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Role of Biogas in Saving Fuel Wood and Mitigating Greenhouse Gas Emissions in Gondar Zuria District, North Western Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

DEPARTMENT OF NATURAL RESOURCE MANAGEMENT

ENVIRONMENT AND CLIMATE CHANGE

MSc PROGRAM

**ROLE OF BIOGAS IN SAVING FUEL WOOD AND MITIGATING GREENHOUSE
GAS EMISSIONS IN GONDAR ZURIA DISTRICT, NORTH WESTERN ETHIOPIA**

Msc Thesis

By

Getaw Jejaw

Dec, 2023

Bahir Dar, Ethiopia

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Getaw Jejaw

**A Thesis Submitted in Partial Fulfillment of the Requirements' for the
Degree of Masters of Science (M.Sc.) in Environment and Climate
Change**

Advisor: Abebe Aschalew (PhD)

Dec, 2023

Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

As a member of the Board of Examiners of the Master of Science (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by Mister Getaw Jejaw Demlew entitled "Role of Biogas in Saving Fuel Wood and Mitigating Greenhouse Gas Emissions in Gondar Zuria District, North Western Ethiopia". We here by certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science (M.Sc.) in Environment and Climate Change.

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DECLARATION

This is to certify that the thesis prepared by Getaw Jejaw Demlew (ID No BDU1401320), entitled: **"Role of Biogas in Saving Fuel Wood and Mitigating Greenhouse Gas Emissions in Gondar Zuria District, North Western Ethiopia"** and submitted in partial fulfillment of the requirements for the Degree of Masters of Science in Environment and Climate Change complies with the regulation of the University and meets the accepted standards with respect to originality and quality. This thesis is my work and has not been presented for a degree in any other university or any other award.

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LIST OF ACRONYMS AND ABBREVIATIONS

AME	Adult Mean Equivalent
AGWT	Anthropogenic Global Warming Theory
CO ₂	Carbon Dioxide
CSA	Central Statistical Agency
CRGE	Climate Resilient Green Economy
°C	Degree Celsius
EREDPC	Ethiopian Rural Energy Development and Promotion Center
EU	European Union
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
FGD	Focus Group Discussion
Gt	Giga Tone
GtCO ₂ e	Giga Tone of Carbon Dioxide Equivalent
GHG	Greenhouse Gas
GWP	Global Warming Potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel for Climate Change
IRENA	International Renewable Energy Agency
KII	key informant interview
KPT	Kitchen performance test
MoARD	Ministry of Agriculture and Rural Development
MoWE	Ministry of Water and Energy
GWDO	Gondar Zuria Districts Agricultural Office

GDWMEO	Gondar Zuria Districts Water Mine and Energy Office
GWOFE	Gondar Zuria Woredas Office of Finance and Economic Development
IAP	Indoor Air Pollution
IEA	International Energy Agency
KWh	Kilowatt Hour
KWh/Sm ³	Kilowatt-Hour per Second per Meter Cubic
LPG	Liquefied Petroleum Gas
CH ₄	Methane
M ³	Meter Cubic
MtCO ₂ e	Million Tons of Carbon Dioxide Equivalents
Mtoe	Million Tons of Equivalent
NBPE	National Biogas Program of Ethiopia
OECD	Organization for Economic Cooperation and Development
SAE	Standard Adult Equivalent
UNEP	United Nation Environmental Policy

ABSTRACT

In our country, biogas energy has been disseminated since 1979; however, in North Western Ethiopia's Gondar Zuria District, biogas energy dissemination started in 2013. As a result, the actual data supporting the general effects of technology on the environment is few. Thus, in the Gondar Zuria District, North Western Ethiopia, this study investigated the role of biogas plays in reducing greenhouse gas emissions and preserving fuel wood. The cross-sectional survey design was used, and a multi-stage sampling process was used to select the respondents. To collect primary data, 181 households of whom 32 were adopters and 149 were non-adopters were surveyed. Eight key informant interviews, three focus groups discussion, and direct observation techniques were used. 40 randomly chosen households, 20 in each category, comprising both biogas adopters and non-adopters, were used for kitchen performance tests. Independent sample t-test and chi-square test were used to analyze the collected data. A binary logistic regression model was used to predict factors that influenced biogas adoption and utilization. The study's result revealed that there was a significant positive relationship with the adoption of biogas technology for the following variables at a 5% significance level: age, educational level, family size, cattle size, farmland size, awareness, and distance to fuel. However, the results on gender, income, and distance to the water source were not significant. Based on the kitchen performance test result, each biogas plant can potentially reduce greenhouse gas emissions by 4.7 tons of CO₂e annually. From 70 operational biogas plants, which results in a 329 tons reduction in CO₂e mitigated annually. As a result, producing biogas is crucial to reducing greenhouse gas emissions and preserving fuel wood. The study's conclusion suggested updating the current biogas technology model to incorporate several burner types for multi-cooking purposes.

Keywords: *Biogas, Climate Change, Fuel wood, Greenhouse Gases, Mitigation Potential*

CHAPTER 1: INTRODUCTION

1.1. Background of the Study

Energy is the primary input for almost all economic activities and has become vital for improvement in the quality of life (Chandrakar, 2015). Biomass is a traditional energy source of the most promising and alternative renewable energy. It is the main source of energy for rural households for cooking, lighting, and heating purposes (Komala and Devi, 2016). There are 2.6 billion inhabitants in developing countries, including 653 million individuals in Sub-Saharan Africa (Bekele *et al.*, 2016). Ethiopia is a developing country in Sub-Saharan Africa, with a population of about 67 million people who rely on biomass energy for cooking, heating, lighting, and hygiene (Bekele *et al.*, 2016). Ethiopia's energy economy is mostly reliant on biomass (firewood, charcoal, crop residues, and animal dung). In Gondar Zuria District, biomass is increasingly used for cooking, heating, and lighting purposes (GWWMEO, 2023). Over-reliance on biomass for cooking and heating is increasingly being linked to the release of toxic substances into the environment. This practice has been found to be the world's worst environmental threat to human health, causing 4 million fatalities each year (Lim *et al.*, 2012). Furthermore, the use of inefficient and unsustainable energy sources causes environmental degradation through forest and woodland deforestation, reduced agricultural productivity due to erosion and unbalanced rainfall regimes, and respiratory disorders due to smoke inhalation caused by carbon originating from incomplete solid fuel combustion (World Bank, 2006).

Greenhouse gases (GHGs) mainly CO₂, N₂O, and CH₄, are the primary contributors to climate change and climate change is a global challenge induced by anthropogenic activities (IPCC, 2007). Climate change, according to the UNFCCC, is defined as a change in climate-induced directly or indirectly by human activities that alter the composition of the global atmosphere. The lack of a modern energy system and technology causes households to become overly reliant on biomass. Two billion people are predicted to be without access to efficient clean energy services around the world. Hydropower, wind power, solar photovoltaic, biogas, ethanol, and biodiesel, as well as geothermal energy for heat and grid electricity, are now widely used in some locations and are being introduced in others in developing countries

(Flavin & Aeck, 2005). According to Flavin and Aeck (2005), using renewable energy has several advantages, including freeing women's time from survival duties, giving opportunities for money generation, reducing indoor air pollution, increasing health, and providing lighting and cooking for households. According to Thapa (2006), utilizing biomass-based energy resources through proper technological interventions is critical for environmental protection and sustainable rural development. Due to such problems, biogas produced from anaerobic digestion of organic waste materials, which helps to capture and utilize methane; by converting organic waste materials into biogas the process reduces methane emissions, which contribute to mitigating GHG emissions. Biogas is made up largely of methane and carbon dioxide and it is one of the most environmentally friendly and clean cooking technologies available (IRENA, 2017). As a result, the purpose of this study is to evaluate the role of biogas in fuel wood saving and greenhouse gas emission reduction in Gondar Zuria District, Northwestern Ethiopia.

1.2. Statement of the Problem

Biomass fuels (Fuel wood, animal dung and crop residues) are used to provide domestic energy needs in Ethiopia's rural and urban areas. Traditional energy sources (biomass fuels) are expected to provide 92 percent of all energy utilized in the country, with the remainder being met by modern energy (Ministry of Water and Energy, 2013).

More than 80% of the country's population lives in rural areas, and traditional energy sources are the primary energy sources (Nachmany *et al.*, 2015). Gondar Zuria District has 40 rural and 3 urban Kebeles; thus, the majority of rural households in Gondar Zuria District use biomass energy for cooking and heating (Gondar Zuria District Agriculture Office Annual Report, 2023). There was a huge demand for biomass; no one considered what these energy consumption practices deplete natural resources. This over-reliance on biomass has negative consequences, such as the production of hazardous particulate matter, deforestation, and environmental damage. Furthermore, there is no concern for energy conservation or the environment, and less emphasis is placed on the use of renewable energy technology.

Ethiopia has been promoting biogas technology as an alternative renewable energy source to reduce its over-reliance on biomass, including fuel wood. However, only a small portion (0.8%) of the 1.1 million rural households with technological potential are benefiting from

domestic biogas (PID, 2014). In Gondar Zuria District, only 121 households installed biogas technologies (Gondar Zuria Districts Water Mine and Energy Office Annual Report, 2023). The reason why certain households in the study area adopt the technology while many others do not adopt is unclear. Additionally, how biogas improves the socioeconomic status of users and their environmental sustainability is also not examined.

Previously studies were conducted on biogas technology from various parts of Ethiopia. As examples, consider the following: the role of biogas use in reducing GHG emissions in Fogera District, Northwestern Ethiopia (Zerihun Yohannes, 2014), did not state explicit methods for estimating the reductions in greenhouse gas emissions; The contribution of biogas to rural livelihood and environment in Ofla and Mecha Woredas, Northwestern Ethiopia (Mulu Getachew, 2016), did not estimate greenhouse gas emission reductions and saved amount of fuel wood; and pattern of biomass energy use and biogas domestication program in Ethiopia (Getachew Sime *et al.*, 2020), didn't carry out Kitchen Performance Test (KPT) Measurement and only evaluates traditional biomass energy system in Ethiopia. Yet, the researchers found roles of biogas, mainly; greenhouse gas emission reductions and fuel wood saving in separately. Thus, the purpose of this study was to fill these knowledge gaps.

The other drawbacks of the previous studies were focused on Southern part of Ethiopia. There are few studies done in Northwestern Ethiopia, Particularly no study has been done in Gondar Zuria District; this study was carried out to fill this gap.

1.3. Objectives of the Study

1.3.1. General objective

- The general objective of this study was to investigate the role of biogas in saving fuel wood and mitigating greenhouse gas emissions.

1.3.2. Specific objectives

- To quantify the percentage of fuel wood usage that can be reduced by using biogas technology in the study area,
- To quantify the amount of greenhouse gas emissions reduced in the study area by using biogas technology, and
- To determine the factors that influence biogas technology adoption in the study area.

1.4. Research Questions

1. How much fuel wood consumption was saved in the study area with the usage of biogas technology?
2. How much greenhouse gas emissions were reduced in the study area, as a result of the adoption of biogas technology?
3. What factors are influencing the study area's adoption of biogas technology?

1.5. Significance of the Study

These findings would be useful to the Gondar Zuria District environment and forest protection office, which would be able to provide information on the amount of greenhouse gases lowered each year due to the usage of biogas technology and useful to governmental organizations in providing enough information about the benefits of biogas technology to the rural population as well as environmental protection in the district. Furthermore, the findings of the study are also useful to the Gondar Zuria districts' water mine and energy office in terms of providing information on the benefits of biogas technology. The study is also expected to stimulate interest in additional research in the field of renewable energy sources, as well as promote new technological advancements in biogas production, efficiency, and quality.

1.6. Delimitations of the Study

The study was limited to investigating the role of biogas in saving fuel wood and mitigating greenhouse gas emissions in only Gondar Zuria District, Northwestern Ethiopia. This study was also limited to only 181 sampled households from the whole representative populations of the district.

CHAPTER 2: LITERATURE REVIEW

2.1. Global Energy Consumption and Energy Sources Overview

Implementing sustainable development and fulfilling the energy needs of the world's ever-growing population is a serious problem in the twenty-first century. According to the International Energy Agency, around 2.4 billion peoples lack access to electricity and rely on unsustainable biomass energy to meet their energy needs (IEA, 2008). Furthermore, forecasts imply that 1.4 billion peoples will be rely on biomass in 2030, based on current energy policy and investment trends in energy infrastructure (IGAD, 2007). Statistics suggests that, 1.86 billion m³ of wood is removed from forests for fuel wood and charcoal production. Around half of this total comes from Asia, with the remaining 28% coming from Africa, 10% from South America, 8% from North and Central America, and 4% from Europe (Karekezi 2002). In this scenario, a substantial amount of total national energy supply is produced from declining biomass energy, according to estimates for Eastern and Southern African countries (Karekezi, 2002). Ethiopia is one of the African countries that are now experiencing both commercial and non-commercial energy shortages. The issue at hand is how to lessen the rural poor's over-reliance on wood-fuel because they have limited access to alternate energy sources. Biogas is an energy technology that has the ability to mitigate many of the negative health and environmental effects associated with the country's traditional biomass energy sources.

Table 2.1: Worldwide fuel wood consumption

Continent	Fuel wood	Charcoal	Black liquor	Total
Africa	5633	688	33	6354
North America	852	40	1284	2176
Latin America	2378	485	288	3150
Asia	7795	135	463	8393
Europe	1173	14	644	1831
Oceania	90	1	22	113
Total	17921	1361	2734	22017

Source: FAO STAT, 2005

2.2. Ethiopian Energy Consumption Patterns

Ethiopia's existing energy sources can be divided into two categories: modern and traditional. Traditional energy sources include fuel wood, charcoal, manure, and crop residues, while modern energy sources include electricity and petroleum. Traditional biomass fuels accounted for 92% of total energy use in 2009, while modern fuels accounted for the remaining 8% (MoWE, 2011).

In Ethiopia, the household sector is the major consumer of energy and it accounts for 89.2 percent of total national energy use, with the remaining 10.8% split between agriculture, transportation, industry, and services (EREDPC and MoARD, 2002). According to MoWE (2011), household energy consumption accounted for 92.6 percent of overall energy consumption in 2009, while all other sectors together accounted for only 7.4 percent. Biomass fuel is more essential in the residential sector than in any other and it accounts for 98.6 percent of the total energy consumption. Fuel wood, dung, crop wastes, and charcoal account for 81.4 percent, 8.1 percent, 7.8 percent, and 1.3 percent of total household energy use respectively, whilst electricity and petroleum account for 1.4 percent (EREDPC and MoARD, 2002). In rural households, the contribution of biomass fuels is still higher than in urban households. Biomass fuels provide for 99.9% of the total energy consumption of the rural HH, according to EREDPC and MoARD (2003).

2.3. History of Biogas Technology in Ethiopia

Energy issues in Ethiopia have given a lot of attention in the past, but rural populations still don't have access to basic energy services. Rural communities do not have access to modern types of energy, while traditional energy sources are fast depleting, exacerbating the rural energy issue (EREDPC, 2007). Biogas was first introduced in Ethiopia in 1979, with the first batch type digester being built at the Ambo Agricultural College. It is a viable alternative to the unsustainable use of wood and charcoal. Around 1000 biogas plants have been built in various sections of the country over the previous two and a half decades (SNV, 2010).

A collaborative EREDPC/SNV team was formed in 2007 to write a program implementation document. More than 120 representatives of the government, non-governmental organizations, and the private and financial sectors gained awareness of the features and functions required for a national biogas program (NBP) and provided ample inputs for the

development of the program. The program's initial phase was implemented in chosen Woredas in the regional states of Oromia, Amhara, SNNP, and Tigray (SNV, 2010). Adaà, Dugda Bora, Hetosa, Ambo, and Kuyu in Oromia; Bahir Dar Zuria, Dembia, Gondar Zuria, Fogera, and Dangla in Amhara; Dale, Mareko, Meskan, Arba Minch Zuria, and Derashe Special Woreda in SNNPRS; and Hintalo Wajirat, Raya Azebo, and Western Tigray in Tigray (SNV, 2010). Nearly 859 biogas units have been built and are in regular service since the inception of the National Biogas Program Ethiopia in 2009. There are 859 operating biogas plants in Ethiopia, with 206 in Tigray, 143 in Amhara, 330 in Oromia, and 180 in the SNNP regional state (Getachew, 2016).

2.4. Factors Affecting Adoption of Biogas Technology

There are several issues that affect the adoption of biogas technology, to explain some: insufficient national policies, lack of credit and subsidy facilities (Mulu Getachew, 2016), lack of active involvement of the private sector, high initial investment costs (Amigun and Blottnitz 2010), technical and training constraints (Parawira, 2009), were among the major factors determining national biogas dissemination. Socioeconomic factors such as: educational level, income level, number of cattle owned, gender, farm land size, distance to firewood and water sources, access to electricity, had a significant influence on the decision of biogas technology adoption in Bangladesh (Kabir *et al.*, 2013), Kenya (Mwirigi *et al.*, 2014), and Ethiopia (Mulu Getachew, 2016).

2.5. The Relationship between Energy Consumption and Climate Change

Carbon-based fuels provide the majority of global energy, yet their emissions endanger the global climate, environment, human health, and the planet's life. The main causes of anthropogenic climate change are energy-related greenhouse gas emissions, which are aggravating global warming and environmental degradation patterns. Carbon dioxide, methane, and nitrous oxide are three primary GHGs (Wamuyu, 2014). Since 1990, global carbon dioxide (CO₂) emissions have increased by more than 46%.

Agriculture is estimated to produce 10% of anthropogenic CO₂, 40% CH₄, and 60% N₂O globally, according to the Intergovernmental Panel on Climate Change (IPCC). By reducing forest area and carbon standing stock, burning fuel wood could result in net CO₂ emissions. Unsustainable harvesting and incomplete biomass combustion add to GHG emissions from

fuel wood. Traditional charcoal production is expected to emit nine tons of CO₂ for every ton of charcoal produced (Wamuyu, 2014). Climate change is a growing hazard to lives and livelihoods in every corner of the world at present moment, driven by fossil fuel burning and deforestation (Ackerman, 2009).

Black carbon emissions from biomass combustion may increase climate change's consequences (Wamuyu, 2014). Despite major advancements in energy efficiency, the world's overall energy demand is estimated to be around 35 percent higher by 2030 than it was in 2005, it is due to projected economic and population growth. According to the IEA, worldwide energy consumption and annual CO₂ emissions were increased by about 50% since 1993. By 2010, the developing world's proportion of commercial energy use was predicted to reach about 40%. This is due to rapid industrial expansion and infrastructural improvement, high population growth and urbanization, and rising wages that allow for the purchase of energy-intensive appliances and cars, causing CO₂ emissions to rise even faster to around 45 percent of global emissions. Transportation, power generation, and heating and cooling for industrial and home reasons account for more than two-thirds of harmful greenhouse gas emissions in the energy sector. This means that the only way to maintain global warming within agreed-upon limits in the long run is to switch to low-carbon energy and improve energy efficiency (Federal Ministry, 2016). Energy-related greenhouse-gas emissions account for nearly two-thirds of all anthropogenic greenhouse-gas emissions, and CO₂ emissions from the sector have climbed steadily over the last century. As a result, effective action in the energy sector is critical to addressing the climate change problem (IEA, 2015).

2.6. Biogas for Reduction of Green House Gas (GHG) Emissions

The use of unsustainable wood for heating or cooking produces positive GHG emissions, whereas the use of biogas produces GHG emissions that are normally neutral (provided that organic materials used to feed the bio-digester are renewable and that there is no methane leakage from the plant). As a result, biogas plants can replace the usage of firewood or charcoal in countries where wood supply is unsustainable, resulting in lower GHG emissions (Rakotojaona, 2013).

2.6.1. Digester Size and Emissions Reduction

Agricultural bio-digesters reduce greenhouse gas emissions while also producing clean electricity (Clean Development Mechanism). Many variables influence emissions reduction, including digester design and size. In Nepal, Winrock and Eco-Securities (2004) discovered that a 6m³ biogas plant could reduce 5 tons of CO₂-equivalent per year (Biogas Support Programme, 2000). Shrestha *et al.*, (2003) found that biogas facilities with capacities of 4, 6, and 8 m³ reduced CO₂ emissions by 3, 4, and 5 tons per year, respectively. Furthermore, a study by Winrock and Eco-Securities (2004) found a carbon reduction of 4.6 tons of CO₂ equivalent per digester. Similarly, AEPC (2008) discovered that biogas reduces GHGs by 4.99 tons per year.

2.6.2. Roles of Biogas to Reduce Fuel Wood Consumption and Climate Change

Mitigation

Biogas is a feasible eco-friendly alternative energy to firewood for cooking, heating, and lighting. As a result, it decreases reliance on trees while increasing vegetation, resulting in a better environment (Adhikari, 2014). Biogas technologies can be adopted at both the micro and macro levels (Hamlin, 2012, Arlette and Franziska, 2012, Eba'a Atyi *et al.*, 2016) (Hamlin, 2012, Arlette and Franziska, 2012). Biogas has the ability to minimize interior air pollution, create energy for lighting and heating, and enhance sanitation by lowering infections, in addition to cooking (Urmila *et al.*, 2008).

Adopting biogas technologies may minimize labour by reducing the requirement for firewood collecting. Its uses has environmental benefits, such as fertilizer substitution, reduced greenhouse gas emissions, and enhanced indoor air quality, as well as economic benefits, such as lower fuel and fertilizer costs (Buysman, 2009). Furthermore, the Forest Law Enforcement, Governance, and Trade (FLEGT) mechanism in many countries is collaborating with REDD+ operations to reduce deforestation and promote forest governance. This activity can be accomplished by implementing and disseminating biogas technology.

2.7. Benefits of Biogas Technology

2.7.1. Environmental Benefits of Biogas Technology

Biogas technology gives a wide range of environmental and climatic advantages. The environmental benefits of biogas technology are often highlighted, as a valid and sustainable alternative to fossil fuels (Cecchi and Cavinato, 2015). As a renewable energy source, it allows exploiting agricultural and livestock by products and municipal wastes, with a lower impact on air quality when compared to combustion based strategies for these biomasses (Giovanis, 2015). It generates a sustainable source of energy, treats and reuses a wide range of organic wastes, reduces the environmental impact of GHG emissions, and alleviates the land use issues associated with disposing of organic wastes (Aggarangsi *et al.*, 2013). Biogas can contribute in environmental sustainability and it plays vital role for reduction of greenhouse gas emissions and fuel wood consumption.

2.7.2. Benefits of Biogas Energy on Biomass Fuel Saving and Forest Conservation

Fuel wood consumption is frequently seen as a cause of environmental degradation, and it can lead to energy insecurity for rural households, particularly where the resource is commercialized (Hiemstra-van der Horst and Hovorka, 2009). In Sub-Saharan Africa, the great reliance on wood fuel has resulted in an alarming pace of tree falling and deforestation (Economic and Council, 2007). According to the Economic and Council (2007), the removal of wood fuel accounts for roughly half of Africa's forest loss. Africa's deforestation rate is believed to be double that of the rest of the globe. Every year, more than 15 million hectares of tropical forests are depleted or burned to meet the needs of small scale agriculture, cattle ranching, and heating and cooking (Rechkemmer, 2004).

Biogas plays a dynamic role to reduce deforestation by reducing fuel wood (firewood and charcoal). In Nepal alone 345,446 trees have been protected per year that enhance greenery and protect environment as well. Hence, biogas contributes in protecting environment through forest conservation. Other Comprehensive study were available, the overall impact of biogas adoption on the nearby forest.

Kanu and Shresthaa (2014) has come up with the following findings, biogas technology led to reduce the pressure on nearby forest and pasture land and replaces 80 to 85 percent of fuel

wood consumption of a family. Take all above scholars' view, the other study showed that Programs to provide alternative energy sources such as biogas potentially reduce pressure on forests from fuel wood collection and charcoal usage. These results indicate the potential for alternative energy sources that reduce dependence on fuel wood to promote regeneration of degraded forests (Agarwala *et al.*, 2017).

2.7.3. Carbon Emission Savings and Climate Change Mitigation Benefits of Biogas Technology

The main objective of biogas technology is the reduction of fossil and biomass fuel consumptions, with the final goal of mitigating global warming (Bachmaier *et al.*, 2013). The effect of household biogas digesters on greenhouse gas emission reduction is mainly reflected in two aspects. First, household biogas digesters can reduce the emission of carbon dioxide (CO₂) (Chen *et al.*, 2017). Second, household biogas digesters can reduce the emission of Methane (CH₄) through efficient manure management system. Since the index of greenhouse potential of methane is 25 times that of CO₂, the greenhouse effect of methane is much greater than CO₂ (Zhang *et al.*, 2013).

Biogas energy plays indispensable role in running the economy of any country and more importantly in the lives and livelihoods of its people. Moreover, greenhouse gas emission reduced from the decrease in the use of fuel wood, agriculture residues, dung cake, and kerosene consumption (Yadav, 2014).

As per the research conducted by Sharma and Nema (2013), biogas technology is considered to provide the benefits of reducing the emission of GHGs and then mitigating global warming in ways of replacing firewood for cooking, replacing kerosene for lighting and cooking purposes, replacing chemical fertilizers and saving trees from deforestation. For example, in India, the introduction of biogas technology decreases 64,684 tones CO₂e per year from emitting to the atmosphere.

CHAPTER 3: MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in Gondar Zuria District, Amhara National Regional State Central Gondar Zone, North-Western Ethiopia, about 738 kilometers away from Addis Ababa. It is located between latitude $12^{\circ}40'59.99''\text{N}$ and longitude $37^{\circ}20'60.00''\text{E}$ (Figure 3.1). Gondar Zuria District has 40 rural and 3 urban Kebeles (Gondar Zuria District Agricultural Development Office Annual Report, 2023).

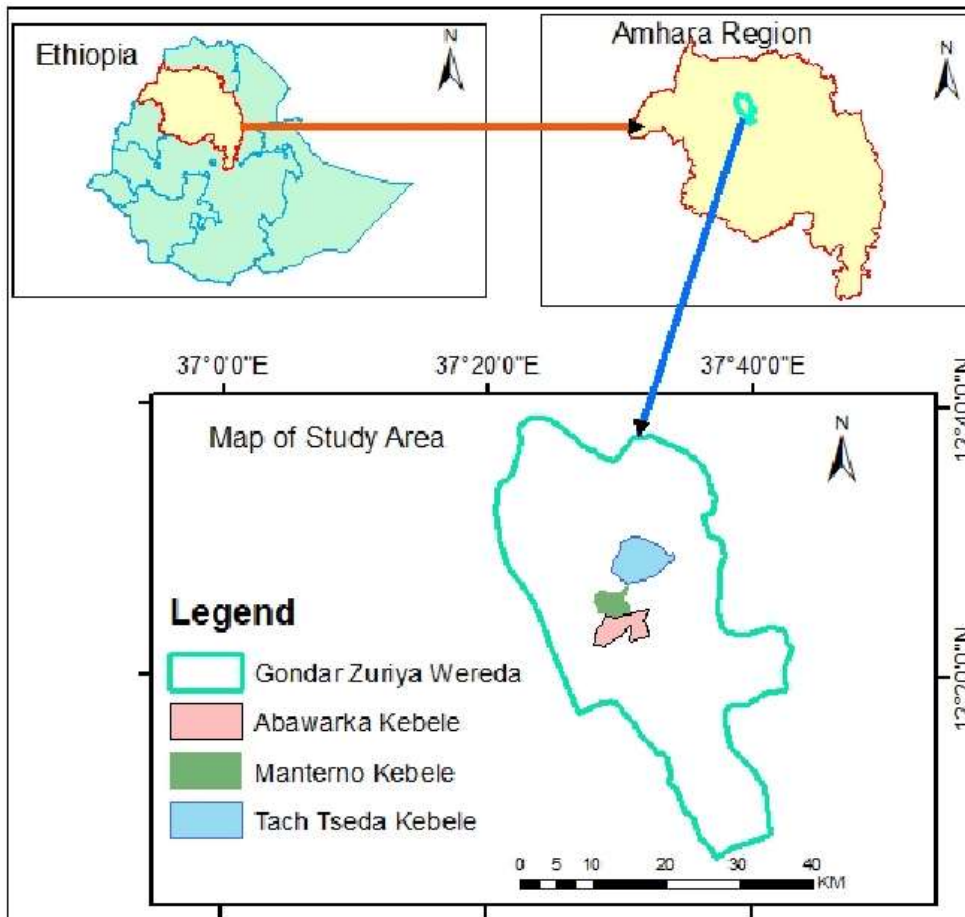


Figure 3.1: Location map of the study area

3.1.2. Topography

The district's topography is composed of 10% valleys, 25% hills, and 65% flat plain. The land area of Gondar Zuria is composed of 63% farmland, 14.8% grassland, 9.6% forest cover,

7.5% physical construction, 2.6% wasteland, and 2.5% other land uses (Gondar Zuria District Agriculture Office, 2023).

3.1.3. Climate

At 1500–3200 m.a.s.l, the district falls into two agro ecological areas named Woyina Dega (72%) and Dega (28%). The average monthly precipitation and temperature are 67.8 mm and 17.5–27.5 °C respectively (Gondar Zuria District Agriculture Office Annual Report, 2023).

3.1.4. Livestock

In the study area, the number of livestock (in cow equivalent) were 142350 cows, 117235 oxen, 45390 heifers, 2928 calves, 54674 sheep, 46519 goats, 58 horses, 25665 donkeys, 1406 mules, and 31565 chickens (Gondar Zuria District livestock development office annual report (GZDLDO, 2023). The Tropical Livestock Unit was used to calculate the size of livestock in the study area, since different age and sex category of cattle do not produce the same amounts of dung. In order to accurately calculate the corresponding amount of dung produced by each cattle category in their actual feeding responses, the conversion factor was used.

Table 3.1: Conversion factors used to estimate tropical livestock units (TLU)

Animal category	Conversion factor/ Cow equivalents
Ox	1.25
Cow	1
Heifer	0.63
Calf	0.25
Bull	1.25

Source: Njuki *et al.*, (2013)

3.2. The Number of Biogas Plants Installed in the District

In the study district, 121 biogas plants were installed between 2013 and 2023 by the district's water, mine, and energy office through the coordination of the Regional Biogas Program Coordination Office. The biogas digesters were constructed in 17 kebeles (Figure 3.2). The following requirements must be met to construct a biogas plant for potential users or biogas plant seekers. But, the requirements may vary depending on the size of the plant that the users

want to construct. Interest for cost-sharing of the digester construction (able to pay 60% of the investment expense); the availability of cow dung (owning a minimum of 6 cows for 6m³ and 8m³ biogas plant); near access to water supply (living within thirty minutes walking distance); sufficient area for biogas plant installment; access to construction materials (sand, cement, and stone) and human labor. In the study's district, out of the 121 installed biogas plants, about 70 were functional (Gondar Zuria District Water, Mine and Energy Office, 2023).

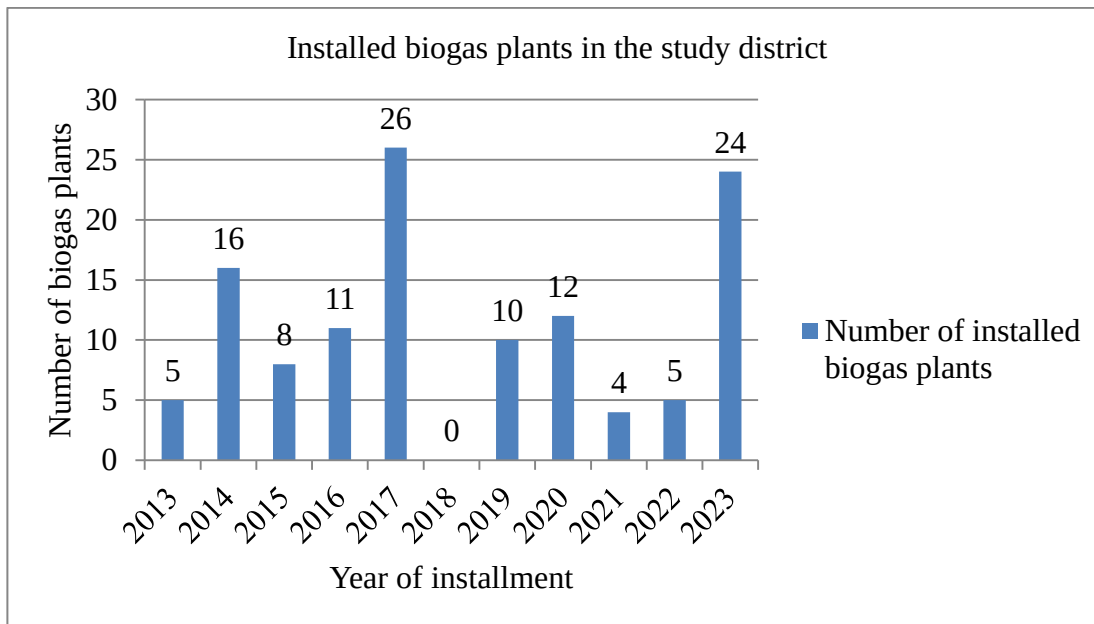


Figure 3.2: Number of annual installed biogas plants in the study district

Source: Gondar Zuria Districts water mine and energy office Annual Report, 2023

3.3. Research Design

In this study, the cross-sectional survey design was used, and data was collected to explore how biogas technology might help to reduce fuel wood consumption and slow the effects of climate change in Gondar Zuria District, North Western Ethiopia. The kebele's inhabitants from various socioeconomic statuses and educational backgrounds were used in this investigation.

3.4. Sampling Technique and Sample Size Determination

Multi-stage sampling techniques were used to select sample households. First, Gondar Zuria District was deliberately selected, because it is a potential location for promoting domestic

biogas technology in the provincial state of Amhara National Regional State. Second, from seventeen Kebeles adopting biogas technology in the district, three Kebeles with relatively higher levels of adoption were selected purposively. Third, lists were collected from the Gondar Zuria Districts water, mine, and energy office of the biogas technology adopter and non-adopter household heads in the selected Kebeles. Accordingly, both household heads that were found in the three Kebeles were intentionally sampled for biogas technology adopters. Fourth, using the formula suggested by Yamane (1967), the number of sample households for the proportion of adopter and non-adopters of the target population of three Kebeles (*Abawarka*, *Manterno*, and *Tach Tseda*) was estimated at 92 percent confidence and 0.08 (8 %) precision levels.

$$n = \frac{N}{1+N(e)^2} \dots\dots\dots (Equ\ 3.1)$$

Where n is the sample size, N is the population size (total number of adopter and non-adopter households in the three kebeles), and e is the level of precision (sampling error) at 92% significance level.

In the three selected kebeles, there were a total of 3208 households, from which 3170 households, *Abawarka* (1255), *Manterno* (872), and *Tach Tseda* (1043) were non-adopters. The remaining 38 households, *Abawarka* (17), *Manterno* (11), and *Tach Tseda* (10) were adopters.

Therefore, the sample size is:

$$n = \frac{3208}{1+3208(0.08)^2} = 149$$

Then, the probability proportional to the size of the sampling procedure was used to calculate the number of household samples from each of the Kebeles chosen (Table 3.2).

Lastly, the three Kebeles were selected from survey households of biogas adopters and non-adopters using a simple random sample technique. Consequently, 181 households made up the sample size, along with 32 purposively selected biogas adopters and 149 randomly selected non-adopters from the three Kebeles.

Table 3.2: Distribution of sample sizes in each selected kebeles

Kebeles	Total number of HHs		Sample size taken	
	Adopter	Non-adopter	Adopter	Non-adopter
<i>Abawarka</i>	17	1255	15	60
<i>Manterno</i>	11	872	9	57
<i>Tach Tseda</i>	10	1043	8	32
Total	38	3170	32	149

‘Kebele’ is the smallest administrative unit in Ethiopia.

3.5. Sources of Data

3.5.1. Primary Source

A survey of houses utilizing a questionnaire, key informant interviews, focused group discussions, field observations, and the kitchen performance test (KPT) was used to collect primary data.

Household Survey (HHS)

The household survey was carried out using semi-structured questionnaires. Data was acquired by a questionnaire survey on the demographic characteristics of households including family size, farmland size, educational level; cattle size, and household fuel consumption.

Key Informant Interview (KII)

In this study, governmental organizations and other stakeholders involved in the promotion of biogas technology were interviewed. Eight Key informant interviews (three from biogas technology promoter energy experts and five from local authority representatives). In this study, both open and closed-ended questions were used. Open-ended questions were used to elicit data on the features of the research area, the characteristics of respondents, and their actual and expected returns about the adoption of biogas technology. On the other hand, closed-ended questions were used to gather data about respondents’ attitudes towards the role of biogas energy.

Field Observation

Field observation was used to compile extra information and counter-check the information provided by focused group participants and household respondents. Additionally, direct observation was utilized to assess the functionality of biogas plants, the existence of biogas plants, their operation, designs, and maintenance. A camera was also utilized to record some structures important to this investigation.

Focused Group Discussion (FDG)

Focused group participants in this study were chosen from both adopter and non-adopter biogas households in each selected Kebeles. There were three focused discussion groups (FDG) (one focused discussion group in each selected kebeles') each with eight participants. Some open-ended questions set the stage for discussions and are crucial in achieving the study's objective.

Kitchen Performance Test (KPT)

The Kitchen Performance Test (KPT) is the principal field-based procedure used to measure households fuel consumption. In this study, the primary objective of the KPT is to quantify the amount of fuel saved by the usage of biogas energy and to calculate how much greenhouse gas decreased (mitigated). The main equipment that was used in the KPT is a spring balance with a 0–50 kg range, a rope with a 1 m resolution, and a cart for moving wood. There are different models of a stove performance test to measure the amount of energy used, which includes the Water Boiling Test (WBT), Controlled Cooking Test (CCT), and KPT. For this study, KPT were used, which is the least controlled and most real world of the three tests (Bailis *et al.*, 2007; Gold Standard Foundation, 2011).

In this study, *Abawarka* and *Tach Tseda* kebeles were selected for Kitchen Performance Test (KPT) measurements because *Manterno* kebele is similar in socioeconomic status, livelihood options, and climatic conditions to *Abawarka* kebele. As a rule of thumb, in a very small target population, mostly less than 300 households, the number of households who can be involved in the initial survey should not be less than 10% of the total sample households (Bailis *et al.*, 2007; Gold Standard Foundation, 2011). The sample size should be as large as

possible if there is a high variation in the amount of fuel used and saved, which is often the case in kitchen performance tests. In this study, to minimize bias and make the samples more representative, 22% of the total sampled households were subjected to a test in KPT measurement. Out of the 181 adopters and non-adopters of biogas technology in sampled households, 40 test subjects (22% of the sample) were selected using a random selection method, because all adopter and non-adopter sampled households agreed to participate in the measurement test. An equal amount of test subjects (20 for both) was considered for the ease of comparison between them.

According to Bailis *et al.*, (2007), a minimum of three days of continuous testing is required. In this study, to get a reliable and genuine result, the KPT have been carried out for seven consecutive days of measurements. Before the KPT had to be carried out, one-day visits were done in the field and ample households were requested whether they had collected a sufficient amount of biomass fuels from each type that was enough for one day and order households to be ready for the next day of KPT measurement.

Households were informed to cook normally (without extra eaters) throughout the testing period and use fuels only from the stock that had been pre-weighed. The aim was to determine their usual behavior in the kitchen throughout the year. During the tests, the researcher recorded how many people had eaten the cooked meal with the weighed fuel per day. People of different ages and genders have different caloric requirements, which can affect fuel consumption. The number of people eating meals per day was converted into “Standard Adult Equivalent” units. Weighting factors were used to calculate Standard Adult Equivalents (SAEs). The SAEs were determined using the guidelines for wood fuel surveys for the Food and Agricultural Organization (Bailis *et al.*, 2007).

Table 3.3: Standard Adult Equivalence Factors

Gender and Age	Fraction of SAEs
Child: 0-14 years	0.5
Female: over 14 years	0.8
Male: 15-59 years	1
Male: over 59 years	0.8

Source: Bailis *et al.*, 2007

Biomass fuels consumed by both adopter and non-adopter households can be measured by recording daily fuel consumption and dividing the amount by the number of adult equivalents served in the KPT procedure. Finally, the biomass fuel saving estimation was obtained by taking the difference between the two measurements under the KPT procedure. The same with the above procedures, the KPT for charcoal consumption was done by the weekly base, because it was difficult to keep track of the overall consumption of charcoal in a daily bases since the sample adopter and non-adopter households used it every three or four days in a week. Finally, for the ease of the KPT procedure with other biomass fuels, it was changed on to daily basis.

Besides this, information on the rates of kerosene consumption was acquired in liters. Finally, for easier of comparisons between the consumptions of various fuel types, the gross weight of each fuel type were converted into equivalent thermal values expressed in joules (Table 3.4). To get the daily amount of biogas energy consumption, the respondents were requested to report the daily average hours each of the biogas stoves and lamps was utilized. Then, the equivalent cubic meter of biogas consumption was calculated. As indicated by Gupta (2009) and IRENA (2016), cooking with a biogas stove consumes about 0.475m^3 of biogas per hour. Whereas, lighting a biogas lamp on average consumes 0.048m^3 of biogas per hour. A cubic meter of biogas is roughly equivalent to 22MJ (Sorensen, 2007).

Table 3.4: Thermal values of biomass and other household energy sources

Fuel type	NCV(MJ/kg)
Fuel wood	15.5
Charcoal	29
Crop residue	15
Dung fuel	13.8
Biogas (M^3)	22
Kerosene (L)	36

Sources: UNFCCC, (2012)

3.6. Data Collection Procedures

Gondar Zuria District's Water Mine and Energy Office were provided information on the household's energy use patterns prior to data collection. Six data collectors collected the data (two data collectors in each Kebele). The entire data collection team was Amharic-speaker. Data collectors received a one-hour training session before administering the questionnaire to familiarize them with the subject of the study and to explain all of its contents. Four weeks passed before the data was obtained. On Monday through Friday, enumerators were scheduled to collect data in the morning (8–10 o'clock) and afternoon (3-5 o'clock), however on weekends, data collection occurred from the morning through the afternoon. Because the respondents are farmers, the enumerators decided on this time in case they were likely to be free of homework for the respondent's data collection time.

3.7. Data Analysis and Presentation

3.7.1. Quantitative and Qualitative Data Analysis

Collected data was entered into Excel spreadsheets and exported to SPSS and then it was coded and keyed in Statistical Package for Social Scientists (SPSS 26.0). Methods for both quantitative and qualitative data analysis were used. Quantitative data was analyzed using descriptive and inferential statistics, while qualitative data was analyzed based on content analysis.

Data obtained from key informant interviews, focused group discussions, and direct field observations were analyzed based on content analysis. The data that were collected using observation is used to counter-check information provided by household respondents and focused group participants.

Quantitative data was analyzed using descriptive and inferential statistics. The following components were analyzed using descriptive statistics, including respondent's socioeconomic and demographic characteristics and attitudes towards biogas technology. Averages, percentages, and Pearson's product-moment correlation are among the descriptive statistics (some sources categorize it as inferential statistics). Binary logistic regression and independent samples t-tests were included in inferential statistics. Frequencies, means, standard deviations, and cross-tabulations were used to display the data. Independent sample

t-tests and Chi-Square (X^2) were used as tests of significance. The significance difference in this investigation was fixed at $p < 0.05$ and P-value plays a significant role in influencing the outcomes. Karl Pearson's coefficient was used to calculate the degree of correlation (r) or relationship between continuous independent variables and dependent variables, while Spearman correlation was applied to discrete (dummy) variables. Statistics were used to present the collected data, including frequency distribution charts and percentages, and the analyzed data was presented using tables, charts, and graphs.

3.7.2. Analysis of Factors Influencing Adoption of Biogas Technology

Besides descriptive statistics and independent sample t-test, a binary logistic regression model was employed to analyze the underlying factors determining household's decisions on the adoption of biogas technology. Both logistic and probit regression models are popular in the analysis of the limited dependent variable having discrete binary responses (Wagayehu Bekele and Drake, 2003; Greene, 2008). The choice of whether to use a probit or logit model is a matter of convenience and simplicity of computation (Greene, 2008). Yet, a binary logistic regression model was preferred as it is easier to interpret and offers odds ratios which is absent in the probit model (Orme and Combs, 2009).

Logistic regression is applied when the independent variables are any type and the dependent variable is a binary, the model is employed. In the present study, the observations were coded "1" for adopters and "0" for non-adopters and were used as a dependent variable.

The Binary logistic regression model calculation for this study was given as:

$$P(Y) = \beta_0 + \beta_1 (X_1) + \beta_2 (X_2) + \beta_3 (X_3) + \dots \beta_n (X_n) + \epsilon_i \dots \dots \dots (Equ\ 3.2)$$

Where: $P(Y)$ is Binary dependent variables denoted as "1" if the household adopts biogas technology and "0" otherwise.

Where: " β_0 " is constant term; " $\beta_1, \beta_2 + \beta_3 + \dots \beta_n$ " are estimated parameters to each explanatory variables; " $X_1, X_2, X_3 \dots X_n$ " are independent explanatory variables; " ϵ_i " is the error terms of regression; and n is number of explanatory variables.

Variables Explaining Adoption of Biogas Technology

The adoption of biogas technology by households was likely depending on the interactions of several different factors. According to an analysis of several related studies (Kabir *et al.*, 2013; Qu *et al.*, 2013), demographic, social, economic, institutional, and biophysical factors play a significant role in determining the adoption of biogas technology. Examining relevant existing research as well as on-the-ground observations and experiences were both necessary for the identification of credible explanatory variables.

Dependent Variables (Biogas Adoption)

Puzzolo *et al.*, (2016) define adoption as “initial technology acquisition and use for less than one year from the acquisition.” In this study, adoption was used as the dependent dummy variable. A value of ‘1’ was assigned to those households that have owned biogas technology and ‘0’ for those that have not owned it. This is because the binary logistic regression model requires a binary choice of the dependent variable.

Independent Variables

The choice of independent variables was determined based on the literature reviewed on the factors that influence farmers’ decisions to adopt biogas technology and the knowledge about energy sources and utilization in Gondar Zuria District. Independent variables are listed and defined as follows:

Age of household head: The young household heads are likely to be more flexible and liable to accept new technologies, but at the same time, they are likely to have less capital accumulation and have lower economic status than the old farmers. Hence, the age of the household head was expected to have either a positive or negative influence on the adoption of biogas technology.

Sex of household head: Men dominantly control the household resources (Lim *et al.*, 2007) and often make final decisions both at household and community levels in the country than female headed households and the use and management of household energy is primarily the duty of women in Ethiopia (EREDPC and SNV, 2008). Thus, sex of the household head was expected to have either positive or negative influence on adoption of biogas technology.

Educational levels of household head: Household heads with higher educational levels were indicated to be less conservative, more informed, more knowledgeable, and more vigilant to the environment (Walekhwa *et al.*, 2009). Thus, household heads who pass through greater number of schooling years were anticipated to have a greater probability of adopting biogas technology.

Family size of household head: Are a number of household members who included in one house. Large family size has sufficient labor required to manage and operate biogas technology. Thus, family size was hypothesized to have either a positive or negative influence on the adoption of biogas technology.

Cattle size of household head: Are a number of cattle owned by households. The primary input for biogas digesters in Ethiopia is cattle dung. Thus, households that have more number of cattle were expected to have a positive influence on the adoption of biogas technology.

Average Annual income of household head: Are amount in money (ETB) in which households earned per year. Construction of biogas needs a cost covered by the farmers, either through own income sources or loans. Thus, household with high income source have more probability to adopt biogas technology.

Farmland Size of household head: is a size of land in hectare which households owned. Households with larger size of farmland were supposed to have better income. Hence, it was be hypothesized to have positive influence on adoption of biogas technology.

Distance to fuel wood sources of household head: is the time taken to collect fuel wood from source to resident. Thus, the distance to the main fuel wood source away from resident was expected to have either positive or negative influence on adoption of biogas technology.

Distance to water sources of household head: For daily feeding of the biogas technology, the source of water was suggested to be within a short walking distance away from home. Therefore, distance to water source from home was expected to have negative influence on adoption of biogas technology.

Awareness levels of household head: Awareness is level of knowledge of household acquired on biogas technology from different sources of information. Awareness affects the

adoption of biogas technology positively, in which aware households adopt biogas than non-aware households.

Table 3.5: Variables explaining adoption of biogas technology and Expected Hypothesis

Variable	Type	Description	expected sign
Age	Continuous	Age of household head in years	+/-
Sex	Dummy	Sex of household head (1= male)	+/-
Income	Continuous	Average annual income of household (Ksh)	+
F.Size	Continuous	Number of household members	+
No. Cattle	Continuous	Number of cattle owned by household	+
Landsize	Continuous	Total area of land owned by household in hectares	+
Edu. Level	Dummy	Educational level of household head	+
Awareness	Dummy	Awareness of household head on biogas	+
Dst.Water Source	Continuous	Average time (minute) taken to reach water source for biogas feeding	-
Dst. Fuel Wood	Continuous	Average time (minute) taken to collect fuel wood	+/-

3.7.3. Reductions of Fuel Wood Consumption by the Usage of Biogas Energy

According to SNV (2010) Fuel wood which was consumed by households in both adopter and non-adopter was measured by recording daily fuel wood consumption and dividing the amount by number of adult equivalent served.

$$F_a = \frac{\text{fuelwood consumed}}{\text{Number of adult served}} \dots\dots\dots (Equ 3.3)$$

Where: F is fuel wood consumption per day and coefficient “a” represent adopter and non-adopter.

$$F_{\text{saved}} = \frac{\text{fuelwood consumed by non-adopter}}{\text{Number of adult served}} - \frac{\text{fuelwood consumed by adopter}}{\text{Number of adult served}} \dots\dots\dots (Equ 3.4)$$

Where: F_{saved} is saved amount of fuel wood.

3.7.4. Greenhouse Gas (GHG) Emission Reductions through the Usage of Biogas Energy

In this study, only three most powerful GHGs, namely; CO₂, CH₄, and N₂O were considered. The aggregation to CO₂ equivalent (CO₂e) was determined by using the global warming potential (GWP) factors. A 100 years' time horizon is used for calculating the global warming potential, and the conversion factors from methane and nitrous oxide (N₂O) to CO₂ equivalents, in accordance with the fourth assessment report of (IPCC, 2007) having an adjusted ratio of 25 and 298, respectively (IPCC, 2007; Yu *et al.*, 2008). All GHGs were converted to CO₂e for emission estimation. CO₂e is a standard unit of measurement that makes it possible to compare the global warming potential of various GHGs (DEFRA, 2012).

To quantify the amount of GHG emissions and emission reductions, the default emission factors were taken from IPCC (2006) (Table 3.6).

Table 3.6: GHG emission factors and thermal values of different types of fuel consumption

Fuel type	Emission Factor (mg/MJ)		
	GHGs		
	CO ₂	CH ₄	N ₂ O
Fuel wood	112,000	300	4
Charcoal	112,000	200	1
Cow dung	100,000	300	4
Crop residue	100,000	300	4
Kerosene (L)	71,900	10	0.6
Biogas (M ³)	54,600	5	0.1

Sources: Sorensen, (2007); and UNFCCC, (2012)

Emission factor and GWP of GHGs are obtained according to IPCC, 2007 and the mass of GHG emissions reduction in CO₂e is calculated according to as follows:

$$\begin{aligned}
 Ea &= \sum (Ci \times EF_{CO_2} \times GWP_{CO_2} + Ci \times EF_{CH_4} \times GWP_{CH_4} + Ci \times EF_{N_2O} \times GWP_{N_2O}) \\
 &= \sum ((EF_{CO_2} + 25 \times EF_{CH_4} + 298 \times EF_{N_2O})) \dots \dots \dots (Equ \ 3.5)
 \end{aligned}$$

Where: E_a is GHG emissions reduction in kg from the combustion of fuel type 'a'; C_i is amount of fuel saved by a sample adopter households 'i'; EF_{CO_2} is CO_2 emission factor for fuel type 'a'; EF_{CH_4} is CH_4 emission factor for fuel type 'a'; EF_{N_2O} is N_2O emission factor for fuel type 'a'; GWP is Global warming potential for the GHG indicated.

Table 3.7: Global warming potential of greenhouse gases

Gas	GWP in 100 years
CO_2	1
CH_4	25
N_2O	298

Source: IPCC, (2007)

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Socio-Economic and Demographic Characteristics of Households

4.1.1. Sex of Sample Households

In this study, out of the total 181 sampled households 136 (75.1%) were male, and the remaining 45 (24.9%) of the households were female. About 26 (81.2 %) of adopter households were male-headed and 6 (18.8 %) were female-headed, while 110 (73.8%) and 39 (26.2 %) of non-adopters were male and female respectively. The chi-square test result showed that, there were no significant mean differences between the sex of households of adopter and non-adopter at ($P = 0.068$, $X^2 = 3.324$) (Table 4.1).

4.1.2. Educational Levels of Sample Households

The educational levels of the sample biogas adopter and non-adopter household heads varied from Illiterate (who are not able to read and write) to literate (who can read and write). From this perspective, out of the total 181 sampled households surveyed in the study area 98 (54.1%) of the sample households were illiterate, whereas 83 (45.9%) of the households could read and write or were enrolled in informal education. Hence, 19 (59.4%) Adopter and 64 (43%) non-adopter household heads were literate, attending informal education and can read and write. the remaining 13 (40.6%) and 85 (57%) were illiterate in the same order. The chi-square test result revealed that, there were a significant mean difference between adopter and non-adopter sample households on an educational level at ($P = 0.037$, $X^2 = 4.337$) (Table 4.1).

Table 4.1: Sex, Education, and their chi-square test value of adopter and non-adopter households

Variables	Category	Adopters (32)	Non-adopters (149)	X^2	P value
Sex of Household	M	26	110	3.324	0.068ns
	F	6	39		
Educational Level	Literate	19	64	4.337	0.037*
	Illiterate	13	85		

*, and ns = significance at $P < 0.05$, and non-significance at $P < 0.05$ respectively.

4.1.3. Age of Sample Households

To help the researcher understand how different age segments of the population examined the use of biogas technology, the sampled respondents were asked to indicate their age. The age of the sample household heads ranged from 32 to 74 years old with an average of 51.94 years. The age of the sample household heads of adopters ranged from 38 to 65 years old with an average of 58.53 years, while the age of non-adopter household heads ranged from 32 to 74 years with an average of 50.53 years. The independent sample t-test result showed that, there was significant mean differences between the ages of sample biogas adopter and non-adopter households at ($P < 0.05$) (Table 4.2).

4.1.4. Family Size of Sample Households

Family size is the number of people living in one house. The numbers of peoples have been converted into standard adult equivalents for both adopter and non-adopter of sample households (Appendix 11). Thus, the family size of the sample households ranged from 4 to 12, with an average of 8 and the average family size of adopters was 9 and 8 for non-adopters (Table 4.2). This result is higher than the national average family size (5.1 in rural and 3.9 in small towns) of Ethiopia (CSA and World Bank, 2013). The independent sample t-test result on family size showed that, there were a significant mean difference between adopter and non-adopter sample households at ($P < 0.05$) (Table 4.2).

Family size had implications on labor availability because biogas requires regular feeding and dung collecting. However, having enough household labor power, which is determined by family size, is essential for biogas digester construction as well as for post-construction management tasks. Once biogas construction is finished, household labor is required to feed the biogas digester daily.

4.1.5. Cattle Size of Sample Households (TLU)

The sample households possessed a variety of livestock, including horses, mules, sheep, goats, donkeys, and cattle, but this study only takes into consideration cows, oxen, calf, heifers and bulls. This is because; cattle are the primary prerequisite to constructing biogas technologies in the study area. Then, the types of cattle owned by the sample households were converted into Tropical Livestock Units (Appendix 3) to compare cattle holding size between adopter and non-adopter households. The total cattle size in (cow equivalents), ox, cows, calf,

heifer, and bull owned by sample households were 724, 1695, 1271, 863, and 1390, respectively. The average cattle size of sample households in cow equivalents was 10.03. The average cow equivalents of sample biogas adopter and non-adopter households were 13.44 and 9.44 in the same order. The independent sample t-test result on cattle size showed that, there was a significant mean difference between adopter and non-adopter sample households at ($P < 0.05$) (Table 4.2).

4.1.6. Annual Income Levels of Sample Households

Households in the study area were dependent on a range of sources of income, but the main economic activity was agriculture, basically dairy and crop production. In addition to farming some households were engaged in either formal or informal sectors or engaged in business of some kind. In this study, adopter households earned income ranged from 96000 birrs to 384000 birrs, while non-adopter earned up to 48000 to 288000 birr with average annual income of 234600 and 196993.29 birrs for both adopter and non-adopter households respectively. The independent sample t-test result showed that, there was insignificant mean annual income differences between adopter and non-adopter sample households at ($P < 0.05$) (Table 4.2).

4.1.7. Farmland Size of Sample Households

In a country like Ethiopia, where the majority of the population engages in agriculture, land is a valuable economic resource for the development of rural livelihoods. The average farmland size of the total sampled households was 2.21 ha and the average farmland size of sample adopter and non-adopter households were 2.78 and 2.09 hectares respectively. This is higher than the national level average household farmland size of 1.37 ha (CSA and World Bank, 2013). The independent sample t-test result on farmland size indicated that, there was a significant mean difference between adopter and non-adopter sample households at ($P < 0.05$) (Table 4.2).

Table 4.2: Age, Family Size, Farmland Size, Cattle Size, and Annual Income of Sample Households

Variables	P-value	Mean		Mean Difference
		Adopter	Non-adopter	
Age of Households	.000**	58.53	50.53	8.001
Family Size of Households	.021*	9.09	8.18	.913
Farmland Size of Households	.000**	2.78	2.09	.694
Cattle Size of Households	.000**	13.44	9.44	4.001
Annual Income of Households	.072ns	234600	196993.29	37606.711

**, *, and ns = significance at $P < 0.01$, significance at $P < 0.05$, and non-significance at $P < 0.05$ respectively.

4.2. Quantifying the Percentage of Fuel Wood Usage that can be Reduced by Using Biogas Technology in the Study Area

The adopter and non-adopter households per day fuel wood consumption were 6.5 kg and 9.9 Kgs respectively (Appendix 11). The amount of average annual fuel wood consumption for single non-adopter households/year was 3613.5 Kgs, while fuel wood consumption by single adopter households/year was 2372.5 Kgs. From this, 1241 Kgs (34.3%) of fuel wood is saved by adopter households per year. This result in agreement with the study Wamuyu, 2014 found that approximately 1519.2 Kgs of fuel wood were saved annually by those households using biogas. As a result, a total of 39712 Kgs of fuel wood were saved annually from 32 functional biogas plants in the study kebeles, while 86870 Kgs of fuel wood were saved annually from 70 functional biogas plants in the study district (Appendix 5). Therefore, households who own biogas technology could save more fuel wood compared to non-adopter households. Thus, increasing the dissemination of biogas in the district reduces fuel wood consumption and overcomes the energy crisis.

4.2.1. Households Energy Consumption Pattern in the Study Area and Roles of Biogas Technology in Fuel Wood Saving

The sampled households were asked how often they use biogas per day, and accordingly, 56.3% of households responded that, they used biogas three times per day (morning,

afternoon, and evening). From the KPT result, about 34.3% of fuel wood consumption per year was reduced in adopter households with the acquisition and use of biogas.

This finding was almost different from a Study by (Xiaohua *et al.*, 2007) which showed that, biogas digesters used in different regions of rural China reduced the use of biomass fuel by 40%. Adopter households in the study area used biogas especially for cooking stew, and making coffee and tea. In the focused group discussion, the group members reflected that they want to use the technology for different cooking purposes (making bread and baking injera).

Table 4.3: Adopter household's number of cooking periods by biogas per day

Number of cooking by biogas per day	Frequency	Percent
Once	1	3.1
Twice	2	6.3
3 Times	18	56.3
4 Times	4	12.5
Not used	7	21.9
Total	32	100.0

4.2.2. Most Commonly Used Tree Species for Domestic Energy Use

From this study, the most commonly used tree species by both adopter and non-adopter households was *Eucalyptus Camaldulnsis* for the source of fuel wood and charcoal production, thus 58% of households used it as fuel wood sources and charcoal production. These results are in conformity with a previous study that pointed out that many people in Ethiopia are dependent on the *Eucalyptus* as a source of fuel wood (Seifu, 2019). There were also other types of tree species used by sample households and it accounts about 14%, 12%, 9% and 7% of the respondents have used *Olea Africana*, *Grevillea Robusta*, *Podocarpus Falcatus* and, *Prunus Africana* respectively (Figure 4.1). Key informant interviews from local authority representatives witnessed that, the major reason of households preferred *Eucalyptus camaldulnsis* were its accessibility, availability, and its fast-growing rates relative to other tree species in the study area. From field observation, the majority of tree species in the study area and on farmlands of households were *Eucalyptus camaldulnsis*. This result tally with Bekele *et al.*, 2013, which found that, *Eucalyptus* is the dominant tree species planted in the homestead.

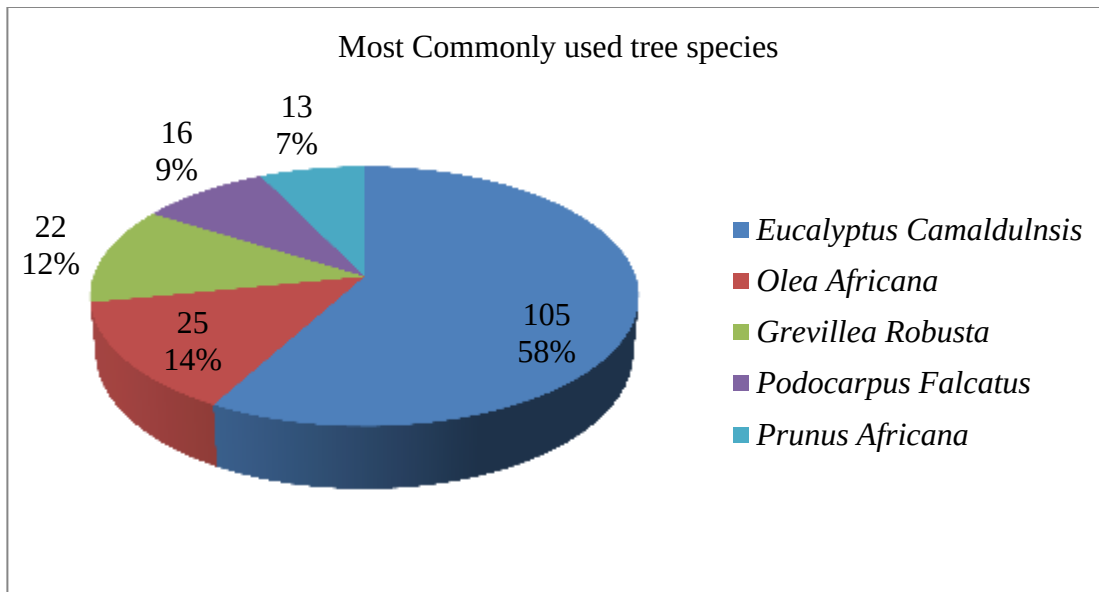


Figure 4.1: Most commonly used tree species for domestic energy use

4.2.3. Types of Energy Sources and Current Status of Energy Utilization

4.2.3.1. Types of Energy Sources for Cooking and Heating Purposes

As a result indicated, about 70 (38.7%) of the households used fuel wood for cooking and heating purposes. About 39 (21.5%) of them have used cow dung to bake Injera and heating. Nearly 33 (18.2%) have used crop residues for cooking and heating. Moreover, about 32 (17.7%) of the households have used biogas energy sources and the remaining 7 (3.9%) of the households have used charcoal for heating purposes. This implies that, a larger proportion of sample households were dependent on traditional biomass fuels. Alternative energy sources like biogas technology had the lowest energy consumption in rural households (Figure 4.2). This result was consistent with Refera's (2017) findings, which stated that, the majority of households use firewood and crop residues for cooking and heating.

Even though in comparing fuel wood, cow dung, and crop residue consumption of households in the study area, majority of surveyed households consumed fuel wood for cooking and heating. Due to this prevalence, the felling of trees, deforestation and a low forest cover have become a growing and serious challenge to the study district.

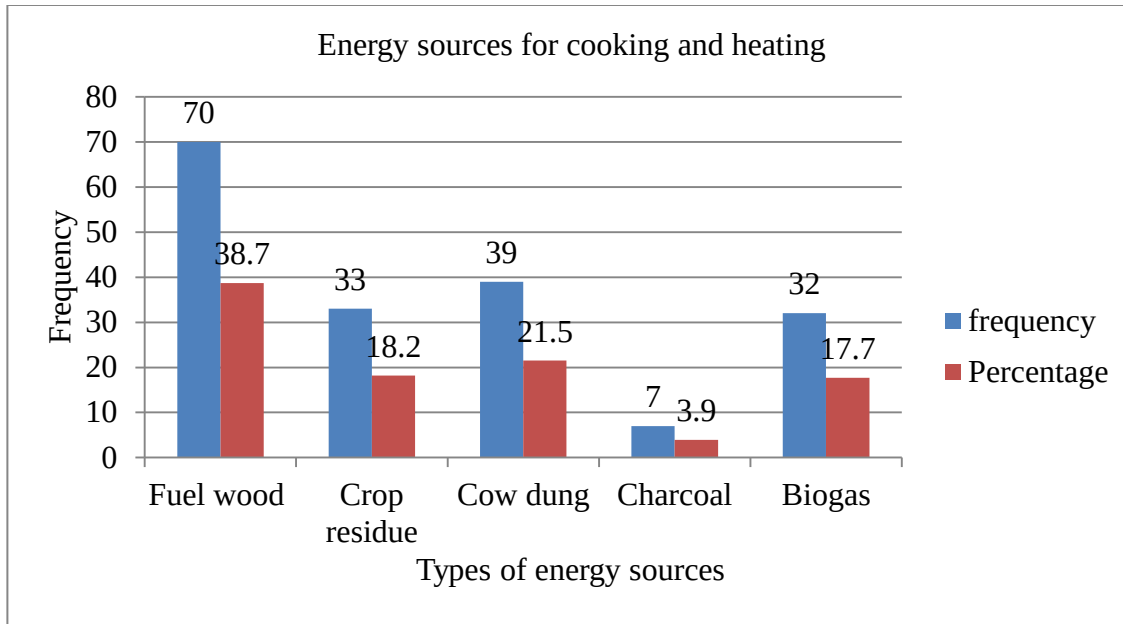


Figure 4.2: Types of energy utilized for cooking and heating in the study area

4.2.3.2. Types of Energy Sources for Lighting Purposes

About 87 (48%), 59 (33%), and 19 (10%) of the households have used battery cells, small-size solar panels, and biogas energy for lighting respectively. Furthermore, the result indicated that about 12 (7%) of the households' have used kerosene lamps for lighting purposes. Nearly 4 (2%) of sample households have used electricity for lighting purposes (Figure 4.3). This result contradicts the findings of Refera (2017) who revealed that the majority of households used kerosene lamps, and only 20% of the households used small-size solar panels for lighting. However, the consumption of electricity and biogas energy sources were found at the lowest level.

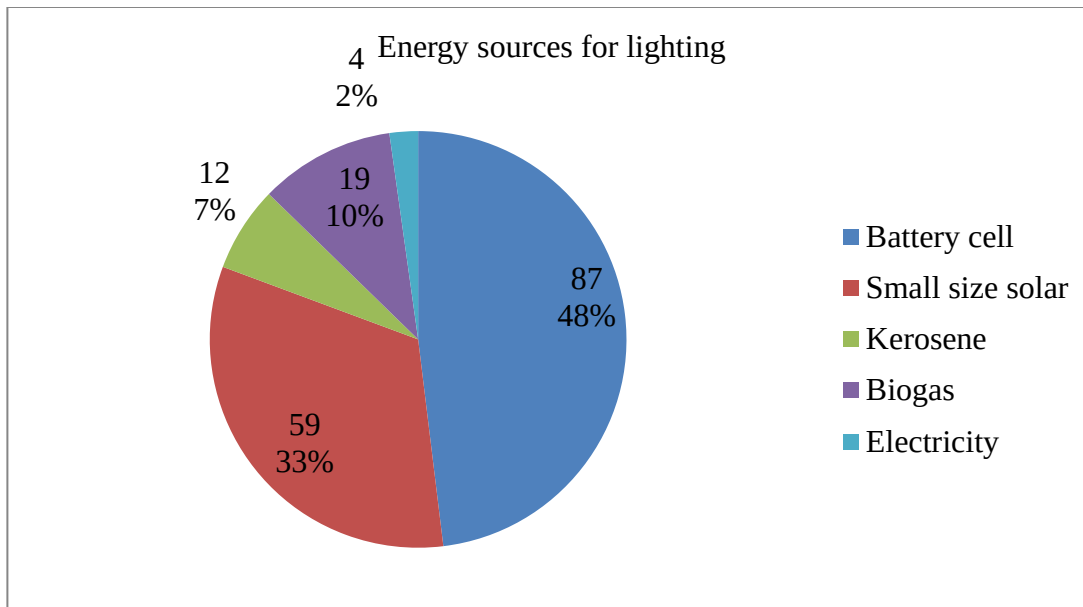


Figure 4.3: Types of energy utilized for lighting in the study area

4.2.4. Cook-Stove Type Used in the Study Area

In the consumption of fuel wood, the frequencies of cook-stoves used across the surveyed kebeles and it was found that, 114 (63%) of households used three-stone open fire, 38 (21%) used both three-stone open fire and biogas stoves, and the remaining 29 (16%) of households used improved cook-stove (Figure 4.4). Respondents pointed out that, they used all type of cooking stoves, three or four times per day for cooking. A three-stone open fire is the most preferred model for rural households for cooking. Using a three-stone open fire results, in inefficient use of energy that exposed to energy wastage and extra fuel wood expenditure. Thus, investing on energy efficient technology and energy efficient cook-stoves is essential way to eliminate the emerging energy wastage in Gondar Zuria District.

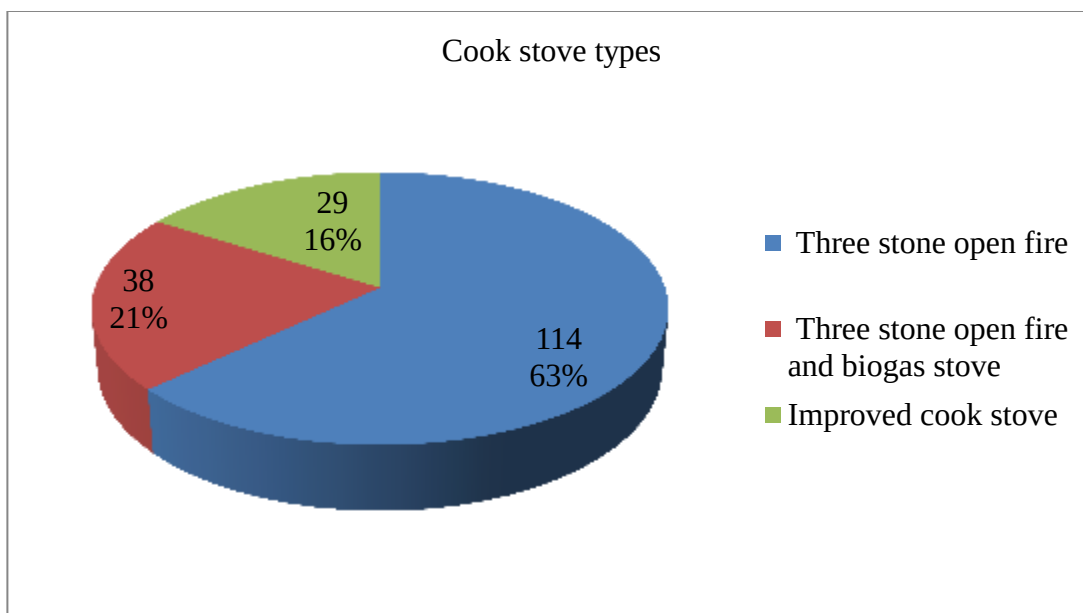


Figure 4.4: Cook-stove types used in the study area

4.3. Quantifying the Amount of GHG Emissions Reduced in the Study Area by Using Biogas Technology

Over-dependence on fuel wood consumption is being one of the leading causes of deforestation, and increased emissions of CO₂ into atmosphere. Since the use of biogas energy enabled the biogas adopter households to be able to reduce the consumption of various traditional biomass fuels and, in turn, emissions of GHGs; the average amounts of GHG emission reductions obtained from the reduced use of fuel wood, cow dung, crop residues, and charcoal were 2321.6 Kgs, 1423.1 Kgs, 476 Kgs, and 496.4 Kgs CO₂e per digester per year respectively (Table 4.4).

The average annual GHG emissions of biogas adopter and non-adopter households were 11.9 tons and 16.6 tons CO₂e respectively. Thus the net annual GHG emission by substitution of biomass fuels by biogas energy use was 4.7 tons of CO₂e saved per digester per year. These findings was greater than the findings of BSP (2012) estimated that, GHG emission reduction was 3 tons of CO₂e per plant annually, while Shrestha *et al.*, (2003) found that biogas plants of sizes 6m³ mitigated about 4 tons of carbon dioxide equivalent per plant annually, the main justification for this variation were; The absence of country specific emission factors, Difference in digester size, and Did not carry out KPT and SAEs when calculating the amount of biomass energy saved by the usage of biogas technology. As a result, a total of 150.4 tons

of CO₂e emissions were reduced annually from 32 functional biogas plants in the study kebeles, while 329 tons of CO₂e emissions were reduced per year from 70 functional biogas plants in the study district.

Reduction in CO₂ emission directly helps to minimize global warming which results in climate change mitigation. Therefore, the result of this finding indicated that, biogas technology has the potential to remarkably reduce emissions by reducing fuel wood consumption. This plays a role in minimizing average global temperature and mitigated climate changes.

Table 4.4: Average annual greenhouse gas emissions and emission reductions by biogas adopter and non-adopter households

Sources of emissions	Emissions in kg CO ₂ e		Emissions reduced
	Biogas non-adopter(a)	Biogas adopter(b)	(a-b)
Fuel wood	6759.90	4438.30	2321.60
Cow dung	3668.10	2245.00	1423.10
Crop residues	3571.00	3095.00	476.00
Charcoal	2607.40	2111.00	496.40
Total	16606.40	11889.30	4717.10

4.3.1. Major Greenhouse Gas Mitigation Potential of Biogas Energy in the District

The greenhouse gas emission reduction potential of biogas was achieved by partial displacing the consumption of traditional biomass fuel sources, kerosene, and efficient manure management system. The most important GHGs such as CO₂, CH₄, and N₂O emissions accounted as being reduced from the sources by biogas technology use. In this study, the available GHG mitigation potential of biogas in CO₂, CH₄, and N₂O were 4376.2 Kgs, 296.5 Kgs, and 45.1 Kgs CO₂e respectively per year per biogas plant. It is already known that, Carbon dioxide (CO₂) is the first most abundant GHG, accounting for about 78 percent of global emissions (IPCC, 2013). From the current finding (Figure 4.5), it was the first reduced GHG, accounting for about 92.7 percent of GHG emission reduction from the sources. Methane is the second most abundant anthropogenic GHG after carbon dioxide (CO₂), accounting for about 20 percent of global emissions (IPCC, 2013). Despite, methane being a

potent greenhouse gas; biogas utilization cuts the emission into a valuable source of domestic energy for rural households. From this study finding, it was the second reduced anthropogenic GHG, accounting for 6.3 percent of GHG emission reduction from the sources.

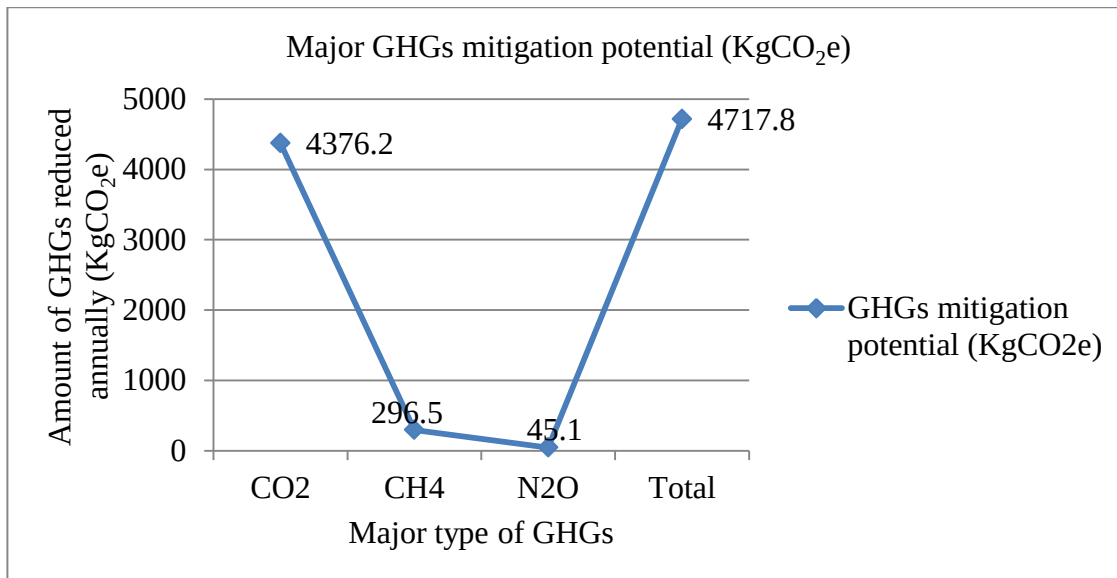


Figure 4.5: The major GHG emission reduction potential of biogas use in the study district

Hence, by the usage of biogas energy the net annual average GHG emission reduction of about 4.7 tons of CO₂e was reduced from being emitted to the atmosphere. The result of this study is greater than the finding of Gosaye and Abraham (2018) in Ethiopia illustrated the average annual GHG emission reduction per domestic biogas installation about 2.2 tons of CO₂e per annum. In this study, 70 functional biogas plants helped to avoid from the source about 329000 KgCO₂e from being emitted into the atmosphere annually, which is an enormous way of mitigating global warming internationally, nationally, and local climate improvements.

4.3.2. Biogas Energy Functional Status and Their Digester Size in the District.

From the total installed biogas plants, about 70 (57.9%) of plants were functional and the remaining 51 (42.1%) were non-functional (Figure 4.6).

A study's field observation and KII result highlighted that, there were multiple reasons for the non-functionality of biogas plants. Households missing regular daily feeding, poor construction of the whole biogas plant, unfinished construction, missing of removing water

from water drain, lack of adequate technical service, and leaving gas controller opened in non-using time were the major reasons for non-functionality of the digester. In this study, 6m³ and 8m³ sizes of biogas plants were available, of which 6m³ volume of digester is the most common. Among the 32 sampled biogas plants, 29 (90.6%) of biogas plants were a digester size of 6 m³, while 3 (9.4%) of biogas plants were digester size of 8m³ (GWWME0, 2023).

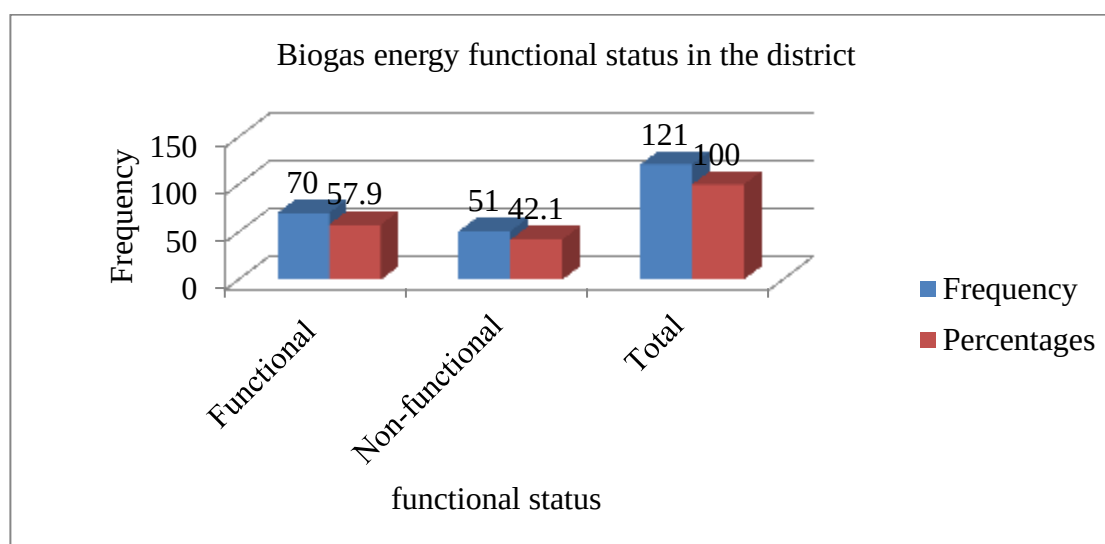


Figure 4.6: Functional status of biogas energy in the district

4.4. Determining Factors That Influence Adoption of Biogas Technology in the Study Area

In this study, the analysis of the results from binary logistic regression model indicated that the model reasonably fitted with the estimated values and observed data. Since goodness-of-fit for the model showed that the odds ratio of adoption was simultaneously related to the independent variables. They were accurately predicted by the model's statistical significance for 93.8% (30 from 32) of the biogas adopters, 93.2% (139 from 149) for non-adopter households, and 93.4% (169 from 181) of the overall sample households. The Cox and Snell R^2 , which is a similar measure of goodness-of-fit, were 0.471, while the Nagelkerke R^2 was 0.777, which is enough to support the model's quality accordingly. The other way to validate the goodness-of-fit of the regression model is the Hosmer and Lemeshow test (X^2 test). A non-significant value ($p > 0.05$) of the test is one routine method in validating "goodness-of-fit" of the logistic model (Julie, 2011). Hence, the test statistics were chi-square = 4.740, degree of freedom = 8, and p-value = 0.785. Moreover, the quality of the model is labeled

robust and not affected when the pseudo-R² value is more than 15% (Garson, 2008; Kabir *et al.*, 2013). To an acceptable degree, this indicated that the model was fitted for the estimated data.

Among ten independent variables included in the model, results confirmed that a total of seven variables were statistically significant ($p < 0.05$) in affecting the adoption decision of rural households (Table 4.5). These variables including age, family size, farmland size, cattle size, educational level, distance to fuel wood and awareness were found to positively affect the biogas adoption decisions of rural households (Table 4.5). On the other hand, three variables namely; annual income, sex, and distance to water source were found statistically insignificant values in the model ($p < 0.05$).

Table 4.5: Binary logistic regression model results for factors influencing adoption of biogas energy

Variables	B	S.E.	Wald	Sig.(P-value)	Exp(B) (Odd Ratio)	95% C.I. for EXP(B)	
						Lower	Upper
Sex (1= Male)	1.563	.928	2.836	.092ns	4.773	.774	29.432
Age (Years)	.149	.054	7.735	.005*	1.161	1.045	1.290
Family size (Number)	.468	.186	6.362	.012*	1.597	1.110	2.299
EduL (1= Literate)	2.725	.989	7.598	.006**	.066	.009	.455
FarmL size (ha)	1.577	.612	6.644	.010*	4.841	1.459	16.058
Cattle size (Number)	.296	.113	6.855	.009**	1.344	1.077	1.677
Income (ETB)	.000	.000	7.008	.082ns	1.000	1.000	1.000
Awareness (1=Aware)	7.946	2.210	12.927	.000**	.001	.000	.027
Dst. Fuel (Minute)	.313	.154	4.148	.042*	1.367	1.012	1.847
Dst. Water (Minute)	.399	.227	3.108	.078ns	1.491	.956	2.325
Constant	-32.477	7.838	17.169	.000	.000	-	-

**, *, and ns = significance at $P < 0.01$, significance at $P < 0.05$, and non-significance at $P < 0.05$ respectively.

Age of Household Head: The study's binary logistic regression result showed that, the adoption of biogas technology had a significant ($p < 0.05$) positive correlation with the head of the household's age (Table 4.5). Elderly household heads were more likely to adopt biogas energy than young people. Thus, the probability of adoption of biogas technology increases by a factor of 1.161, as the household head's age increases by one more year. This is because older people have the financial and land ownership resources to construct biogas plants.

This finding is tally with the study by Sufdar *et al.*, (2013) which found that, the probability of adopting biogas increased with age.

Educational Level of Household Head: Binary logistic regression result revealed that, there was a strong statistical association between educational level and adoption of biogas at ($P < 0.05$) (Table 4.5). The probability of adoption of biogas technology increases by a factor of 0.066, as the household head's educational level increases by one more year of schooling. Thus, more educated households have a greater probability of adopting biogas technology. This result matches with adoption studies conducted by Mulu Getachew (2016) which revealed a positive relationship between education levels and the adoption of biogas.

Family Size of Household Head: According to the binary logistic regression result, Family size and the adoption of biogas technology had a significant positive correlation at ($P < 0.05$) (Table 4.5). As a family's size increases by one, the probability of adopting biogas technology increases by a factor of 1.597. Then, the adoption of biogas technology increases with increasing family size. These findings support a Chinese study that indicated that, labor shortages caused by rapid urbanization have hindered the utilization of biogas technology (Zuzhang, 2014).

Cattle Size of Households Head: Binary logistic regression result showed that, there was a strong relationship between cattle size and adoption of biogas technology at ($P < 0.05$). For each additional unit of cow or cow equivalent, the probability of adopting biogas technology increases by a factor of 1.344 (Table 4.5). The mean cattle size of the households that had adopted biogas was 13.44, and almost all adopter had more than six cattle's. Therefore, cattle size positively affected the adoption of biogas technology. This result seems to be with the study by Iqbal *et al.*, (2013), which found that having more cattle increased a household's probability of adopting biogas technology since they would produce enough cow dung. Thus, households with a lesser number of cattle might not have enough cow dung to feed the biogas digester daily.

Farmland Size of Household Head: In this study, there was a strong relationship between farmland size and adoption of biogas energy at ($P < 0.05$). When the households farmland increases, adoption of biogas technology also increases by a factor of 4.841 (Table 4.5).

Thus, the adoption of biogas increases with the increased farmland size of households. This result is similar to Gulbrandsen (2011) who found that, households with larger sizes of land had adopted the technology as opposed to households with smaller sizes of land in Tanzania.

Fuel wood Distance of Household Head: This study found that, the maximum time that households had taken to collect fuel wood was 25 minutes. The average minute that adopter and non-adopter took to collect fuel wood was 16.66 and 14.76 minutes respectively (Table 4.5). The opportunity cost of gathering fuel wood increases with the increasing distance of its source away from the resident (Guta, 2014); and binary logistic regression result showed that, there was a significant positive relationship between fuel wood distance and the adoption of biogas technology at ($P < 0.05$). This finding differs from the finding of Jebesa, 2017 that, on average households traveled 0.5hr, with minimum and maximum 0.1hr and 2hr to collect firewood.

Awareness Levels of Household Head: There is a statically significant value between awareness and adoption of biogas technology at ($P < 0.05$) (Table 4.5). This finding contradicts the Wawa, (2012) which revealed that, awareness on biogas technology had an inverse relationship with adoption, thus, people with low awareness adopted biogas technology.

4.4.1. Reasons for Adopting Biogas Technology at the Household Level in the District

In adopting biogas technology by the adopter households, various reasons were indicated as the motivating factors. Anderson (2002) stated that decisions that involve allocation of resources include consideration of multiple alternative reasons. Hence, the reasons given for the adoption of biogas technology included: energy, economic, social, and environmental aspects. The major reasons highlighted by the respondents to install biogas digester were the high cost of other energy sources and government subsidy for the plant which constitutes about 62 (34.1 %) and 47 (25.8%) of the households respectively (Figure 4.7). The government particularly subsidies cement; biogas appliances; pipe; and contract mason for the construction of the plant; critically for the installation of biogas technology. For example; in Bangladesh, the study showed that subsidy was indicated to be a reason for 90 (60 %) of the households taking a decision to adopt biogas technology (Kabir *et al.*, 2013). The third possible reason can be associated with saving time and reducing workload. Among the sample biogas adopters, 36 (19.8 %) of them said that they benefited from saved time for further

agricultural and household activities. The other reasons for the adoption of biogas technology includes: give better quality bio-slurry for 25 (13.7%) and using as a light for about 11 (6%).

Surendra *et al.*, 2014 stated that the primary uses of biogas technology in developing countries are cooking and lighting. Getachew Eshetie *et al.*, (2006) also pointed out that, biogas is utilized both for cooking and lighting in Ethiopia. In rural areas, where electricity is absent, biogas lighting is highly appreciated. As a result, the interest in biogas plants decreases when the biogas lamps fail to work.

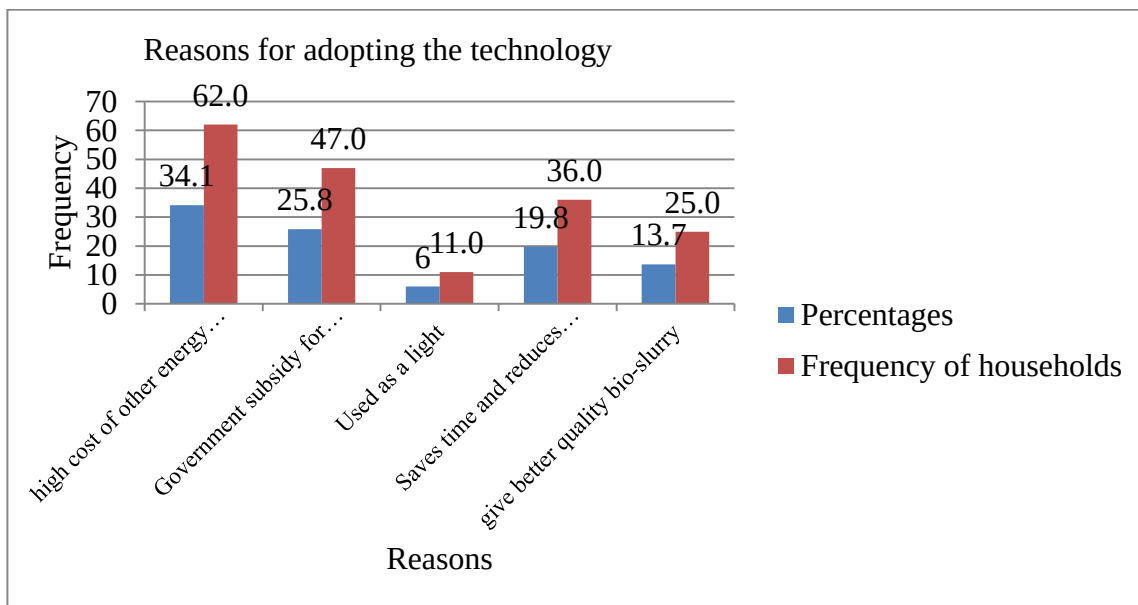


Figure 4.7: Reasons for sample households for adopting biogas technology

4.4.2. Reasons for Sample Households not to Adopt Biogas Technology

The result indicated that, 78 (43.1 %) have heard (aware) of the technology, and 103 (56.9 %) have never heard (not aware) of the technology (Figure 4.8). Having the results above; even if the interest to invest in biogas technology is too low; awareness is a noble indicator for the installation and dissemination of biogas technology on household labels. The majority of sample households are calm and seen the problems faced by biogas user friends, neighbors' and relatives and observe the easiness; complexity; institutional support, and how biogas works easily (Mulu Getachew, 2006). In this result, a reason given by 59 (32.4 %) of households was the higher installation cost, and 45 (24.7%) of households were told the problem associated with a lack of human labor. Family size was a key challenge to a

considerable number of non-adopter households in the area. In contrast with the result from key informant interviews and focus group discussions, labor in rural areas was not a problem for the adoption of biogas technology. Instead, available workforce demand for biogas operation is computed with labor from other farm activities. Hence rural farm households focused on only for other farming activities and waited to return from these activities. According to the participants, rural households often give priority to farm activities that either ensure household food security or provide profitable returns. As a result, the labor allocated to biogas operation and management would be small, which may lead not to adopting the technology. In addition, 38 (20.9%), 20 (11%), and 19 (10.4%) of the households observed the problem of less number of cattle owned, lack of awareness about the benefits of biogas technology and lack of sufficient and reliable water respectively.

To summarize the outcomes, non-adopter households observed the problems faced by adopter friends, neighbors and relatives. Therefore, due to such problems perceived by adopter households, non-adopter households were calm, and delayed to adopt the technology. In this regard, the result supports a study conducted by Mulu Getachew (2016) and Kabir *et al.*, (2013) indicated that, adjacent non-adopter households to the biogas adopters have the chance to observe the nature, benefits, and limitations of the biogas installations and usage. Hence, improving such indicated problems from adopter households can inspire and increase non-adopter households to adopt and use biogas technology (Kamp and Forn, 2016).

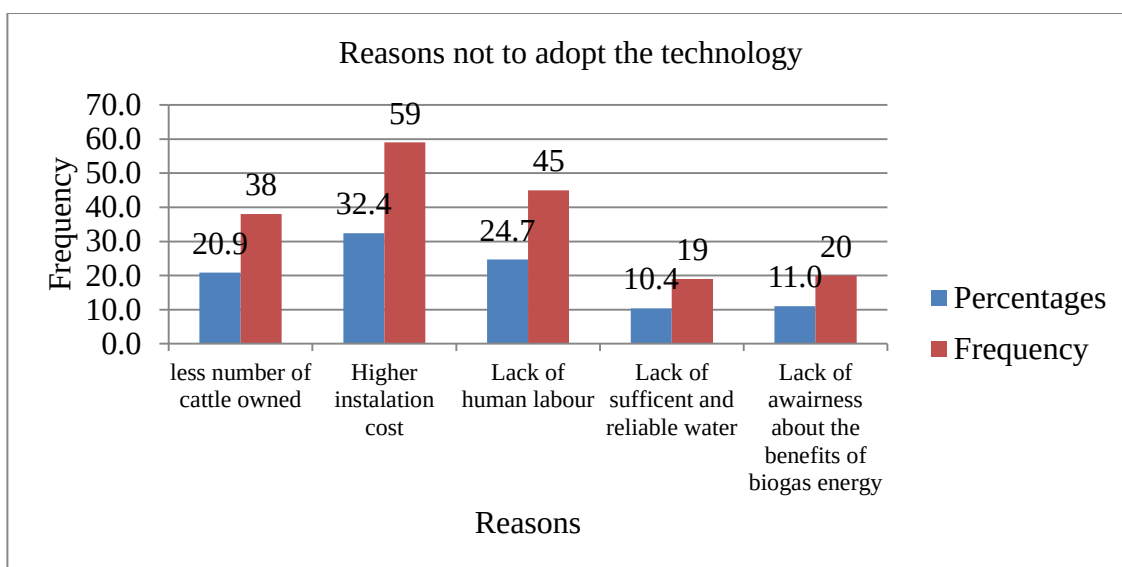


Figure 4.8: Reasons of sample households for not to adopt biogas technology

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Households in the study area most frequently use fuel wood, crop residues, cow dung, and charcoal as traditional biomass fuels for cooking and heating. For lighting purposes, the majority of responders chose modest solar panels and battery cells. Due to such problems, biogas produced from anaerobic digestion of organic waste materials, which helps to capture and utilize methane; by converting organic waste materials into biogas the process reduces methane emissions, which contribute to mitigating GHG emissions. Age, family size, farm size, cattle size, average annual income, fuel wood distance, and distance to water were the factors impacting the adoption of biogas technology in the study area.

In comparison to non-adopter households with comparable family sizes, adopter households in the research area consume less fuel wood and primarily utilize biogas for cooking, heating, and lighting. A decrease in the usage of fuel wood leads to a decrease in greenhouse gas emissions into the atmosphere. The main barriers to installing biogas and the slow rate adoption of rural households in the study area are: fewer cattle owned; higher installation costs; a shortage of labor; inadequate and unreliable water supply; and a lack of knowledge about the technology's advantages.

Based on the kitchen performance test result, by using biogas energy instead of biomass fuels, each biogas plant was potentially saved 1241 kg (34.3%) of single fuel wood and each digester was able to reduce 4.7 tons of CO₂e (from fuel wood, crop residues, cow dung and charcoal production usage) annually in net greenhouse gas emissions. Thus, biogas energy lowers greenhouse gas emissions from the atmosphere and lowers average world temperatures; it contributes significantly to mitigating climate change. The results of all of these processes show that using biogas as energy lowers the need for fuel wood, emits fewer greenhouse gases into the atmosphere, saves the work of women, protects forests, and creates waste management strategies. In order to enable more rural households to use biogas technology in the study district, future biogas energy planning strategies should focus on raising awareness of biogas energy and facilitating better access to information about biogas energy.

5.2. Recommendations

Based on the findings of the study the following recommendations were suggested;

- Upgrading the existing model of biogas technology to include different stove types which used to multi cooking purposes; this is supposed to reinforce adoption of biogas technology,
- It is necessary to find a solution to the shortage of biogas technicians, and engineers. Biogas users should be contacted in order to develop a communication network, and biogas masons with basic skill gaps should be closely monitored and addressed as soon as feasible, and
- Development and research efforts should focus on an aspect of biogas technology that lowers costs, enhances its efficiency by creating a biogas stove for baking injera, and increases the longevity of biogas lamps and related accessories.

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APPENDICES

Appendix 1: Household Survey Questionnaire

Dear Respondents:

The main purpose of this interview questionnaire is to acquire information relevant for a research entitled “Roles of biogas in saving fuel wood and mitigating greenhouse gas emissions”. The research outcome is expected to be helpful for the improvement of biogas dissemination program and other energy and environment related interventions. Therefore, your genuine answer to the interview questionnaire is a necessary condition for the reliability of this research outputs. I am very much grateful to the favorable contribution of your time and energy to the success of this study.

N.B:

✓ for some tabular questions, please put tick mark () where needed.

✓ for questions that request ranking, please write the ranks 1, 2, 3, in the boxes only for choices applicable to your case by giving value 1 for the best choice, 2 for the 2nd best, etc.

Name of interviewer: _____ Name of respondent _____ Kebele _____ Date: _____

Section one: Socio-economic and demographic characteristics of households

- 1) Gender of household head: a) Male b) Female
- 2) Age of household head
- 3) Marital status: a) Single b) Married c) Divorced d) Widow
- 4) Educational level of household head: a) Literate b) Illiterate
- 5) Family Size of household.....
- 6) Average annual income in birr (ETB).....
- 7) Cattle size of sample households.....

Table 1: Cattle size of sample households'

Fill the table below (indicate by using number 1, 2, 3, 4...)

Types of livestock	Number Kept	TLU
Calf	1017	1271
Heifer	863	863
Bull	2206	1390
Ox	2894	724
Cow	1356	1695
Total	8336	5943

8) Land size in hectare-----

Section two: Domestic energy sources

9) On average, how many minutes take to reach the place where you collect fuel wood in minute? -----

Section three: Households' awareness on biogas technology

10) Do you have awareness about biogas technology? a) Aware b) Not-aware

Section four: Utilization and Adoption of Biogas

11) Do you have biogas plant? a. Yes b) No

12) If your answer in Q12 is no what are the major reasons for not having biogas plant? If yes jump Q12.

a) Less Number of cattle owned b) Higher installation cost c) Lack of human labour d) Lack of sufficient and reliable water e) Lack of awareness about the benefits of biogas technology f) other, specify

13) Do you have access local material for biogas plant construction? a) Yes b) No

Section five: For biogas users

14) What was the major reason for starting a biogas plant?

- a) High cost of other energy sources b) Government subsidy for the plant
- c) Saves time and reduces work load d) Give better quality bio-slurry e) Used as a light

Section six: Promotion of biogas technology

15) In your view how can biogas production and utilization are promoted in Gondar district?

Section seven: Observation Schedule

- 1. Biogas plant a) Present b) Absent
- 2. Is its construction status a) Complete b) Incomplete
- 3) Functional status of biogas plant: a) functional b) non-functional
- 4) Structural problems: a) Cracked digester b) Chocking of outlet/inlet
 - c) Broken or leaking pipes d) Shortage of cow dung e) No gas
- 5) Presence of cattle: a) Present b) Absent

Section eight: Focus Group discussion Checklist

- 1) What are the major energy sources in your area?
- 2) Is there energy problem in your area? If yes, to what extent?
- 3) Do you see a need for alternative energy sources? If yes which alternatives do you think are appropriate to your area?

Section nine: KII Checklist

- 1. Which tree species are most commonly used for domestic energy consumption in your locality? Why?
- 2. What is your view on the current status of fuel wood sources? Why?

3. Is charcoal production common in your locality?
4. When was dissemination of biogas technology started in the kebele?
5. What are the problems that have been faced to on dissemination of biogas?

Appendix 2: KPT procedure in sample households

Section one: Kitchen Performance Test Format

1. Name of Household Head -----
2. Cattle size (Number) -----
3. Annual income (ETB) -----
4. Adoption of Biogas Technology: a) Adopter b) Non-adopter
5. Family size (Number)

KPT measurement for seven consecutive days

Amount of fuel wood collected in last 24 hours _____kg

Amount of fuel wood used in last 24 hours _____ kg

Number of people served in last 24 hours.....

Children 0-14 years _____ Women over 14 years_____

Men aged 15-59 years _____ Men over 59 years_____

Section two: Photographs during field survey



Figure 1: Photos taken during focused group discussion



Figure 2: Photos taken during KPT measurements of fuel wood



Figure 3: Photos taken during KPT measurements of cow dung



Figure 4: Dung stored in the inlet pit for later use

Table 2: Average biomass fuel consumption of biogas adopter households from seven consecutive days of KPT measurement

		Fuel types average daily result					
		Fuel wood consumption		Crop residues consumption		Cow dung consumption	
Days	No. of adult equiv.	Fuel wood used in 24 hrs. (kg)	Fuel wood used per adult equiv.	Crop residues used in 24 hrs. (kg)	Crop residues used per adult equiv.	Cow dung used in 24 hrs. (kg)	Cow dung used per adult equiv.
Day 1	4.1	24.5	5.9	14.4	3.5	16.9	4.1
Day 2	4	24	6	19	7.8	17.5	4.4
Day 3	4.2	31.7	7.5	28	6.7	15.5	3.7
Day 4	4.1	28.4	6.9	25.1	6.1	19	4.6
Day 5	3.8	24.2	6.4	19	5	18.4	4.8
Day 6	3.9	20.8	5.3	21.8	5.6	13.7	3.5
Day 7	4.1	30	7.3	17	4.1	12.6	3.1
Average	4	26.2	6.5	20.6	5.2	16.2	4.1

Table 3: Average biomass fuel consumption of biogas non-adopter households from seven consecutive days of KPT measurement

		Fuel types average daily result					
		Fuel wood consumption		Crop residues consumption		Cow dung consumption	
Days	No. of adult equiv.	Fuel wood used in 24 hrs. (kg)	Fuel wood used per adult equiv.	Crop residues used in 24 hrs. (kg)	Crop residues used per adult equiv.	Cow dung used in 24 hrs. (kg)	Cow dung used per adult equiv.
Day 1	4.1	42.5	10.4	32.5	7.9	30.2	7.4
Day 2	4.3	43.9	10.2	26.4	6.1	29.3	6.8
Day 3	4.7	42.4	9	23.5	5	25	5.3
Day 4	4.2	41.8	9.9	27.9	6.6	31.9	7.6
Day 5	4.5	43.3	9.6	22.9	5.1	32	7.1
Day 6	4	43	10.7	21.8	5.5	25.5	6.4
Day 7	4.2	41	9.8	25.8	3.1	26.6	6.3
Average	4.3	42.6	9.9	25.8	6	28.6	6.7

Table 4: Conversion factors used to estimate tropical livestock units (TLU)

Cattle	Conversion factor
Calf	1.25
Heifer	1
Bull	0.63
Ox	0.25
Cow	1.25

Source: Njuki *et al.*, (2013)

Table 5: Multicollinearity tests

Variables	Tolerance	VIF
Sex	.993	1.007
Age (Years)	.902	1.108
Family size	.961	1.041
Educational level	.981	1.019
Size of farm land (ha)	.796	1.257
Cattle size	.754	1.327
Average annual income (ETB)	.892	1.121
Awareness level	.984	1.016
Distance to fuel wood (Minute)	.873	1.145
Distance to main water (Minute)	.963	1.039

BIOGRAPHICAL SKETCH

Getaw Jejaw was born on February 20, 1996 in North Gondar Zone, Amhara National Regional State of Ethiopia. He attended his primary education at Abay elementary School and his secondary and preparatory education at Debark secondary and preparatory school. Then, the author joined Wollega University College of Agriculture and Natural Resources in 2016 in Natural Resource Management department and he graduated on June 28, 2018. Then after, on September 2021 the author joined school of graduate studies of Bahir Dar University College of Agriculture and Environmental Sciences. He currently studies Masters of Science in Environment and Climate Change and he is Environmental Impact Assessment and Monitoring Expert at North Gondar Zone Mine Resource Development Department.