services and meet the energy needs of the rural communities.

Climate change, together with an increasing demand for energy, volatile oil prices, and energy poverty have led to a search for alternative sources of energy that would be economically efficient, socially equitable, and environmentally sound. Cleaner energy systems are needed to address all of these effects (NEMA, 2009)

2.3 Biogas Energy

Biogas fuel is colourless, odourless and flammable gas due to presence of methane and hydrogen (Jorgensen, 2009). The biogas does not produce smoke, it is clean and easy to use compared with other solid fuels. During its production of biogas fuel, the process includes three stage biochemical processes that is hydrolysis, acetogenesis and methanogenesis (Ofoefule *et al.,* 2010). It comprises 50 to 70 % of methane (combustible gas); 30 to 40 % carbon dioxide; 5 to 10 % hydrogen; 1 to 2 % nitrogen; 0.3% water vapour, hydrogen sulfide, and other trace gases by volume (Lam *et al.*, 2009). The primary end use application of domestically produced biogas is cooking; however, especially in remote rural areas where electrification does not exist, biogas is also used for illumination purposes. The residue of the biogas process, bio-slurry, can be collected relatively easy and can be used as organic fertilizer and soil improver (Ghimire, 2013).

2.4 Design of Biogas Plants

There are different types of biogas reactors used throughout the world. Three major types of digesters are used in developing countries for livestock waste, such as the Chinese fixed dome digester, the Indian floating drum digester and balloon (or tube) digesters (Plochl and Heiermann, 2006). Digesters are mainly sized to be fed by human and animal waste from one household and to deliver the energy demand of the household. Floating drum digesters are normally made from concrete and steel, whereas fixed dome digester are constructed with various available materials, such as bricks. The most developed domestic biogas biodigester technology in Africa and Asia is the fixed dome digester (Eshete and Kidane, 2008). In fixed dome digester the waste enter through the inlet and after digestion process the gas accumulates in the upper part of the fixed dome and the slurry settle at the bottom due to gravity. As more gas is produced it builds up pressure which pushes the slurry in to the collection chamber through the outlet.

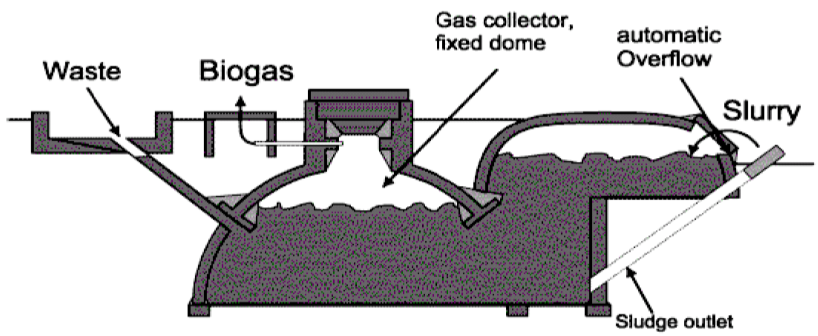

Figure 2: Fixed - dome biogas digester
Source: IRENA, 2016b

Balloon digesters are manufactured from folded polyethylene foils, with porcelain pipes as inlet and outlet. The principle of these digester designs is very much the same. Raw material enters through the inlet pipe either directly or after a mixing pit. Biogas is collected above the slurry before leaving through an outlet pipe for utilization (Sasse, 2014).

2.5 Global Outlook of Biogas

Biogas technology is very popular in this region especially in China, India and Nepal. China reported 17 million existing biogas users in 2005, up from previous reports of 12 million (Renewable Global Status Report 2006). By the end of 2010, the total number of domestic biogas installations reached 40 million (Dong, 2012). Biogas remains a priority in India, with about 3.8 million household-scale biogas plants were installed in 2005, up from previous reports of 3.7 million (Renewable Global Status Report 2006). By the end of March 2011, the number of its domestic biogas installations reached 4.4 million.

The benefit of biogas to generate electricity is on the rise as well, with production increasing an estimated 7 percent during 2008. Biogas is used for electricity generation mainly in OECD countries, with some 30 TWh produced in the OECD in 2008. Germany passed the United States in biogas-generated electricity in 2007 and remained the largest producer in

2009; it is also the world's largest generator of electricity from liquid biomass, at 2.9 TWh in 2007.The number of German biogas plants increased by 570 in 2009, to nearly 4,700, and associated capacity rose by 280 MW to 1.7 GW; total domestic production was an estimated 9–12 TWh of electricity. In 2008, United States generated some 7 TWh with biogas, followed by the United Kingdom at 6 TWh and Italy at 2 TWh (Renewable global status report 2010).

Diffusion of biogas across Africa to comply with safe environmental and sanitary conditions, large, medium and household biogas digesters has been installed in several African countries. It includes countries like Burundi, Botswana, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Namibia, Nigeria, Rwanda, Zimbabwe, Tunisia, Morocco, Tanzania, South Africa and Uganda. (Mulida *et al.*, 2013). The total numbers of biogas installations constructed up to 2011 in nine African countries, namely: Rwanda, Ethiopia, Tanzania, Kenya, Uganda, Burkina Faso, Cameron, Benin and Senegal summed up 24,990 (SNV, 2013).

2.6 Status of Energy and Biogas Technology in Ethiopia

Ethiopia is potentially gifted with various energy resources; the gross hydro-energy potential of the country is about 650 TWh per year, of which 25% could be exploited for power production (CESEN, 1986). The most promising hydropower development potential is found in the Blue Nile, Omo, and the Wabi Shebelle river basins (MEDaC, 1999). The energy potential of the country so far discovered comprises between 30 and 50 billion m^3 natural gas, more than 1000 MW geothermal power, and several hundred million tons coal and oil shale (Mariam, 1992). The total solar radiation reaching the territory is 2.3 TWh per year while wind energy potential is estimated at 4.8 million Tcal per year (CESEN, 1986). Country's energy regime is dominated by biomass energy (Eshete *et al.,* 2006) and traditional fuels contributed 92% of the rural energy consumption, with fuel-wood being by far the most dominant source (81.8%), followed by dung (9.4%), crop residues (8.4%) and small amount of charcoal (EPA, 1997). In general, over 97% of the domestic energy needs are met from bio-fuels (Anderson *et al.*, 1999).

In Ethiopia as a result of increasing consumption of woody biomasses to satisfy domestic energy needs, environmental degradation and climate change related challenges are imminent to occur (Lam and ter Heegde, 2011), also deforestation, loss of soil nutrients and organic matter would become intensive (Anderson *et al.*, 1999). To minimize this problem, the Ethiopian government Promote improved bio-energy conversion technologies including agro-industrial waste for thermal and power applications, biogas from urban, livestock and poultry waste. However, inadequate energy infrastructure, coupled with the sparse nature of rural settlements, would be a critical challenge for both technical and economic reasons (MoWIE, 2012).

Over 77% of agricultural families in rural areas in Ethiopia own livestock (EREDPC, 2008), and most farming households are eligible for the installation of biogas digesters as they have the capacity to collect adequate volume of animal manure that can also be used for the production of biogas. Properly managed, animal dung collected at household level can have the potential to fill gaps in household energy needs through the production of biogas energy and thereby reduce the demand for fuel-woods (Subedi *et al.,* 2014). Therefore Biogas can help to solve many of the problems that are associated with traditional biomass fuels.

But, there was limited success in the technology penetration (EREDPC, 2008). Within the period 2008 to 2014, there was a plan by the national biogas program of Ethiopia (NBPE) to install 15,100 domestic biogas digesters at national level. The technology uptake was sharply rising during the inception period followed by a rapid decline and only 63% of the plan was achieved (NBPE, 2015).

2.7 Benefits of Biogas

2.7.1 Socio - economic benefits of biogas

Seadi *et al.* (2010) outlined the economic and social benefits of biogas production. Economic benefits include solid waste treatment without long term follow up coast incurred duo to soil and water pollution. The social and health effect associated with biogas include soil improving fertilizer, decreased Oder and reduce the number of scavenger.

The use of biogas technology at the household level helps to empower women by reducing and alleviating the drudgery of fuel-wood collection. Amare (2015) in Ethiopia found that biogas installation makes each biogas households to save on average 144 minute per day from fuelwood collection, cooking, cleaning kitchen materials. According to Wondyfraw (2015), 90% of fuel consumption (wood, agricultural residue, dung cake) has decreased especially for cooking wot and boiling of (potato, maize, peas, beans) and 100% of fuel (wood, agricultural residue, dung cake) has decreased for coffee preparation. Gosaye and Abrham (2018) reported that, the average amount of fuel-wood saved by the biogas adopter households was 1066.8 kg/year. A study by Mwakaje (2008) in Tanzania revealed that households with biogas were saving 3-4 hours per day that was previously used in fuel-wood collection A study carried out in Nepal revealed that households that used biogas energy for their cooking had their respiratory diseases, eye infection and headaches decreased by approximately 40% for women and 20% for male (Katuwal and Bohata, 2009).

Biogas presents an opportunity to move towards more decentralized forms of electricity generation where a plant is designed to meet the needs of the local consumers, avoiding transmission losses and increasing flexibility in system use, which in turn provides an opportunity to increase the diversity of power generation plants and competition in energy generation within the economy (Erdogdu, 2008). Biogas could savings the household economy by reducing fuel-wood, charcoal and kerosene expenses. According to Claudia and Yitayal (2011) the maximum amount of money saved by the biogas user households from fuel-wood, charcoal and kerosene replacement is 4493 ETB/year.

2.7.2 Environmental benefits of biogas

2.7.2.1 Greenhouse gas emission reduction through substituting traditional biomass burning with biogas

Unsustainable utilization of biomass for cooking and heating increase greenhouse gas emissions, there is needed to find out better alternative clean fuel to meet our needs. Biomass (animal dung and crop residues), if used for biogas production in a anaerobic digestion process, can be a major source of renewable energy and reduce greenhouse gas emissions by reducing the smoke from traditional energy sources of cooking and improving management of manure and biogas residues.

The biogas digester employed (4500) reduce about 1984tonnes of CO_2e of GHG emissions per year (Gabisa and Gheewala 2019). Biogas technology has a great potential to reduce greenhouse gas emissions (GHG) through substituting fuel-wood for cooking, Kerosene oil for lightning and cooking and chemical fertilizers (Pathak *et al.*, 2009).

Katuwal (2009) illustrated that as a result of family sized biogas plants; there is enormous reduction in the fuel-wood, dung cake and sawdust, amounting to approximately 53%, 63% and 99% respectively. This is a satisfactory and significant step to reducing GHG emissions. A Household biogas plant in India has a capacity of 9.7t of CO2 e/year Global Warming Potential (GMP). This is further estimated that household biogas plant can achieve carbon credit of US $ 97/year by reducing greenhouse emissions under clean development (CDM) project (Pathak *et al.*, 2009). According to Tajebe (2016), about 66,463 tons of biomass and 485 tons of fossil fuel were substituted with the total implemented biogas plants. This leads to the reduction of 64,684 tons of CO2e per annum due to the introduction of biogas technology.

2.8 Technology Adoption

Adopting a technology mentioned by Manros and Rice (1986) include absence of users' involvement, lack of understanding, technical difficulties, lack of training and ineffective support from top management and perceived technology complexity. Adopting a technology according to Abukhzam and Lee (2010) depends on many factors which cause a prospective or targeted user to adopt or reject the technology. These factors include absence of users' involvement, lack of understanding, technical difficulties, lack of training and inefficient support from top management and perceived technology complexity.

2.8.1 Theoretical frameworks for technology adoption

2.8.1.1 Diffusion of innovation theory

This theory developed by Rogers (1995) is the most widely recognized technology adoption framework. The Theory suggests three categories of determinants of technology adoption, these include characteristics of an innovation, individual categories and communication channels. The characteristics of an innovation which may influence its adoption include relative technology advantages such as ease to use, cost saving, efficiency and convenience. Compatibility, complexity and observability and triability of an innovation are other technology characteristics which, according to Rogers (1995), play a significant role in the adoption of an innovation. Rogers Theory further considers the categories of adopters as determinant of technology adoption. Rogers (1995) and Feder *et al.*, (1985) classify members of a social system into five adopter categories. These are innovators, early adopters, early majority, late majority and laggards. These categories follow a standard deviation-curve, very few innovators adopt the innovation in the beginning (2.5%), early adopters making up for 13.5% a short time later, the early majority 34%, the late majority 34% and after some time finally the laggards make up for 16%.

Innovators are venturesome individuals in a social system, who is very eager to try new ideas, have substantial financial resources and the ability to understand and apply complex technical knowledge. They are also capable of coping with a high degree of uncertainty and play an important role in importing new ideas. They are regarded as the first to adopt a new idea (Rogers, 1995, Feder *et al.,* 1985).

Early adopters are more integrated into the social system than innovators. Members of this category are said to speed up the diffusion process and are the ones from whom potential adopters seek advice and information about the innovation since they find it necessary to make judicious innovation decision (Lionbergen and Gwin, 1991). According to Rogers (1995) this category decreases the uncertainty about a new idea by adopting it and then conveying a subjective evaluation of the innovation to a near peer by means of interpersonal networks.

The early majority category of adopters comprises members who adopt the new idea just before the average member of the social system but after the early adopters. The members interact frequently with the peers but they seldom hold leadership positions unlike early adopters. This category links the very early adopters and the relatively late adopters in the diffusion process. The innovation decision period of early majority is relatively longer than that of the innovators and early adopters (Feder *et al.*, 1985).

Late majority are the members of the social system who adopt innovations relatively late. The members of this category adopt the innovation after the majority of people in the society have adopted. The adoption by this category has been described to rely on economic necessity and peer group pressure (Rogers, 1995).

Laggards are the last group in a social system to adopt innovations, according to Rogers (1995) these people posses no opinion leadership and are the most localized in their outlook. The individuals often make decisions in terms of what has been done in previous generations and interact primarily with others who also have certain traditional values. It can therefore be argued that laggards tend to be suspicious of innovations and change agents (Msuya 1998).

2.9 Determinants for Adoption of Biogas Technology

There are a lot of studies that assess the factors that affect adoption of biogas technology technologies. Education level had significant influence on biogas adoption (Erick *et al.*, 2018). Kalinda (2019) illustrated that lack of awareness and limited information on the benefits and potential of biogas technology among some of the farmers is major hurdle faced by the extension agents in their biogas extension services. Gender of household head significantly affected adoption of biogas technology (Mbali *et al.,* 2018). Adoption was more welcome if a house hold had experienced increased economic status since they could be able to afford the initial cost of a biogas plant (Walekhwa *et al.*, 2010). In a study carried out for sub-Saharan Africa Lettinga (2004) concluded that the investment cost of even the smallest of the biogas units is prohibitive for most rural households due to extreme poverty in the region. Mwirigi *et al.* (2009) also showed that the household's socioeconomic status influences adoption but it did not significantly influence the long term utilization of a biogas digester.

Technical problems associated with installations of biogas plant (Quadir *et al.*, 2010). This is due to the fact that at the start-up phase after the biogas plant has been installed, problems like odor nuisance, low methane productions are experienced (Van Der Werf, 2010). Low end use awareness and lack of post installation service had discouraged some people from adopting biogas (Obwogi, 2014). Biogas technology requires space in terms of the area for constructing the biogas plant and providing pastures for the cattle needed to provide the feed stock, thus the area owned is a necessary determinant of biogas adoption as established by (Walekhwa *et al.*, 2010).

Reviews by Gitonga (1997), indicates that lack of credit schemes to help farmers to acquire biogas plants, is another barrier that hinders the adoption of biogas technology. Njenga (2013) observed that male headed households are more likely to adopt biogas than female headed households because men dominate and control access to resources.

Some potential users are reluctant to try biogas technology out of concern about sanitation. Use of human wastes and animal dung's for biogas production and the subsequent digested sludge as a source of fertilizer faces cultural and health resistance in Ghana (Amigun *et al.*, 2008). In addition, lack of coordination among institutions and conflicting interests has been cited as other obstacles inhibiting good penetration of biogas technology into the African market (Laichena, 1997). Mengistu *et al.* (2016) in Ethiopia found that male-headed households were more likely to adopt biogas technology compared to female headed households.

2.10 Empirical Review

In Ethiopia, Kelebe *et al.* (2017) reported that years of education of household head was found to be positively and significantly ($P = 0.05$) related with the biogas adoption. As the level of education increases by one year, the odds ratio of biogas adoption increases by a factor of 1.14. This is perhaps due to the fact that households with no formal education are more likely to be laggard their domestic needs and thus may be inclined to adopt biogas technology. Abayneh and Tasew (2017) reported that, the age of the household head was found to have negative and a statistically significant at ($p < 0.05$) relation with the households' decision on adoption of biogas technology. Older ages of household heads appeared to have lesser probability of adopting biogas technology than the younger households were less likely to adopt biogas technology by a factor of 0.06 as compared to the young-counterpart.

A study conducted by Getachew (2016) in Northern Ethiopia pointed out that cattle holding was found to be a significant ($p < 0.01$) factor that affect adoption of biogas technology positively. The finding stated that for each additional unit of cow, the probability of adopting biogas technology increases by a factor of 1.99. A study conducted by Mengistu *e.t al* (2016) in Northern Ethiopia reported that Biogas technology generally assisted in reducing the overall household workload by 13.3 hours per week (1.9 hours per day) at $p<0.01$significant level.

Also a study conducted by Shegenu and Seyoum (2018) in Southern Ethiopia pointed out that non-adopter households consume on average 2058kg biomass (fuel-wood and crop residue) annually but for adopter households is 991.20kg per household. There was a considerable saving adopter over non-adopter households by 1066.80kg (51.8%) of biomass (fuel-wood and crop residue) per year per household.

2.11 Conceptual Framework

The conceptual framework (Figure 3) gives a diagrammatic representation of the variables in the study. Socio-economic factors such as sex, age, education level and family size determine an individual's ability to access information, perception and knowledge which in turn influence one's decision to adopt biogas technology or not adopt.

The framework also shows the influence of institutional factors in adoption of the biogas technology. The study makes an assumption that government institutions in particular can influence the adoption of biogas technology through financial support.

Factors related to the environment include accessibility to water and fuel-wood. The study makes an assumption that the willingness of individual household to adopt biogas technology in addition influenced by these factors.

Therefore, based on the interaction of all the above mentioned factors, households can acquire knowledge and awareness on biogas technology, and develop attitude towards using the technology, and finally may decide to adopt and start the actual use of the technology.
Once biogas technology is adopted, sustained and efficient utilization of the technology can lead to various development outcomes. Some of the major sustainable development outcomes may include: Saved costs of fuels, saved time and reduced GHG emissions.

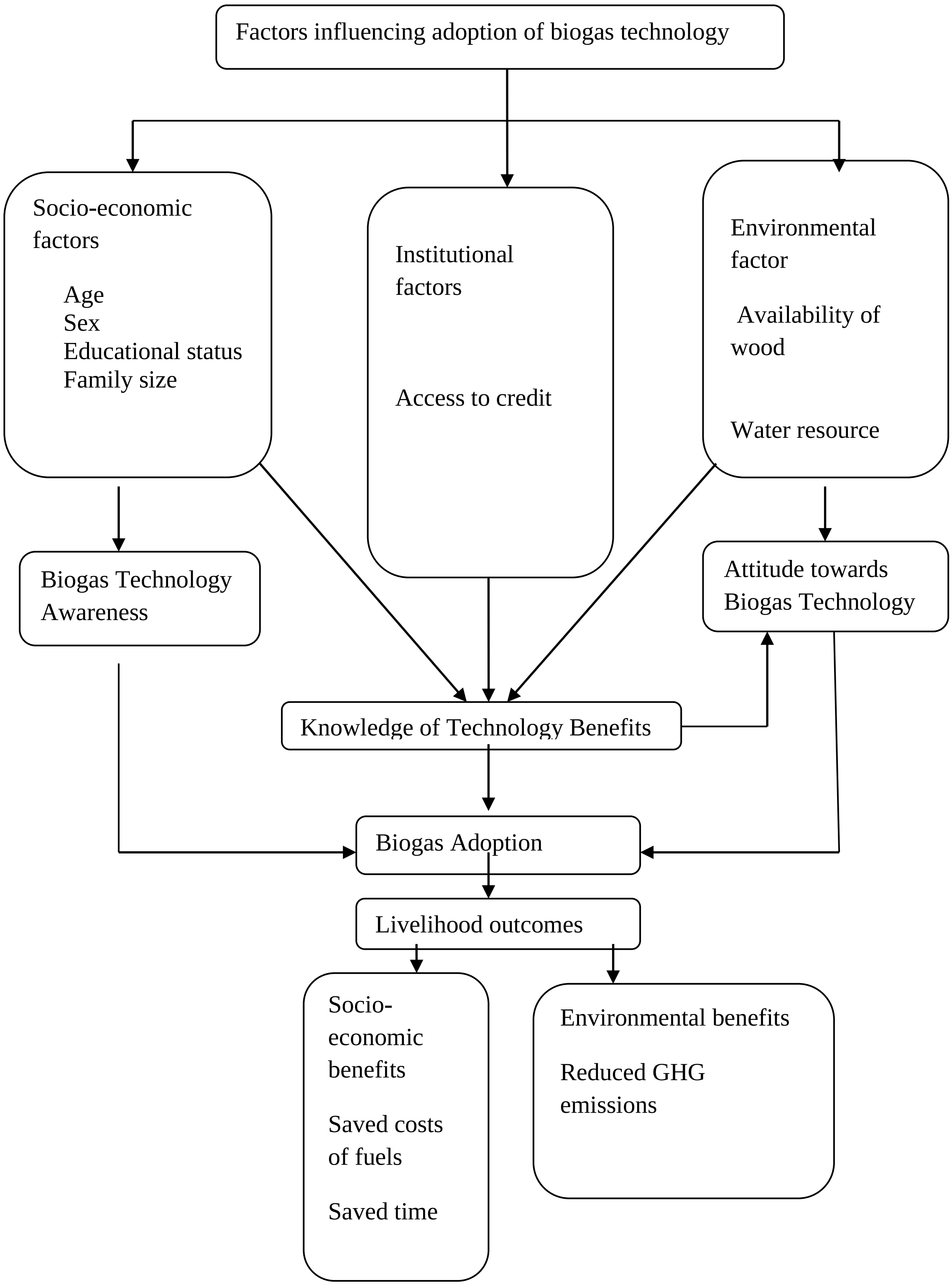

Figure 3: Conceptual framework
Source: Own, 2019

3 RESEARCH METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

Arbaminch Zuria is geographically located between 6^0 05’ N to 6^0 12’ N and 37^0 33’E to 37^0 39’ E, it is a part of Gamo Zone 400 km south of Adiss Ababa. The altitude varies between 1200 - 3050 meters above sea level.

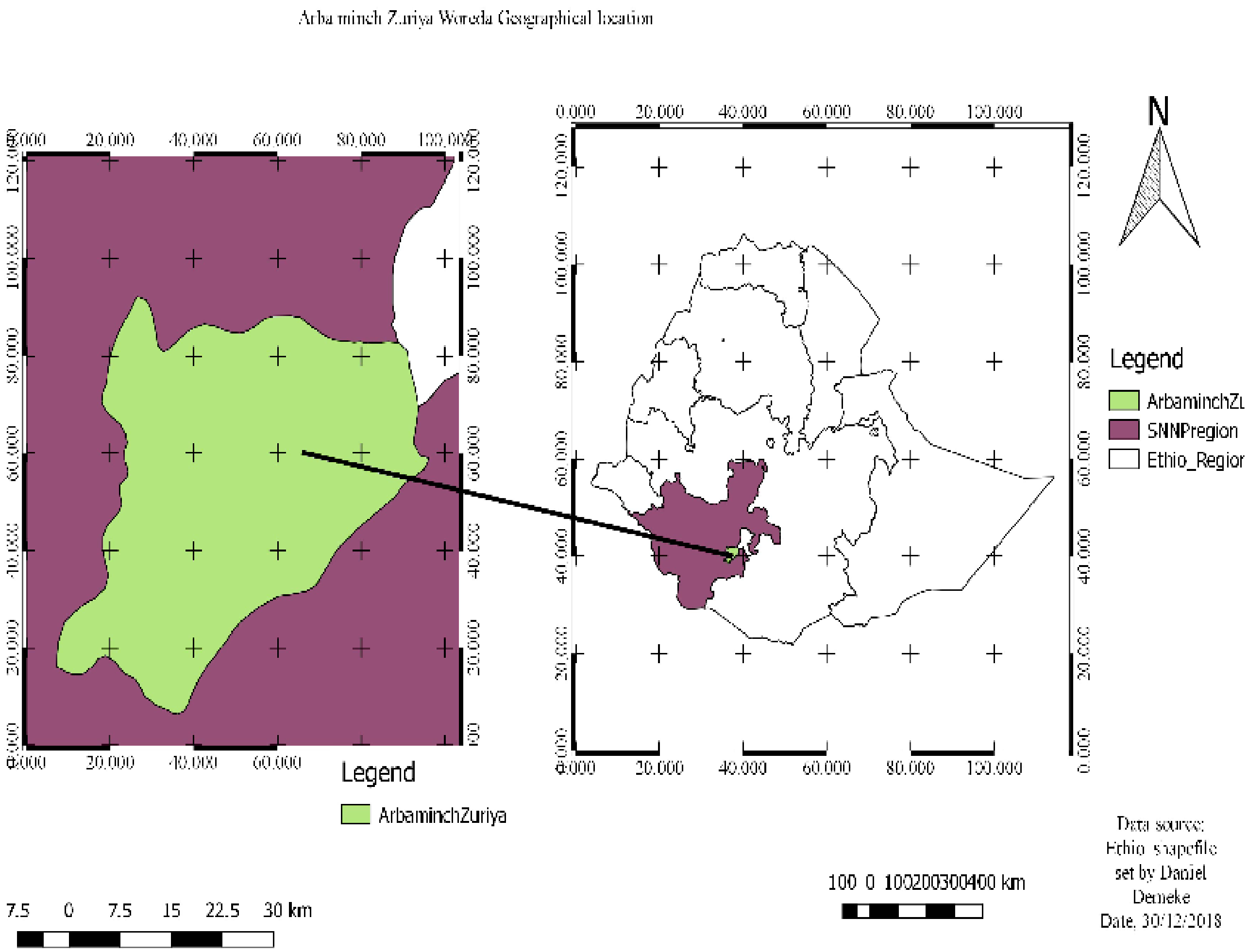

Figure 4: Map of study area

3.1.2 Topography

The Arbaminch Zuria is one of the woredas in the Southern Nations, Nationalities, and Peoples' Region of Ethiopia. A part of the Gamo Zone located in the Great Rift Valley; Arbaminch Zuria is bordered on the south by the Dirashe woreda, on the west by Bonke, on the north by Dita and Chencha, on the northeast by Mirab Abaya, on the east by the Oromia Region, and on the southeast by the Amaro woreda. A total of 188,890 peoples live in 38,604 households. The number of persons per household is 4.9. (BoFED, 2012).

3.1.3 Socio economic characteristics

The Arbaminch Zuria woreda is known for its high potential in tropical fruit production (mainly mango, banana, lemon and papaya). The area contributes 10% to 15% of the estimated 135,000 tones of national fruit production. The potential is much higher and supply to the Addis Ababa market could be as high as 40% of the total amount delivered to the Capital City (http://en.wikipidia.org/wiki /Arba Minch). The woreda has a total of 29 kebeles.

3.2 Sampling Techniques and Sample Size

For this study, a three stage sampling procedure was followed to select adopter and non-adopter households. At first stage, Arbaminch Zuria Woreda was purposively selected due to presence of large number of biogas installations. Then, out of the 29 kebeles found in the Arbaminch Zuria Woreda three kebeles were purposively selected due to presence of relatively largest number of biogas within the woreda. At the second stage, households of the selected Kebeles were stratified, based on adoption characteristics into two groups, namely, adopters and non-adopters of the biogas technology. A list of biogas technology adopter and non-adopter household heads in the selected kebeles was collected from the Arbaminch Zuria Woreda water, mine and energy office. Due to homogenous socio-economic characteristics of the population in the study area, the number of sample households for both adopter and non-adopter of the target population at 92% confidence level and 0.08 (8%) level of precision, were determined by using a simplified formula developed by Yamane (1967)

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

Where "n" is the sample size, "N" is the targeted population size, and "e" is the level of precision (0.08). $n = \frac{113}{1+113(0.08)2}$ = 66 (biogas adopter households) and $n = \frac{4284}{1+4284(0.08)2}$ = 151 (biogas non- adopter households)

At the third stage, probability proportional to size (PPS) sampling technique was employed to calculate the number of sample sizes in each kebele. Finally, sample households were randomly selected for the household survey.

Table 1: Distribution of sample size in each selected kebeles

Kebeles	Total number of households		Sample size		Total sample size
	Adopter	Non–Adopter	Adopter	Non–Adopter	
Shara	49	1691	29	60	89
Chano mile	41	1158	24	41	65
Lante	23	1435	13	50	63
Total	113	4284	66	151	217

3.3 Data Sources and Types

Both primary and secondary data were collected to achieve the objectives of the study. Primary data was linked to, factors affecting household's decisions on adoption of biogas technology, contribution of adoption of biogas technology on the socio-economic status of the biogas users and environmental benefits of biogas technology. Secondary data were collected from water, mine and energy office of the district, kebele administration offices, different published and unpublished sources including books, journal articles, web sites, etc.

3.4 Data Collection Methods

Various methods were used to collect both qualitative and quantitative data. These include structured and semi-structured household survey, key informant's interview, focus group discussion and direct observations. Additional fuel mass measurement data were collected.

3.4.1 Household survey

Detailed information was gathered through households' survey using face-to face interview. Questionnaire was prepared in English language and translated in to Amharic language to collect information related on demographic characteristics, access to water, amount of household energy consumption by type and access to fuel-wood. Both structured and Semi-structured questionnaires were used.

3.4.2 Key informant interview

Experienced and knowledgeable persons such as Keble's development agents (DAs) who participated in biogas technology promotion, biogas masons and district's senior energy experts, who had essential information on biogas technology, was purposefully selected.

Then semi-structured interviews were prepared to identify the main factors affecting household's adoption decision of biogas technology.

3.4.3 Focus group discussion

The advantage of this method is it helps to focus on group norms and dynamics around the issue being investigated. Also useful in verifying and clarifying information and filling in gaps of information caused by inadequate information gathered from the key informant interview and household survey. In this study, FGDs were conducted among the people comprising 8 participants in each group. The members of focus group were selected from both adopters and non-adopters of biogas technology in each selected kebeles. It assists to gather information about, contribution of biogas technology on farmer's livelihood, barriers to adoption of biogas technology, status of fuel-wood, access to water and availability of institutional supports. The checklist was prepared to conduct focus group discussions.

3.4.4 Direct observation

Direct observations were used to acquire information about type and quality of biomass fuels gathered, existence of biogas plants, current status of biogas installations. The information gathered using observation was used to counter-check information provided by household respondents and focus group participants.

3.4.5 Energy quantification

The amount of traditional biomass fuel consumption was collected in terms of local measurement units like the number of bundles, sacks or baskets of fuels consumed per week and later converted into kg/week then kg/year. The averages of these local measurements were taken. These helps to estimate the weekly amount of biomass fuel consumption of each sample household. Finally, for easier comparisons between the consumptions of various fuel types, the gross weight or volumes of each fuel type were converted into equivalent heating values expressed in joules as shown Table 2.

Table 2: Thermal values of biomass and other household energy sources

Fuel type	Thermal values
Air dried fuel-wood	15.5 MJ/ kg
Charcoal	29.0 MJ/ kg
Air dried crop residue	15.0 MJ/ kg
Kerosene	36.0 MJ/ L

Sources: WBISPP Amhara, 2002; WBISPP Oromiya, 2002; WBISPP Tigray, 2003

3.5 Method of Data Analysis

The data was analyzed by using descriptive and inferential statistics. The descriptive statistics included: averages, percentages, and inferential statistics encompassed binary logistic regression. Independent and dependent samples t-tests were also employed to analyze the collected data. The data was coded and entered into the Statistical Package for Social Sciences (SPSS) for analysis.

To analyze the underlying factors determining households' decisions on adoption of biogas technology, binary logistic regression model was employed. In the binary logistic regression analysis biogas adoption status of households was considered as dependent variable. If the household installed biogas technology, then it is considered as "adopters" and coded as "1" and the non-adopters were coded as "0". Taking the natural log of odd of adopting, the model is given as:

$$\ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \cdots \qquad + \beta_n X_n \text{ -------------------------------------- (2)}$$

Where P_i is the probability of adopting biogas technology

1-P_i is probability of not adopting

$\frac{P_i}{1-P_i}$ is odd of adopting

Z_i is logit of adoption.

β_o is an intercept

β_i is vector of coefficients

X_i is vector of predictors/ factors

To analyze the environmental benefits of biogas technology adoption in reducing GHG emission only three most potent GHGs, namely, CO_2, CH_4 and N_2O were considered. The global warming potential of CO_2, CH_4 and N_2O over a 100 years' time horizon 1, 25, and 298 IPCC (2007), respectively were utilized in this study. The emission factors were taken from IPCC (2006) as shown in Table 3.

Table 3: GHG emission factors in mg/MJ by fuel type

Fuel type	CO_2(mg/ MJ)	CH_4(mg/ MJ)	N_2O(mg/ MJ)
Fuel-wood	112,000	300	4
Charcoal	112,000	200	1
Crop residue	100,000	300	4
Kerosene	71,900	10	0.6

Source: IPCC, 2006

The mass of GHG emissions from the combustion of the use of a given fuel types 'a' in CO_2e were calculated according to (Mengistu *et al.*, 2016)

$$E_a = \sum_{i=1}^{n}(C_i \times EF_{CO_2} \times GWP_{CO_2} + C_i \times EF_{CH_4} \times GWP_{CH_4} + C_i \times EF_{N_2O} \times GWP_{N_2O})$$

--- (3)

Where, Ea = GHG emissions in kg from the combustion of fuel type 'a'

n = total number of sample households

C_i = amount of fuel consumed by a sample household 'i'

EF_{CO2} = CO_2 emission factor for fuel type ‘a’

EF_{CH4} = CH_4 emission factor for fuel type ‘a’

EF_{N2O} = N_2O emission factor for fuel type ‘a’

GWP = Global warming potential for the GHG indicated.

GHG emission reductions obtained from the use of biogas energy were acquired through calculating the difference in GHG emissions before biogas adoption and after biogas adoption.

Although, the average annual emission of methane from the biogas digesters was calculated as follows:

$$EF_{CO_2e} = YG \times P_{CH_4} \times GW_{CH_4} \times R \quad (4)$$

Where, EF co_2e = average annual emission of methane from the biogas plants in kg CO_2e

YG = yearly average estimated biogas generation from the two digester sizes ($6m^3$ and $8\ m^3$) in kg, where the daily average biogas generation = $1.2\ m^3$ (EREDPC and SNV, 2008); and 1 m^3 biogas = 0.7 kg (Pathak *et al.*, 2009)

P_{CH_4} = volume fraction of methane content in biogas which is about 60 % (Eshete *et al.*, 2006; EREDPC and SNV, 2008)

GW_{CH_4} = GWP of methane in CO_2e which is 25 (IPCC, 2007)

R = Average estimated rate of emission of methane from the biogas digesters which is about 10%.

3.6 Description of Variables and their Expected Sign

Dependent variable: It is taken as the adoption of biogas technology. It was represented in the model by “1”if a household own biogas plant and “0” is otherwise.

Independent variables: The measurement and expected sign of selected independent variables are given below.

Table 4: Description of study variables

Variables name	Measurement	Expected sign/effect
Age of household head	Continuous	+/-
Sex of household head	Dummy (0 = female and 1= male)	+/-
Education level of household head	Continuous	+
Family size	Continuous	+
Availability of water	Dummy (0 = no and 1= yes)	+
Availability of fuel-wood	Dummy (0 = no and 1= yes)	-
Awareness on biogas	Dummy (0 = no and 1= yes)	+
Access to credit	Dummy (0 = no and 1= yes)	+

3.7 Diagnostic Tests

Before the variables were taken into the binary logistic model, it was necessary to check the existence of correlation problems among explanatory variables. Multicollinearity problem might cause the estimated regression coefficients to have wrong sign, smaller t-ratios for many of the variables in the regression and high Rj^2 value. For this study, the correlations among dummy explanatory variables were checked by the Contingency Coefficient (CC) test. Thus, if the value of CC is greater than 0.75, the variable is said to be collinear (Gujarati, 1995).

$$CC = \sqrt{\frac{x^2}{(n+x^2)}} \text{ --- } (5)$$

Where, x^2 is chi-square value and n is total sample size.

The results of CC tests were described under appendix 2.

The correlations among continuous explanatory variables were checked by Variance Inflation Factor (VIF) technique. The results of VIF tests were described under appendix 3.

4. RESULTS AND DISCUSSION

4.1 Socio-economic Characteristics of Respondents

Seven essential characteristics of respondents were considered for their influence with biogas technology adoption. These include sex of household head, age of household head, education level of household head, family size, availability of water, awareness on biogas technology and access to credit.

4.1.1 Age and biogas adoption: Finding in table 5 indicated that, the average age of the sample biogas adopter was 51.77 and 50.7 years for non-adopter household heads. The result was found to be statistically insignificant with a t-value of -0.458 and P-value of 0.648. Therefore, it can be concluded that there is no significant relation between household age and biogas adoption decision.

4.1.2 Education level and biogas adoption: The average education level was 8.95 and 4.57 for biogas adopter and non-adopter households, respectively. The result was found to be statistically significant. This is an indication that the level of education has a greater role to play in creating awareness of the technology. The result concur with those of Fabiyu and Hamidi (2011) who found out low levels of education act as a hindrance to technology adoption due to limited access to knowledge.

4.1.3 Family size and biogas adoption: The average Family size of biogas adopters and non-adopters were 7.84 and 5.62 persons/household, respectively. Large Family size may mean having sufficient labor required to manage and operate biogas technology. Or it may mean greater pressure on the household resources. The statistical result showed that there was significant mean different between family size of biogas adopters and non-adopters (Table 5).

Table 5: Socio-economic characteristics of respondents (n=66 adopter, and n=151 non adopter) variables

Variables	Adopters		Non-adopters			
	Mean	SD	Mean	SD	t-test	p-value
Age of HHH	51.77	15.83	50.7	15.85	-0.458	0.648
Education level of HHH	8.95	4.31	4.57	4.02	-7.2	0.000***
Family size	7.84	3.12	5.62	2.61	-5.42	0.000***

*NB: *** indicates 1% level of significance.*

4.1.4 Sex and biogas adoption: The household survey analysis revealed that out of the 217 household head interviewed, 138 were Male in which 40 of them were biogas technology adopters and 98 of them are non-adopters while 79 were Female in which 26 are biogas technology adopters and 53 of them are biogas technology non-adopters.

Therefore, it can be concluded that there is an insignificant relationship between sex of household head and biogas technology adoption decision.

Table 6: Sex of household head and Biogas technology adoption

	Biogas technology					
	Adopters		Non-Adopters		Total	
Sex	Freq.	%	Freq.	%	Freq.	%
Male	40	60.6	98	64.9	138	63.6
Female	26	39.4	53	35.1	79	36.4
Total	66	100	151	100	217	100

4.1.5 Availability of water and biogas adoption: Finding in table 7 indicated that the majority of sample population 90.3% had access to water supply. On the other hand, the proportion of biogas technology adopters with short supply of water sources was 3 % while for non-adopters was 12.6 %. This shows that an availability of water source was not a factor influencing households' decision for adopting biogas technology.

Table 7: Availability of water and Biogas technology adoption

		Biogas technology					
		Adopters		Non-Adopters		Total	
Variable	Responses	Freq.	%	Freq.	%	Freq.	%
water availability	Yes	64	97	132	87.4	196	90.3
	No	2	3	19	12.6	21	9.7
	Total	66	100	151	100	217	100

4.1.6 Awareness and biogas adoption

Table 8 shows that out of 217 surveyed households, 145 were not aware on biogas in which 128 of them were biogas technology non adopters and 17 of them are adopters while 72 were aware on biogas in which 23 are biogas technology non adopters and 49 of them are biogas technology adopters. This implies that majority of non adopters households in the study area were not aware on biogas technology.

Therefore, it can be concluded that there is significant relationship between awareness and biogas technology adoption decision.

Table 8: Awareness and Biogas adoption

Variable	Responses	Biogas technology: Adopters Freq.	%	Non-Adopters Freq.	%	Total Freq.	%
Awareness	Yes	49	74.2	23	15.2	72	33.1
	No	17	25.8	128	84.8	145	66.9
	Total	66	100	151	100	217	100

4.1.7 Access to credit and biogas adoption

As it can be seen from the Table 9, 68.1 % of biogas adopters had access to credit, whereas 13.2 % of the non-adopters had access to credit. This implies that access to credit motivate the household to adopt biogas technology. Access to credit will enable the poor and empower households interest in the adopting the technology.

Therefore, it can be concluded that there is significant relationship between access to credit and biogas technology adoption decision.

Table 9: Access to credit and Biogas adoption

Variable	Responses	Biogas technology: Adopters Freq.	%	Non-Adopters Freq.	%	Total Freq	%
Access to credit	Yes	45	68.1	20	13.2	65	30
	No	21	31.9	131	86.8	152	70
	Total	66	100	151	100	217	100

4.2 Benefits of Biogas Technology to the Socio-economic Status of the Biogas Users

4.2.1 Benefits from fuel-wood consumption replacement

The weekly average fuel-wood consumption of the biogas adopter households before adopting biogas technology was 43.77Kg. This number went down to 22.65Kg after biogas usage (Table 10).

Due to the installation of biogas plant, there is an annual reduction of fuel-wood consumption approximately 1101.26Kg per year per household. Additionally, using biogas as a source of fuel has promoted financial capacity of the users. It provides each biogas user households an equivalent saving of 1824.62 ETB per year per household at local rate of birr 41.62 per 25.12kg of fuel-wood. Also 17069 MJ of energy was saved per household annually. These variations certainly resulted from the use of an energy efficient biogas technology.

The statistical result shown that there was a highly significance mean different between fuel-wood consumption of biogas adopter households before adopting and after adopted biogas technology ($p<0.01$).

Table 10: Weekly fuel-wood consumption before and after biogas installation

	Minimum	Maximum	Mean	Std. Deviation	t-value	p-value
Fuel-wood consumption before adopting biogas	.00	100.48	43.77	25.23		
Fuel-wood consumption after adopted biogas	.00	125.60	22.65	22.38	5.885	0.000***

*NB: *** represents1% level of significance*

A previous study conducted in Aletawondo woreda, Sidama Zone, Southern Ethiopia reported that, the average amount of fuel-wood saved by the biogas adopter households was 1066.8 kg/year (Gosaye and Abrham 2018). Alemneh (2011) reported that, the average amount of fuel-wood saved by the biogas adopter households was 1730.1 kg/year with the equivalent amount of money saved is ETB 1903.11/year.

4.2.2 Benefits from charcoal consumption replacement

The weekly average charcoal consumption is 11.79kg/household (HH) and 4.20kg /household (HH) before adopting and after adopted biogas technology (Table 11). Therefore, due to the installation of biogas plant there is an annual reduction of charcoal consumption approximately 395.84 kg per year per households and provides each biogas households an equivalent saving of 1275.59 ETB per year at local rate of 62.71 birr per 19.46 kg of charcoal. Also 11479.36 MJ of energy was saved per household annually.

The statistical result shown that there was a highly significance mean different between charcoal consumption of biogas adopter households before adopting and after adopted biogas technology ($p<0.01$).

Table 11: Weekly charcoal consumption before and after biogas installation

	Minimum	Maximum	Mean	Std. Deviation	t-value	p- value
Charcoal consumption before adopting biogas	.00	58.38	11.79	14.15		
Charcoal consumption after adopted biogas	.00	19.46	4.20	6.874	5.642	0.000***

*NB: *** represents1% level of significance*

Similar results were reported by Amare (2015), who found out that after household biogas investment, 324 kg of charcoal is fully replaced by biogas. This amount of charcoal provides each biogas households an equivalent saving of 1243.2 ETB.

4.2.3 Benefits from crop residue consumption replacement

According to the result point of view as shown in (Table 12), the consumption of crop residue also decline from13.08kg/household before biogas to 9.52kg /household per week. Due to household biogas investment, 106.972kg of crop residue was saved per year per households. As a result, 1604.58MJ of energy was saved per household annually.

The statistical result shown that there was a significance mean different between crop residue consumption of biogas adopter households before adopting and after adopted biogas technology ($p<0.01$).

Table 12: Weekly crop residue consumption before and after biogas installation

	Minimum	Maximum	Mean	Std. Deviation	t-value	p-value
Crop residue consumption before adopting biogas	.00	51.56	13.08	16.53		
crop residue consumption after adopted biogas	.00	51.56	9.52	12.61	3.639	0.001***

*NB: *** represents1% level of significance*

4.2.4 Benefits from kerosene consumption replacement

The study showed that in the surveyed area, the weekly average kerosene consumption of the biogas adopter households before adopting biogas technology was 0.43L. While after adopted biogas technology was 0.25L respectively (Table 13).

Therefore, the biogas adopter households after adopted biogas technology were able to save annually kerosene consumption by 9.49L/HH. This shows that Birr 237.25 was saved annually at local retail market rate of Birr 25/L of kerosene per household. As a result, 341.64 MJ of energy was saved per household annually.

The statistical result shown that there was a significance mean different between kerosene consumption of biogas adopter households before adopting and after adopted biogas technology ($p<0.01$).

Table 13: Weekly kerosene consumption before and after biogas installation

	Mini mum	Maxim um	Mean	Std. Deviation	t-value	p-value
Kerosene consumption before adopting biogas	.00	4.00	.43	.843		
Kerosene consumption after adopted biogas	.00	3.00	.25	.583	3.263	0.002***

*NB: *** represents1% level of significance*

A previous study conducted in Ethiopia by Wondyfraw (2015) reported that the average reduction in the use of kerosene is in the order of 4 liter (80 birr) per HH per month. Therefore, biogas plant owners are getting an annual savings of 48 liter (960 birr) of kerosene per HH per year. The amount of kerosene and money saved in the study area was small; the difference is may be due to the biogas adopter households of this study were used additional energy source in addition to kerosene lamp for light in the area before adopting biogas technology.

4.2.5 Benefits biogas technology in reduction of time spent for fuel-wood and crop residue collection.

The study reveals that after installation of biogas plant it reduced the work load of the family members, especially of the female members. It has saved the time of fuel-wood and crop residue collection.

Table 14: Reduction of working time per week by work category

Category of work	Before biogas installation	After biogas installation	Saving time
Fuel-wood collection	1.88	0.97	0.91
Crop residue collection	3.81	2.30	1.51
Total	5.69	3.27	2.42

The women and children of the respondent family spent an average of 5.69 hours a week in fuel-wood and crop residue collection before biogas installation whereas they have saved an average of 2.42 hours per week after installation of biogas plant.

A previous study conducted in north Ethiopia reported that, the average times taken for cooking food, cleaning utensils and kitchen, and collecting wood-fuel and its preparation for use were reduced by 12.8 hours, 3.1 hours, and 0.6 hours per week, respectively and the technology generally assisted in reducing the overall household workload by 13.3 hours per week (1.9 hours per day) (Mengistu, 2016).

The time consumed in collecting fuel-wood and charcoal carried out by women and children results less time available for education. This means as the study revealed that women can allocate the saved time to other activities such as other household works, social works, agricultural activities, and other income generating activities.

However, Amare (2015) report that, biogas installation makes each household to save on average 51 min/day from fuel-wood collection, cooking, cleaning utensils/kitchen materials. The sensible reason for this difference could be because of collecting fuel-wood and preparing it for use, collecting dung and feeding the biogas, cooking food, cleaning utensils and kitchen were not considered in this study.

4.3 The Environmental Benefits of Biogas Technology

4.3.1 Role of biogas technology in GHG emission reduction

4.3.1.1 GHG Emission Reductions from the reduced use of fuel-wood, charcoal, crop residue, and kerosene

The study showed that in the study area, biogas technology produce a great potential to reduce greenhouse gas emissions by substituting traditional biomass and kerosene. There was a considerable reduction of GHG emission by 2.4t of CO_2e per year per household.

Table15: GHG emissions and emission reduction in Kg of CO_2e before and after biogas installation

Fuel type	GHG emissions in kg CO_2e		Emissions reduced (a-b)
	Before adopting biogas technology(a)	After adopted biogas technology(b)	
Fuel-wood	3591.22	2209.009	1382.21
Charcoal	2091.91	745.24	1346.67
Crop residue	548.58	399.15	149.43
Kerosene	59.65	34.97	24.68
Total	6291.36	3388.37	2902.99

The average annual GHG emissions are 6.3t CO_2e before adopting biogas technology and 3.4t CO_2e after adopting biogas technology. Without consideration of the problem of leakages and other means of gas releases during biogas production, the technology helped in reducing GHG emission by about 2.9t of CO_2e per digester annually.

But 10% of the methane generated was assumed to be emitted. Therefore, the average annual emission of methane from the biogas plants is 460 kg of CO_2e. Thus, the net annual average GHG emission reduction per unit biogas installation can be 2.4 t of CO_2e T

he result of this study is higher than the finding of Gosaye and Abrham (2018) in Ethiopia illustrated that the average annual GHG emission reduction per domestic biogas installation (about 2.2 tons of CO_2e per annum). Also Mengistu *et al.,* (2016) in Ethiopia revealed that the net annual average GHG emission reduction per unit biogas installation has a capacity 1.9 t of CO_2e.

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Moreover, the result of this study is smaller than the finding of Amare (2014) in Ethiopia which report the net annual average GHG emission reduction per unit biogas installation has a capacity 3t of CO_2e. Davis (2013), in Tanzania reported relatively higher amount of average GHG emission reduction per domestic biogas installation (about 6.4 tons of CO_2e per annum). Also Pathak *et al.,* (2009) in India reported (about 9.7 tons of CO_2e per annum). The main justification for this variation could be associated to the efficiency of the biogas plants under consideration in generating biogas energy. This result was in line with study of Shrestha (2010) in Nepal reported that, the average amount of GHG emission reduced per biogas installation was estimated to be about 2.4t of CO_2e per annum.

4.4. Factors Affecting Biogas Technology Adoption

In the previous section, factors affecting rural households' biogas technology adoption decision were analyzed using descriptive statistics. Further, to understand the extent to which these factors affect biogas technology adoption decision, binary logistic model was employed.

Multicolinearity problem was tested using CC and VIF technique, and the data set show absence of a multicollinearity problem (presented in appendex 2 and 3). To assess the usefulness of the model in indicating the amount of variation in the dependent variable, the Cox & Snell R Square and the Nagelkerke R^2, described as pseudo R^2 statistics were tested. Since R^2 was found 0.571, the model was fitted.

Table 16: Logistic regression estimation result

Variables	B	S.E.	Wald	Sig.	Exp(B)
Age of household head	.008	.013	.376	0 .540	1.008
Sex of household head	.077	.441	.030	0.862	1.080
Education level of household head	.121	.058	4.357	0 .037**	1.129
Family size	.158	.076	4.304	0.038**	1.171
Availability of water	1.107	1.071	1.069	0.301	3.026
Availability of fuel-wood	-1.345	.524	6.588	0.010**	.261
Awareness	1.877	.468	16.083	0.000***	6.533
Access to credit	1.345	.463	8.446	0.004***	3.837
Constant	-4.537	1.322	11.788	0.001	0.011

*NB: *** indicates significant at 1% and ** indicates significant at 5%*

Educational level of household head: It was found to have a statistically significant ($p < 0.05$) positive influence on adoption of biogas technology. This can be explained by the fact that education helps in improving beliefs and habits which in turn creates favorable mental attitude for acceptance of new practices.

This is consistent with a previous finding of Yektiningsih *et al*. (2019) reported that, education level and adoption of biogas technology are positively related. Also Mulu (2016) reported that positive association between education level of household heads and adoption of biogas technology. Similar finding Surendra *et al.* (2014) showed that lack of education is among the most critical factors that limits the dissemination of biogas technology in economically less developed countries. Also Momanyi (2015) revealed that level of education of household head positively correlated with biogas adoption. To establish biogas technology as a viable and long-lasting option, it is quite essential to educate the people about the socio-economic, health, and environmental benefits of the technology (Landi *et al.*, 2013).

Family size: It was found to have a statistically significant ($p < 0.05$) positive influence on adoption of biogas technology. This can be explained by labor availability due to the fact that biogas technology requires labor force for biogas plant operations. Biogas plant operation involves activities like collecting cow dung, feeding the biogas plant, cleaning the cow shed and ferrying the slurry to the farm. This finding is in line with Wang *et al.* (2012), who reported that, size of household members could influence adoption in case where a large household size is viewed as additional help especially in providing labor for routine operation and maintenance.

Availability of fuel-wood: It was found to have a statistically significant ($p < 0.05$) negative influence on adoption of biogas technology. The shortage of fuel-wood implies that people will have to look for alternative energy sources which are more efficient for domestic use. This is consistent with, Legesse (2011) in Enderta district found that as the distance from the head of the household home to both wood and dung collection have negative influence on the consumption of modern source of energy decision of households.

Perception of households towards biogas technology: Awareness of the technology involves people getting information about the technology: what it is, how it functions and its advantages to influence people's decisions on its adoption. The coefficient on biogas awareness was positively and significantly ($p < 0.01$) associated with biogas technology adoption (Table 16). This result indicates that households who have an opportunity to attend on awareness creation activities such as training, workshop, and seminar and demonstration are more likely adopt than household who never attended on such awareness creation activities.

This result was in line with study of Kalinda (2019) who showed that, Lack of awareness and limited information on the benefits and potential of biogas technology among some of the farmers is major hurdle faced by the extension agents in their biogas extension services. Similar finding Obwogi (2014) reported that, low end use awareness and lack of post installation service had discouraged some people from adopting biogas.

Access to credit: It was found to have a statistically significant ($p < 0.01$) positive influence on adoption of biogas technology. Access to credit enables the poor to be able to afford adoption of biogas technology. The result of the present study is supported by Mengistu *et al.* (2016) who reported that access to credit is a significant factor. It is likely to increase households' decision on adoption of biogas technology by a factor of 8.93. Similar finding Workalemahu and Hiwot (2017) reported that, access to credit is a significant factor to scale up adoption of biogas technology. Provision of subsidy to biogas construction is a temporal solution but to scale up adoption and dissemination of biogas technology over a wider market, access to credit is quite essential (Ghimire, 2013).

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Biogas energy was found to be a very fundamental resource to the adopter households. The technology showed great potential and real benefits for uplifting the livelihoods of adopting households. Among these benefits included; financial savings, time savings and energy saving which, overall helped to improve the welfare of adopting households. Biogas provided user households with clean, smoke free, locally available and instant energy, thereby eliminating or reducing the need for fuel-wood, Charcoal, Crop residue and Kerosene. This helped the households achieve huge financial savings that would have otherwise been used to purchase the fuels. An average household using fuel-wood, charcoal and Kerosene before the acquisition of the technology was able to save a total of ETBs 3337.46 annually upon shifting to biogas energy.

Time savings after acquisition and use of biogas technology was another significant benefit to technology adopters, since the need to go out to collect fuel-wood and other fuel like crop residue declined significantly. This saved time is utilized for social activities and productive purposes which definitely empower women.

Biogas technology is realized to have different environmental benefits. One of its promising benefits is GHG emission reduction. Through the substitution of traditional biomass fuels and kerosene alone, the technology on average reduces about 2.4 t of CO_2e annually. As a result, biogas minimizes GHG emissions, and hence assists the world climate change mitigation efforts via capturing methane and reducing use of traditional biomass.

The study identified a number of constraining factors that influence adoption of biogas technology in the study area, education level, family size, fuel-wood availability, awareness on biogas and access to credit has significant influence to determine households' decision on adoption of biogas technology.

5.2 Recommendations

Based on the findings of the survey the following recommendations have been proposed.

- ✓ Improving educational levels: For further promotion of the biogas technology, attention should be given towards improving educational levels of the household heads.
- ✓ Awareness creation on biogas technology: Lack of awareness was found to be the main barrier of biogas technology adoption decision. Any project office, political leaders, development agents and any other concerned bodies have to do more to raise awareness on biogas technology.
- ✓ Financial support: Since access to credit was found to be statistically significant determinant factor of biogas technology adoption decision, appropriate access to credit should be prepared for the rural and poor households.
- ✓ Given the GHG emission reduction potentials of the biogas technology, exploiting the existing carbon market can assist its further expansion.
- ✓ In this study, the dependent and independent variables were limited and therefore, further studies may be taken up based on situational and infrastructural variables.

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APPENDICES

Appendix 1: Questionnaire, Questions for Interviews and Focus Groups Discussion

Hawassa University

Wondogenet College of Forestry and Natural Resource

Department of Renewable Energy Utilization and Management

Dear Respondents,

I am student at Hawassa University and as part of my study program am required to undertake a study in my area of specialization and therefore, am undertaking a study to investigate socio-economic and environmental contribution of biogas technology adoption and its determinants in Arbaminch Zuria Woreda, Gamo Zone of southern Ethiopia. To this end you are kindly requested to answer the following questions.

Your response will be highly appreciated and will be treated with confidentiality and it will only be used for academic purposes.

Please do not enter your name or contact address on the questionnaire. Thank you for sparing your time to assist.

Part One: Household characteristics

1) Sex of household head   Male ( )   Female ( )

2) Age of household head in year_______________

3) Highest level of education of household head (No of class) ____________

4) Family size _____________

Availability of important resources

5) Are the following resources available in your area?

Resource	Availability (use key)
Water for domestic use Fuel-wood	

Key on availability of resources

(i) Yes (ii) No

Part Two: Awareness, utilization and adoption of Biogas

6) Do you have awareness about biogas technology? Yes ( ) No ( )

7) Have you been engaged in biogas production?

Yes ( ) No ( )

If NO to question 7 above go to question 8

If YES to question 7 above go to question 8 - 14

8) Do you have access to credit? Yes ( ) No ( )

9) For how long have you been engaged in biogas production?

0-5 years ( ) 5-10 years ( ) Above 10 years ( )

10) Are still engaged in biogas production?

Yes ( ) No ( )

11) If No give reasons if yes go to question 13

Lack of technical services ( )

Feeding related problems ( )

Lack of water ( )

Any other ____________

12) What is the size of your digester?

4m3 ( ) 6m3 ( ) 9m3( ) other______

13) What was the source of initial capital for construction of the biogas plant?

Own savings ( ) NGO support ( ) Government support ( )

Cost sharing with NGO or Government ( )

14) Are there regular campaigns for promotion of biogas technology in your area?

Yes ( ) No ( )

Part Three: For biogas user

Impacts of biogas on consumption of fuelwood and charcoal

15) Does your household ever use fuelwood? Yes ( ) No ( )

(If No, continue to Question 24)

16) If yes, how do you usually obtain the firewood that you use? Buy only ( )

Collect only ( ) Buy and Collect ( )

17) If you buy fuelwood, before the Biogas what is your monthly average expense (Birr)? ______________ . And ____________ Birr per bundle.

18) After the Biogas what is your monthly average expense (Birr)? ______________ And ____________ Birr per bundle.

19) If collect fuelwood, who is responsible person? Men ( ) Women ( ) Boy child ( ) Girl child ( )

20) From where do they collect the firewood?

a) ___________________

b) Distance? _____________km

21) How long does each trip to collect firewood take? ____________________hours, minutes

a) Before the bio-gester, how often do they go to collect wood? ____________trips per week

b) After the bio-gester, how often do they go to collect wood? ____________trips per week

22) Before the bio-gester on average human load, how many bundles of fuelwood do you consume per week? ________________

23) After the bio-gester on average human load, how many bundles of fuelwood do you consume per week? ________________

24) Does the household use charcoal for fue? Yes ( ) No ( )

25) If yes, before the bio-gester how many sucks or baskets of charcoal do you consume per month? ____________sucks or baskets.

26) After the bio-gester how many sucks or baskets of charcoal do you consume per month? ____________sucks or baskets.

27) From where does the household get charcoal? Purchasing ( ) Preparing by yourself ( ) Others, specify ______________

28) If you purchase charcoal, before the biogas what is your monthly average expense in birr? __________. And _____________ birr per suck or basket.

29) After the biogas, what is your monthly average expense in birr? __________. And _____________ birr per suck or basket.

30) If preparing by yourself, who is responsible person? Men ( ) Women ( ) Boy child ( ) Girl child ( )

31) Before the bio-gester, how much times they prepare charcoal? _____________ per week

32) How much does each preparation takes _______________ hours, minutes

33) After the bio-gester, how much times they prepare charcoal? _____________per week

34) How much does each preparation takes _______________ hours, minutes

35) Before the bio-gester how many sucks or baskets of charcoal do you consume per week? _____________sucks or baskets.

36) After the bio-gester how many sucks or baskets of charcoal do you consume per week? _____________sucks or baskets.

Impacts of biogas on consumption of Crop Residue, dung Fuel and kerosene.

37) Do you use crop residues for fuel? Yes ( ) No ( )

(If yes, continue to Q. #38 and if no, go to Q. #48)

38) How do you usually obtain the crop residues that you use? Buy only ( ) Collect only ( )

Buy and Collect ( )

49) If you buy crop residues, before the biogas what is your monthly average expense in birr? ___________. And ___________ Birr per bundle

40) After the biogas, what is your monthly average expense in birr? ___________. And ___________ Birr per bundle

41) If collect crop residues, who is responsible person? Men ( ) Women ( ) Boy child ( ) Girl child ( )

42) From where do they collect the crop residues?

a) ____________________

b) Distance? _____________km

43) How long does each trip to collect crop residues take? _____________________hours, minutes

44) Before the bio-gester, how often do they go to collect crop residues? ________trips per week

45) After the bio-gester, how often do they go to collect crop residues? _________trips per week

46) Before the biogas on average human load, how many bundles of crop residues do you consume per week? ________________

47) After the biogas on average human load, how many bundles of crop residues do you consume per week? ________________

48) After installation of biogas, does your household use dung fuel? Yes ( ) No ( )

(If yes, continue to Q. #49 and if no, go to Q. #51)

49) Before the biogas on average, how many baskets of dung fuel do you consume per week? ___________

50) After the biogas on average, how many baskets of dung fuel do you consume per week? ___________

51) Do you use kerosene for fuel? Yes ( ) No ( )

52) If yes, before the biogas how much litter of kerosene do you consume per month? --------.

53) After the biogas, how much litter of kerosene do you consume per month? --------.

54) Before the biogas what is your monthly average expense in birr? __________ And ____________Birr per litter.

55) After the biogas what is your monthly average expense in birr? __________. And ____________Birr per litter.

56) Do you think use of biogas saves time? Yes ( ) No ( )

❖ If yes, in terms of saving time, what are the main benefits of biogas installation?

a. Children have been enrolled in the school ( )

b. Reduce workload and stress for women and children ( )

c. Enable women to have more time for agricultural work ( )

d. Enable women to engage in income generating activities ( )

e. Reduce the need to get up earlier in the morning for cooking ( )

f. Others, specify ____

Part Four: Key Informant Interview Guide to Arba Minch Zuria District water, mine and energy officer

1) How long have you worked in the Water Mine and Energy office (in years) 0-5 ( ) 5-10 ( ) 10-15 ( ) over 15 ( )

2) How long have you been promoting biogas? ---------------

3) Did you take training about biogas?

Yes ( ) No ( )

4) When did you take training? --------------

5) What kind of support do you contribute for biogas adopters?

6) Is there sufficient water for biogas production in the area? If your answer is yes, what are the main sources?

7) How do you evaluate the current woodfuel availability of the area?

8) How do you evaluate access to credit in the area?

9) What are the key challenges and problems faced in your organization for slow dissemination of biogas technology?

Part Five: Key Informant Interview Checklist for Masons

1) Did you take biogas construction training?

Yes ( ) No ( )

2) How many biogas digesters have you constructed in the previous years?

3) Do you give maintenance services to any biogas users up on request?

4) In your opinion what are the major factors affect biogas adoption?

Part Six: Key Informant Interview Checklist for Development Agents

1) Do you have any involvement in the biogas technology dissemination?

2) How do you see the expansion of biogas installations in your locality?

3) What favorable and constraining factors are there to further promote biogas technology in the area?

4) Is there sufficient water for biogas production in the area? If your answer is yes, what are the main sources?

5) How do you evaluate the current woodfuel availability of the area?

6) How do you evaluate access to credit in the area?

Part Seven: Checklist for Focus Group Discussion

1) How do you evaluate the impacts of biogas technology on farmers‟ livelihoods?

2) With increased dissemination of biogas technologies, among the community and household members, who do you think getting more benefits?

3) Is there sufficient water in this region for biogas production?

4) How do you evaluate the current status of woodfuel in your locality?

5) What are the major factors affect biogas adoption?

6) Do the concerned institutions provide supports like financial, materials and training to the biogas adopter?

Appendix 2: Contingency Coefficient for Dummy Explanatory Variables

	Sex	Availability of water	Availability of fuel-wood	Awareness on biogas	Access to credit
Sex	1				
Availability of water	0.149	1			
Availability of fuel-wood	0.024	0.153	1		
Awareness on biogas	0.097	0.065	0.017	1	
Access to credit	0.049	0.177	0.014	0.448	1

Appendix 3:-Variance Inflation Factor of Continuous Explanatory Variables

Independent Variables	Tolerance	VIF
Age	0.993	1.007
Education Level	0.970	1.031
Family Size	0.973	1.028