Biogas Technology Adoption and Its Contributions to Rural Livelihood and Environment in Northern Ethiopia, the Case of *Ofla* and *Mecha Woredas*

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This is to certify that the thesis prepared by Mulu Getachew Mengistu, entitled: *Biogas Technology Adoption and Its Contributions to Rural Livelihood and Environment in Northern Ethiopia, the Case of Ofla and Mecha Woredas* and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Development Studies (Environment and Development) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Biogas Technology Adoption and Its Contributions to Rural Livelihood and Environment in Northern Ethiopia, the Case of Ofla and Mecha Woredas

Mulu Getachew Mengistu, Ph.D Thesis, Addis Ababa University, July, 2016

The implementation of domestic biogas technology programme at national level is a recent experience in Ethiopia. Consequently, there are limited empirical evidences concerning to both its dissemination and the overall impacts of the technology. Thus, this study examined the dissemination of biogas technology and its socio-economic and environmental impacts on the rural community in Northern Ethiopia. It employed a cross-sectional survey approach involving a total of 358 sample biogas user and non-user households. Both qualitative and quantitative data analysis techniques were utilized. The study results showed that the major factors influencing households' decisions on adoption of the technology include sex of the household head, educational level, cattle size, access to credit, income level, and the absence of biogas 'injera' stove. Various institutional problems like the existence of less suitable institutional structure, user training gaps, maintenance service gaps, and human resource gaps also hamper the pace of its dissemination. Besides, failure to incorporate biogas technology in the renewable energy list in documents like Energy Policy may negatively influence stakeholders' commitment towards its development and dissemination. Nevertheless, the use of biogas technology has significant contributions in improving the lives of the rural people. It helps to reduce per capita energy consumption by 75.1 MJ per week. It significantly reduces fuelwood, dung fuel, and kerosene consumptions. It also improves health and sanitation as per the perception of the majority of the respondents. It minimizes the overall household workloads on average by 13.2 hours per week and significantly increases men's involvement in the household chores. It helps to improve agricultural productivity through the use of bio-slurry and the labour saved. Fuel substitutions with biogas reduce greenhouse gas (GHG) emission on average by about 1.9 t of carbon dioxide equivalent (CO_2e) per digester per year. It reduces the depletion of woody biomass through improving efficiency of energy use and energy substitutions, and hence increases carbon sequestration. Empowering females and female-headed households, improving educational levels of the household heads, raising income levels, improving access to credit, upgrading the existing biogas model through addition of 'injera' stove, and creating satisfied biogas users are likely to increase the adoption of biogas technology. The institutional structure should be increased to programme implementation, 'woreda', level. Standby biogas technicians who can give immediate maintenance services should be assigned at 'woreda' level in the earliest time possible. Biogas being a new technology to farmers, provision of timely user training to each biogas user household involving women and children should not be compromised. Incorporating biogas technology into energy policies, proclamations, and national development plants can positively push the stakeholders to give the necessary attention to its development and dissemination. To sustainably utilize the technology, maximize its benefits, and proliferate its expansions, non-operating and partially operating biogas plants should be repaired in the earliest time possible. People's awareness about how to store and use bio-slurry should be raised. An operational platform for joint stakeholders' actions should be in place to assist in exploiting its full potentials, and seeking and realizing the carbon reduction financial incentive.

Author's Declaration

I, the undersigned, declare that this dissertation is my original work, it has not been presented for a degree in any other university and all the resources utilized for this dissertation have been duly acknowledged.

Declared by:	Confirmed by:
Mulu Getachew (Ph.D Candidate)	Dr. Belay Simane (Internal advisor)
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ACRONYMS AND ABBREVIATIONS

ABPP	African Biogas Partnership Programme
AFREA	Africa Renewable Energy Access programme
ASS	After sales services
CO_2e	carbon dioxide equivalent
CSA	Central Statistical Agency
DAP	Di-Ammonium Phosphate
EEA	Ethiopian Energy Authority
EEPCO	Ethiopian Electric Power Corporation
ENERGIA	International Network on Gender and Sustainable Energy
EREDPC	Ethiopian Rural Energy Development and Promotion Center
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
GHG	Greenhouse gas
GTP	Growth and Transformation Plan
GWP	Global warming potential
HIVOS	Humanist Institute for Cooperation in Dutch
IEA	International Energy Agency
IFA	International Fertilizer Industry Association
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied Petroleum Gas
MoARD	Ministry of Agriculture and Rural Development

MoWIE	Ministry of Water, Irrigation and Electricity
MoWE	Ministry of Water and Energy
NBPCO	National Biogas Programme Coordination Office
NBPE	National Biogas Programme of Ethiopia
NBPSC	National Biogas Programme Steering Committee
NMA	National Meteorological Agency
OECD	Organization for Economic Cooperation and Development
PCC	Population Census Commission
PID	Programme Implementation Document
QC1	Quality control Stage One
QC2	Quality control Stage Two
RBPSC	Regional Biogas Programme Steering Committee
REN21	Renewable Energy Policy Network for the 21st Century
SNNP	Southern Nations Nationalities and Peoples
SNV	the Netherlands Development Organization
TERI	The Energy and Resources Institute
TGE	Transitional Government of Ethiopia
toe	tonnes of oil equivalent
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNHCR	United Nations High Commissioner for Refugees
WBISPP	Woody Biomass Inventory and Strategic Planning Project
WHO	World Health Organization
WWAP	United Nations World Water Assessment Programme

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Operational Definitions

- **Fuelwood:** Part of a tree or shrub which is ready to be used as fuel.

- **Household**: A group of people, whether with blood relations or not, who live together and share a single meal.

- **Institution**: An entity which has its own specific line of commands with clear accountability, defined members and membership criteria, defined members' responsibilities, rules and regulations to be abided by all members, and clear objectives or goals to be achieved in specified time schedules.

- **Livelihood**: A means of attaining a living through involving assets, capabilities, and activities (Chambers and Conway, 1991).
- **Traditional biomass fuels**: Types of energy sources that are locally available and produced, and require no high level of conversion. They include fuelwood, charcoal, cow dung and crop residues. They may simply be called traditional fuels or biomass fuels.

- **Technology adoption**: Adoption of a technology, as stated in Rogers (1983), is a process in the mind that ranges from hearing about the technology, gathering information, developing interest, evaluating its attributes, to making eventual decision of either acquiring for use or rejecting it out rightly. However, this research is a cross-sectional study which focused on finding out, not the entire process of adoption, but the underlying factors that led households to the final decisions of either using or not using biogas technology. So adoption is taken as a binary decision to have or not to have biogas installation. A household is labeled as biogas technology adopter if it owns biogas technology installation; and non-adopter if it doesn't own a biogas installation.

- **Technology dissemination**: A process by which the final version of a technology is multiplied, communicated, evaluated, accepted, and spread through a certain channels over time in a given community. Thus, technology adoption is part of technology dissemination.

- **Wood-fuel**: Any fuel derived from tree or shrub including firewood and charcoal.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy is a critical requirement for human life. It deeply influences all aspects of human welfare: food preparation and preservation, access to water, agricultural productivity, health care, education, job creation, climate change, and environmental sustainability (Legros et al., 2009). Thus, access to sustainable, affordable, and dependable sources of energy is crucial to address many of the current global development challenges such as poverty, gender inequality, climate change, food insecurity, and problems of access to health care, and educational services (Bazilian et al., 2010).

However, the majority of the people in developing countries in general and Ethiopia in particular have no access to reliable and affordable sources of domestic energy. About 83 % of the total population in Sub-Saharan Africa and 91 % in least developed countries have no access to modern fuels. Even worse, access to modern fuels is much lower for rural people than the urban counterpart. By the year 2007, the proportions of urban population in Sub-Saharan Africa and least developed countries having access to modern fuels were 42 % and 27 %, respectively. But for the rural counterparts, the figures were merely 5 % and 3 % in the same order (Legros et al., 2009).

Ethiopia, being one of the least developed countries in Sub-Saharan Africa, suffers from a severe domestic energy problem. Among other things, the country’s domestic energy problem can be manifested by the relatively very low per capita energy consumption and the dominance of traditional biomass fuel use. According to IEA (2015), in 2013, the per capita total primary energy supply in Ethiopia was merely 0.51 toe while it was 0.67 toe, 4.2 toe, and 1.9 toe for Africa, OECD countries, and the world average, respectively. The same source also indicated that the annual per capita electricity consumption in Ethiopia was only 65 kWh while it was 584 kWh, 8072 kWh, and 3026 kWh for Africa, OECD countries, and the world in the same order. Moreover, in 2009, the percentage of population who relied on traditional use of biomass fuels for cooking was 93 % in Ethiopia while it was 65 % for Africa, 77 % for Sub-Saharan Africa, and 39 % for the world as a whole (IEA, 2011).

Even worse, the demand for wood-fuel far exceeds the sustainable supply in Ethiopia. In 2009, the demand for wood-fuel was estimated to be 77 hm^3 whereas the sustainable supply was merely 9.3 hm^3 (Bekele, 2011). Thus, in conditions of unaffordable and escalating prices of imported oil, inaccessibility of electricity, and increasing scarcity of wood-fuel, the option for the majority of the population would be increasing use of animal dung and crop residues for fuel which could have been otherwise used as organic fertilizer and/or animal feed. In this regard, Barnard and Kristofferson (1985) rhetorically described the options that the majority could face when wood for fuel is difficult to obtain as follows. “For many, ‘the wood-fuel crisis’ is essentially over. What they have entered is a new phase in the evolution of fuel scarcity where the struggle is not to find wood, but to obtain enough dung, straw, and crop stalks to cook their food and heat their homes”.

The scarcity of wood-fuel and associated problems are more severe in northern Ethiopia where most of the forests were lost and nearly all available areas have been converted into cultivation and pasture lands (Darbyshire et al., 2003). For instance, in Tigray and Amhara regions, dung fuel accounts for about 22.8 % and 20.4 % of the total domestic energy consumption, respectively. The situation in Gambella, Oromiya, and the national level is almost nil, 13 %, and 12 % in the same order (WBISPP, 2004).

Hence, energy transition has been occurring in the reverse direction in Ethiopia. Fuels of the lowest rungs on the energy ladder – dung and crop residues (Leach and Gowen, 1987) have increasingly become dominant in some areas. Dung and crop residues generate low-grade fire, less heat, and more smoke thereby causing health risk and make cooking chore time consuming and less pleasant. The scarcity of wood-fuel may also force households to have fewer hot meals and adopt meals often less nutritious but can be cooked more quickly (Wright, 1993). Thus, scarcity of wood-fuel has further been deteriorating the lives of the people. It causes worsening of the household welfare through spending much productive time in search and collection of it, increased use of inferior fuels, higher wood-fuel price, and reducing agricultural productivity.

Therefore, despite the country's endowment with huge potentials of renewable energy sources such as hydropower, wind, geothermal, and biofuels including biogas, the resources have not yet been developed to economically optimal levels. Various assumptions and arguments are forwarded with regard to the underdevelopment of the energy sector in the country. Some of the major assumptions and arguments include: less attention given to improve the traditional energy production, supply and utilization; little or no attention provided to develop renewable energy; the non existence of strong energy organization; the low level of household income; and lack of capital, technical know-how, and trained man power (Woldegiorgis, 2002).

However, since the last decade due emphasis has been given to the development of the energy sector and intervention efforts have already started providing some fruits. One of the crucial areas of intervention in the energy sector is the development and dissemination of biogas technology. In four regional states alone, namely Tigray, Amhara, Oromiya, and SNNP regions where feasibility study for national domestic biogas programme covered, the potential for mass dissemination of biogas technology ranges from 1.1 million to 3.5 million households (Eshete et al., 2006). Accordingly, Ethiopia has launched implementation of successive domestic biogas programmes. It already completed the first phase (2009-2013) and has begun implementing its second phase. In the first phase, it was able to build 8063 (57.6 %) out of the 14,000 domestic biogas plants intended to be constructed in the period (Kamp and Forn, 2015, 2016). Therefore, assessment of factors affecting the pace of biogas technology dissemination and the cumulative impacts of biogas installations on sustainable rural livelihood is a timely and crucial area of research to the future up scaling.

1.2 Statement of the Problem

The rural part of Ethiopia, where about 85 % of the population resides, suffers disproportionately from the problems of ever deteriorating qualities of traditional biomass fuels and their manifold adverse impacts, as well as inaccessibility of modern fuels. Thus, to address the problems of domestic energy and improve rural peoples' access to modern fuels, the government of Ethiopia has been undertaking various intervention measures. One of these measures is the development and disseminations of domestic biogas.

Though biogas technology was introduced five decades ago[1] into the country (Bekele, 1978), its dissemination for the most part has remained limited. The total number of biogas installations of all types constructed up to the establishment of NBPE was approximately 1000 (EREDPC and SNV, 2008). According to this same source, of these total installations, about 40 % were not functioning for various reasons like lack of monitoring and follow up, technical problems, reduced cattle size, and shortage of water. However, currently, with the establishment of the NBPE, the dissemination of particularly domestic biogas technology has been given due attention in the country. Lessons are believed to have been learnt from previous failures. The programme commenced with new institutional structure, standardized design, shared costs of installations that involve beneficiary households, and linking installations with credit associations. The country already completed its first phase (2009-2013) and has commenced implementing the second phase of its national biogas programme. Nevertheless, it was able to construct only 57.6 % of the total 14,000 biogas installations intended to be built in the first programme period.

Therefore, thorough understanding of the problems why the progress of biogas technology adoption has been slow in rural Ethiopia, and to what extent the biogas installations, which have been built to date, have contributed to the sustainable rural livelihood are quite crucial for the next successful plans and dissemination endeavors. Indeed, there are some researches done on biogas technology in Ethiopia. To mention a few examples, the research works include: the economic feasibility of a polythene biogas digester (Seyoum, 1986), the feasibility study of national domestic biogas (Eshete et al., 2006), the operational status of biogas installations (Negusie, 2010; Yilma 2011), bio-slurry is "a fertilizer in the making" (Eshete, 2011), the environmental-impacts of replacing dung combustion by a biogas-system (Lansche et al, 2011), biogas-bio-slurry as a package for narrowing gender disparity (Araya, 2012), a cost-benefit analysis of biogas installations (Gwavuya et al., 2012), and the role of biogas generation and use in reducing GHG emissions (Amare, 2014).

However, none of these studies provided due attention to the institutional and socio-economic factors influencing dissemination of domestic biogas. There are also scanty empirical evidences about the socio-economic impacts of the biogas installations. Moreover, with the exception of a brief study done by Eshete (2011) on bio-slurry as a fertilizer, there are hardly other studies on the environmental impacts of the technology. Amare (2014) provided no clearly stated methods about how the greenhouse emission reductions were estimated. Thus, this study aimed at filling this knowledge gaps.

Besides, interest on the problem was initiated due to personal experiences and observations as well as reading from literature. In the area where I grew up, due to scarcity of wood-fuel, it is very common to observe children and women competing for dung fuel in communal grazing fields. Seeing the problem of household energy in the area, it was about a dozen years ago that the government built model biogas installations in the area. But for a couple of reasons that in fact needs assessment, the biogas installations did not survive for long. However, recently, I have learnt from literature that dissemination of domestic biogas installations has been given a new emphasis and an independent office has been established for the purpose. Thus, this research is intended to study dissemination of biogas technology and its overall impacts on user households and the community as a whole.

1.3 Objectives

The main objective of this research was to investigate biogas technology adoption and its contributions to rural livelihood and environment in Northern Ethiopia. Specifically, the study was intended to:

1. identify factors affecting households' decisions on adoption of biogas technology;
2. examine institutional factors influencing the dissemination of biogas technology;
3. evaluate the socio-economic impacts of biogas technology on user households and the community at large;
4. quantify environmental benefits of biogas technology in reducing GHG emissions and woody biomass depletion, and improving the soil fertility.

1.4 Research Questions

1. What are the major factors influencing households' decisions on adoption of biogas technology?
2. How do institutional factors affect dissemination of biogas technology?
3. What are the socio-economic impacts of biogas technology on user households and the community at large?
4. To what extent does biogas technology reduce GHG emissions and woody biomass depletions, and improve soil fertility?

1.5 Significance and Scope of the Study

Given modern energy is critically important for rural transformations, biogas is one of the promising modern sources of energy particularly for dispersed and remote rural settlements where electricity connection from the grid system is almost impossible from economic feasibility point of view. Biogas is a multipurpose technology which helps to resolve or minimize the problems of domestic energy, health risks associated with traditional use of biomass fuels, unemployment, environmental sanitation, climate change, and land degradation simultaneously.

However, despite the presence of huge potential and more than five decades time since its introduction into the country, adoption and dissemination of biogas technology is very much limited. Clear understanding of a problem is a decisive step towards successful interventions. Thus, this study uncovered factors affecting its adoption and dissemination, its socio-economic and environmental impacts. Therefore, the results of this study is expected to be helpful for policy makers in the sense that information of a more local situations of different parts of a country is of crucial importance in order to design appropriate policies and strategies that compromise spatial disparities. It may assist programme planners to improve their upcoming plans and programmes. It can still help administrative bodies for their informed decisions in taking appropriate remedial actions against domestic energy and related environmental problems. Donor and funding agencies may as well use the information as an input to their decision in financing future biogas installations. Furthermore, the results of the study can fill the existing literature gaps in the topic under discussion specific to the study sites and serve as future reference for researchers and other individuals.

The study was delimited to *Ofla* and *Mecha woredas* located in Tigray and Amhara regions, respectively. However, the findings of the study may be useful and applicable to similar *woredas* in the regions specified and even beyond.

The study primarily focused on factors affecting households' decisions in adopting domestic biogas technology, institutional factors influencing dissemination of domestic biogas technology, socio-economic and environmental impacts of domestic biogas technology on user households and the nearby communities. The institutional factors spun around the pre-planned biogas programme activities or functions. Assessment of socio-economic impacts of biogas technology emphasized on the benefits of the technology in reducing household energy consumptions; perceived benefits of the technology on health; the role of the technology in reducing household workloads; and bio-slurry management and use, the respondents' practical experience on its relative fertilizer qualities, and the amount of chemical fertilizer forgone. Examination of the environmental benefits of biogas technology focused on the roles of the technology in reducing GHG emissions and woody biomass depletion, and direct and indirect benefits of the technology towards improving the soil fertility.

1.6 Organization of the Paper

This paper comprises of five chapters. The first chapter, introduction, includes background of the study, statement of the problem, objectives, research questions, and study significance and scope as well as this specific part. The second chapter consists of review of the related literature. The third chapter encompasses research methodology. The fourth chapter presents results and discussions. The last, fifth chapter, is devoted to conclusions and recommendations.

CHAPTER TWO

REVIEW OF THE RELATED LITERATURE

2.1 Global Overview of Biogas Technology: Disseminations and Benefits

2.1.1 Disseminations of Biogas Technology

2.1.1.1 Current Dissemination Status

Biogas, the mixture of gases generated from biodegradable resources in an anaerobic fermentation by methanogenic bacteria, has increasingly been utilized in the globe. It comprises 50 to 70 % of methane (combustible gas); 30 to 40 % carbon dioxide; 5 to 10 % hydrogen; 1 to 2 % nitrogen; 0.3 % water vapour, hydrogen sulfide, and other trace gases by volume (Lam et al., 2009; Lam and ter Heegde, 2011).

The beginning of anaerobic fermentation particularly for the treatment of organic wastes traced back to the period before the Birth of Christ (Deublein and Steinhauser, 2008). However, it was in 1895 for the first time that biogas generation from a “carefully designed” sewage treatment installation began providing street light in Exter in England (Mital, 1997). People’s interest to use biogas as fuel grew particularly during the Second World War. In 1940s, French scholars showed particular concern to the development of biogas technology and as a result a large number of biogas installations were built in its colonies. It was also during this period that fuel famished French and Germany commenced using biogas to fuel vehicles and tractors. With the end of the war, a number of countries including England, United States of America, Canada, Russia, Japan, China, Kenya, Uganda, South Africa, New Zealand, and India became more interested in the use of biogas (Mital, 1997).

Nevertheless, interest on the utilization of biogas diminished considerably since about the mid 1950s mainly due to the low-priced availability of fossil fuels. Consequently, nearly all biogas installations were abandoned (Mital, 1997; Deublein and Steinhauser, 2008). However, interest on biogas generation revived once again following the global oil shocks of the 1973 together with the mounting concern for environmental protection in the decade (Mital, 1997; Deublein and Steinhauser, 2008). Thus, since this decade onwards, the use and dissemination of biogas technology has continued in both developed and developing countries. Indeed, the focus and scales of biogas generation differs between developed and developing countries. Developed countries focus dominantly on large scale biogas installations for combined heat and power generation whereas the primary focus of developing countries is on the construction of small scale biogas digesters that particularly generate heat for cooking (REN21, 2013).

Among the developed world, Germany is by far the leading country in biogas generation. In 2010, it had about 5,800 large scale biogas installations from which it generated 2300 MW of electricity. Whereas United States of America possessed merely 160 anaerobic digesters from which it generated 57.1 MW of electricity (Bramley et al., 2011). In this same year, Europe's total biogas production was 10.9 million tonnes of oil equivalent from which Germany accounted 61 % while United Kingdom, the second country in the hierarchy, constituted only about 16.5 % (van Foreest, 2012). Germany has also a grand plan to raise the number of biogas projects to 43,000 up to 2020 (Deublein and Steinhauser, 2008). Next to Germany and United Kingdom, other top biogas producing countries in Europe encompass: Italy, France, the Netherlands, Czech Republic, Spain, and Austria (Kaparaju, 2013).

Of the developing countries, China outstandingly leads the world in the number of domestic biogas plants. By the end of 2010, the total number of domestic biogas installations reached 40 million from which the country produced 15,400 hm^3 biogas annually (Dong, 2012). By the end of 2011, the number of domestic biogas installations grew to 41.7 million (Zuzhang, 2013). In addition, the country's grand plan of building 6 million new domestic biogas plants every year in the 11th Five Years Plan continued to be implemented in the 12th Five Years Plan (2011-2015) of Rural Biogas Construction (Chen et al., 2010; Christiaensen and Heltberg, 2012). Thus, as shown in Figure 1, since about 1982, there has been a continuous and uninterrupted growth in the number of small scale-domestic biogas installations in China.

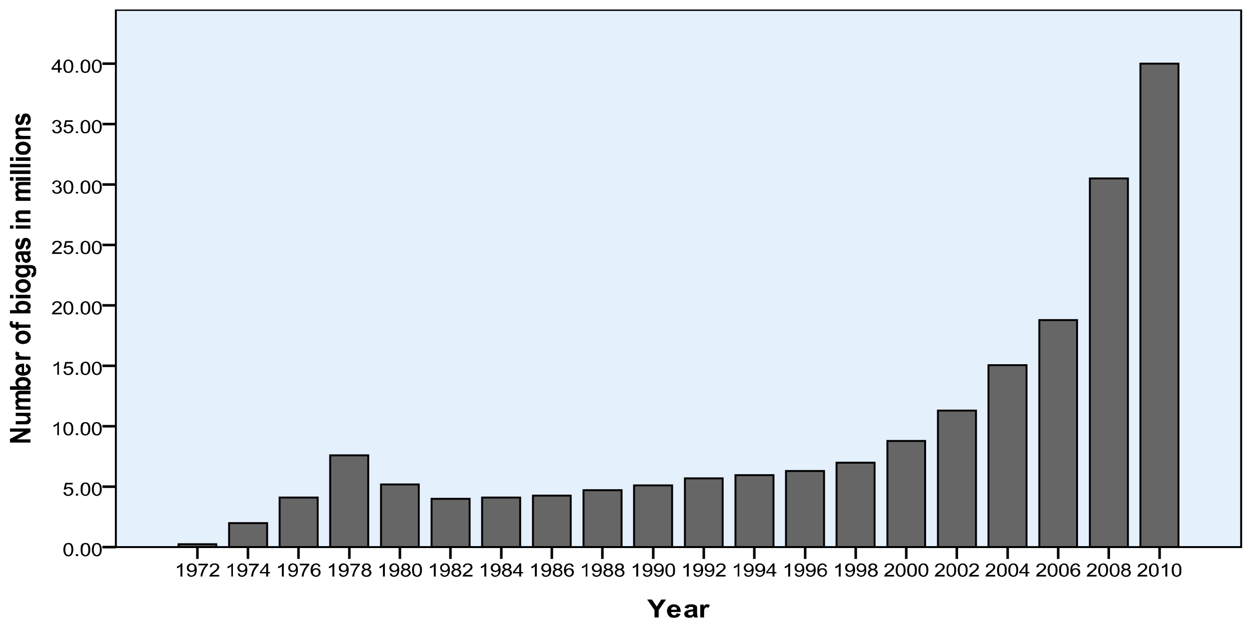

Figure 1. Expansion of domestic biogas installations in china

Sources: Compiled from (Deublein and Steinhauser, 2008; Yao, 2010; Dong, 2012)

China is also among the world's top countries in the number of large scale biogas generation. In 2010, from a total of 4700 large scale agricultural and 1600 industrial organic waste biogas installations, it produced 4 billion cubic meters biogas annually (Dong, 2012).

India stands second in the number of domestic biogas installations in the world. By the end of March 2011, the number of its domestic biogas installations reached 4.4 million. There are also a number of other Asian countries where domestic biogas installations are being expanded. Some of these countries with their total numbers of biogas installations constructed up to 2011include: Nepal (268,464), Vietnam (152,349), Bangladesh (26,311), Cambodia (19,173), Indonesia (7835), Lao Peoples Democratic Republic (2888), and Pakistan (2324) (SNV, 2013). In comparison to its population size, Nepal has the largest number of biogas installations in the world (Deublein and Steinhauser, 2008).

Some African countries have also been working on the dissemination of biogas technology with renewed interest. The total numbers of biogas installations constructed up to 2011 in nine African countries, namely, Rwanda, Ethiopia, Tanzania, Kenya, Uganda, Burkina Faso, Cameron, Benin and Senegal summed up 24,990 (SNV, 2013). ABPP, which was created by SNV and HIVOS, planned to construct 70,000 biogas installations in six African countries (Kenya, Burkina Faso, Ethiopia, Tanzania, Uganda, and Senegal) with the aim to provide sustainable source of energy for about half a million people by the end of 2013 (AFREA, 2011). HIVOS manages the programme, SNV provides technical assistance whereas national agencies take the responsibility of implementing the programmes with a range of partners. The major source of funding for ABPP is the Dutch Ministry for Development Cooperation (DGIS). Currently, ABPP is active in five countries with the dropped out of Senegal at the beginning of 2012 (ABPP, 2012).

2.1.1.2 Controls of Dissemination

Dissemination of renewable energy technologies in general and biogas technology in particular are constrained by a number of factors. Some of the factors that specifically influence dissemination of biogas technology include policies and institutions, financial constraints, subsidies, availability of inputs, awareness about the technology, consumers' considerations, and success stories about the technology.

The use of the right policy instruments and institutions can accelerate dissemination of energy technologies; as a result, multiple societal challenges related to energy may be minimized or removed (IIASA, 2012). Appropriate government policies create conducive environments to stimulate dissemination of renewable energy technologies, mobilize resources and encourage involvement of private investors (Karekezi and Kithyoma, 2003). Feng et al. (2012) also pointed out that the existence of supportive policies initiates the development of renewable energy resources. To the contrary, unregulated development programmes, as in the case of biogas technology in Africa at present, will not only impair its future development and manifold benefits to the farmers but also be a loss to the national economy (Okudoh et al., 2014).

Success in the dissemination of biogas technology in Nepal is predominantly attributed to its appropriate policies and institutional arrangements in the sector. Some of the important institutional and policy related measures which deserve mentioning encompass: practicing demand-and market based biogas technology dissemination programme, taking stringent quality control measures, using performance rating technique on biogas technology installers, providing incentives for better quality installing companies, selecting and implementing single standardized biogas model, and providing consistent and sustained subsidies. The use of single standardized biogas technology model has made quality control task easier. Practicing stringent quality control measures has helped to build confidence among technology adopters, credit institutions and donor organizations (Winrock International, 2007).

Financial constraint is one of the most frequently cited challenges limiting the expansion of biogas technology. According to Arthur et al. (2011), though biogas technology can solve some of the energy and environmental problems of rural and urban communities and industrial institutions, it requires high initial investment cost. The principal obstacle for the use of the technology by rural cattle farmers is their inability to afford the full cost of biogas installations. Similarly, Bensah and Brew-Hammond (2010) indicated that the main problem to the expansion of biogas technology in Ghana remains the inability of the farmers to cover the full cost of investment. Thus, financial incentives such as soft loans and subsidy are among the recommendations forwarded for the success of biogas technology dissemination programmes (Arthur et al., 2011).

Subsidies enhance the speed and relative advantage of adoption. Subsidies lead to adoption of technologies by those individuals who would not adopt otherwise (Rogers, 1983). Certain technologies have socially desirable characteristics. Adoption of such technologies is beneficial not only for owners but also to the society. In several OECD countries, firms and individual households can collect government subsidies if they adopted technologies that have socially desirable characteristics. Even if cost of investment exceeds private benefits but lower than the social benefits, government should provide subsidies to stimulate adoption of socially beneficial technologies (Aalbers et al., 2007). Similarly, Lam and ter Heegde (2011) argued that subsidies are justifiable if investment of individuals benefit the whole community. Furthermore, FAO (1996) stated that it is unjustifiable to make the individual users to shoulder the entire cost of the technology provided that benefits are shared by the non-users too. Therefore, subsidies to adoption of biogas technology are justified not only to increase the relative advantage of the technology to adopters but also to benefit the whole society.

Even the sizes of subsidies greatly influence the rate of adoption. For instance, in China at one point in time, interest in adoption of biogas technology faded away immediately after the government reduced subsidies from two-third of the investment cost to one-third (Rajendran et al., 2012). Bajgain and Shakya (2005) also revealed that without subsidies, the Nepalese farmers would have little financial incentive to adopt the biogas system. In fact, increasing subsidies may not always lead to intended positive adoption outcomes. Individuals who adopt a technology for the sake of getting the subsidies may be less motivated to keep on using the technology (Rogers, 1983). In this regard, Eshete et al. (2006) pointed out the existence of a popular view that full subsidies deter beneficiaries from exercising solicitous ownership care for the technology. Therefore, in principle the amount of subsidy to household size biogas installation should be equivalent to the difference between the overall net benefits of the technology and the benefits exclusively enjoyed by individual users (FAO, 1996).

Availability of sufficient inputs for biogas digesters such as animal manure and water are among the principal factors limiting the pace of biogas technology expansion. Even in some circumstances, where households possess adequate number of livestock, the nature of grazing systems: nomadic, semi-nomadic, and free grazing systems have created inconvenience to gather manure and feed the biogas digesters (Winrock International, 2007). In Pakistan, Nepal, and some African countries like Ethiopia, a larger proportion of cattle are roaming in the field. This clearly minimizes the availability of manure to feed the biogas digesters. In contrast, in countries like China, Vietnam, and Cambodia where large pig populations are confined, nearly all the available manure can be fed to the biogas digesters. The amount of biogas generation per unit manure also varies with the livestock type. A kilogram of manure from cattle (buffalo), pig, chicken, and human can produce 23-40 dm3, 40-59 dm^3, 65-116 dm^3, and 30-50 dm^3 of biogas, respectively (Lam et al., 2009; Lam and ter Heegde, 2011).

Awareness about the technology is another important constraint limiting adoption and dissemination of biogas technology. For instance, in Ghana, lack of awareness about the technology is mentioned to be one barrier for the adoption of biogas. Some cultural outlooks like stigmatization of utilization of human excreta as input to biogas digesters can also potentially discourage its dissemination (Arthur et al., 2011).

Success or failure stories of previous biogas installations can also promote or constrain biogas dissemination. According to Gitonga (1997) where the first biogas installations perform well, words of mouth from satisfied users encourage other potential users to build their own installations. Where installations failed, failure creates a negative impact on the dissemination of the technology, discouraging potential users in the process. Winrock International (2007) also stated that unsuccessful biogas demonstration projects may have deterring effects instead of enhancing adoption of the technology. In Africa, the success of biogas demonstration projects has been relatively low. Several reasons are given for the failures. Some of the reasons include: absence of focused energy policy, poor design and construction of the biogas installations, wrong operation and lack of maintenance by the users, lack of project monitoring and follow up, and low ownership responsibility by the users (Arthur et al., 2011).

Furthermore, consumers consider various issues in their decisions of either adopting or rejecting the use of a modern energy technology. Among other things, cost is a critical factor affecting consumers' decisions. Several consumers prefer a modern energy technology that has low initial cost rather than the one that minimizes operation cost which runs over an extended period of time. This creates a balance between initial costs against operation costs. In low income countries where people lack access to cash and/or credit, low initial cost bias is more prevalent (Reddy and Painuly, 2004). In support of this argument, Gebreegziabher (2007) stated that the high initial investment cost of biogas technology remains to be a major obstacle for its widespread dissemination in Ethiopia.

Consumers also judge the various attributes of a modern energy technology in their decisions of adoption. Rogers (1983) identified five attributes of a technology that can accelerate or retard the rate of its adoption. These attributes are relative advantage, compatibility, complexity, trialability, and observablity. The relative advantage of a modern energy technology may be evaluated in economic terms, social prestige, convenience, and satisfaction. A renewable energy technology which is perceived to have better relative advantages than the one at hand is likely to be adopted faster. A technology that is compatible to the existing cultural values, norms and experiences of a given community has greater probability to be adopted quicker than others. A technology that is easier to understand and utilize is expected to be adopted more rapidly than those requiring new knowledge, understandings and skills. Still a technology that can be tried and experimented easily for its appropriateness, and has observable results to other individuals is likely to be adopted more rapidly than others. Similarly, Khoumbati et al. (2010) indicated that in the traditional technology adoption model, consumers' adoption of a technology is primarily determined by perceived 'ease of use' and perceived 'usefulness'. Hence, in the process of making decisions of either accepting or rejecting a new technology, consumers consider whether the technology is easier to utilize (i.e., perceived ease of use) and improves one's productivity (i.e., perceived usefulness).

2.1.2 Benefits of Biogas Technology

Biogas technology offers a wide range of benefits which include economic, health, social, and environmental ones.

2.1.2.1 Economic Benefits

Two of the most important outputs of biogas technology are energy and bio-slurry. Biogas energy is utilized commonly for cooking, lighting, refrigeration, and running internal combustion engine (FAO, 1996). Biogas burns more efficiently as compared to fuelwood and dung. It burns at an efficiency of about 60 % whereas fuelwood burns at 5 % to 8 % efficiency in open fire place and dung burns at 60 % of that of fuelwood (FAO, 1997). Unlike the use of traditional biomass fuels, cooking with biogas is much easier because there is no need to keep the fire burning (Arthur et al., 2011).

Biogas installations can generate electricity and offer transportation fuel. Electricity generated from biogas could be useful for local pumping, lighting, communication, refrigeration, etc. When methane, the combustible component of biogas, is enriched, it can be used as transportation fuel (Larson and Kartha, 2000; Murphy et al., 2004). With regard to the role of biogas as transportation fuel, Kapdi et al. (2005) stated that after removing carbon dioxide, biogas enriched in methane becomes equivalent to natural gas. Thus, methane enriched biogas can be useful for all applications that natural gas can do.

The bio-slurry from biogas digesters has been attested to be the best organic fertilizer which will lead to increased crop productivity. It can substitute chemical fertilizer and thus reduces the importation of chemical fertilizer and saves foreign currencies (Arthur et al., 2011). As stated by Breinholt (1992), the ammonia content of bio-slurry from biogas digester is about 10 % higher than the fresh manure. Moreover, bio-slurry is easier to dose and apply on crop fields than the fresh manure as it is less viscous and lumpy manure. Biogas effluents are also rich in phosphorus (the most expensive fertilizer) and potassium.

Biogas technology generates employment opportunities for both skilled and unskilled labour. Specifically, in a well organized biogas development sector, biogas technology expansion opens employment opportunities for masons, plumbers, civil engineers, and agronomists. They are usually key promoters of the technology. Building of biogas installations, design and production of appliances, and construction equipments are crucial areas of employment opportunity. Researchers may engage themselves in the area of improving the biogas system (Lam et al., 2009; Arthur et al., 2011). For instance, in China, India and Germany, the total estimated number of people who directly or indirectly engage in biogas related jobs were 90,000, 85,000, and 50,000 respectively (REN21, 2013).

In a nutshell, Ghimire (2008) enumerated the economic roles of biogas technology as follows. It saves expenditures on fuel sources; saves time to utilize in other income generation activities; increases soil fertility and reduces the required quantity of chemical fertilizer due to the use of bio-slurry; reduces health expenditures due to a decrease in smoke-borne diseases; and creates employment opportunities.

2.1.2.2 Health and Social Benefits

The use of biogas technology has numerous health and social benefits. The health benefits encompass: reduction in smoke borne diseases such as headache, eye-burning, eye-infection, and respiratory organ infection; improvement in household sanitation via toilet connection with bio-digesters and absence of sooth and ashes in the kitchen; and reduction in burning accidents (Ghimire, 2008). Similarly, Bajgain and Shakya (2005) revealed that utilization of biogas greatly ameliorates the quality of indoor air. It burns cleanly so that its use minimizes eye illnesses which results from burning of traditional biomass fuels. Besides, it assists maintaining sanitation of areas surrounding households via dung management and hygienic toilets connected to biogas digesters. Thus, it lowers the probability of expansion of contagious diseases. In other words, as stated by Aggarangsi et al. (2013), biogas technology provides health benefits not only to its users but also to the whole community in its environs. Indeed, Bajgain and Shakya (2005) also remind that smoke free rooms may not always be advantageous. The smoke is habitually utilized to keep out insects. But the smoke free biogas stoves are unable to keep mosquitoes away.

Globally, around two million deaths a year from pneumonia, chronic lung disease, and lung cancer are linked to indoor air pollution from the use of solid fuels. In least developed and Sub-Saharan Africa countries, more than half of all the deaths from these three diseases are associated with solid fuel use while it is merely about 38 % for the overall developing countries (Legros et al., 2009). Thus, clean energy interventions such as dissemination of biogas technology in these regions can considerably reduce deaths due to indoor air pollution.

Biogas technology has also various social roles. It improves social relations via minimizing bad odors and environmental pollutions of organic wastes which would have been otherwise serve as a source of grievance among neighbours and negatively affect social relations (Aggarangsi et al., 2013). It saves time for social activities; it improves social status in the community; it lessens women and children's work burden; and it offers brighter light that assists quality education and household duties (Ghimire, 2008). Similarly, ENERGIA (2010) stated that the use of biogas installation cuts back time spent on fuelwood collection, cooking, and cleaning utensils and kitchens. This saved time is utilized for rest and leisure, schooling, social activities and/or productive purposes which definitely empower women and promote women and girls' education. The bright biogas light also assists in succeeding in children's educational performances.

In Nepal, due to the use of biogas, women are able to save on average three hours daily from the overall time required for cooking, cleaning pots, and collecting fuelwood (Winrock International, 2007). Another study in Nepal revealed that biogas users on average save 96 minutes per day for cooking as compared to traditional stove users. Moreover, biogas is a clean cooking fuel. Consequently, the time saved for washing cooking utensils is estimated to be on average 39 minutes per day (Renwick et al., 2007). This time saved may be utilized for schooling or other productive purposes. Children who have been tightly occupied with fuelwood collection could get time to attend school. Thus, the use of biogas narrowed the gap in educational status between males and females (Arthur et al., 2011).

2.1.2.3 Environmental Benefits

Biogas technology offers a wide range of environmental benefits. It provides sustainable source of energy and soil enriching bio-slurry as a by-product, ii) it gives an opportunity to treat and re-utilize variety of organic wastes, iii) it minimizes the environmental impacts of GHG emissions, and iv) it reduces land use problem associated with disposing organic waste (Aggarangsi et al., 2013).

Biogas technology is one of the promising solutions to the diverse environmental problems associated with the use of traditional biomass fuels. According to Arthur et al. (2011), the rampant exhaustion of wood-fuel supplies, predicted increase in wood-fuel demand in the future and the resulting social and environmental effects urge the need to look for alternative sources of cooking fuel in developing countries. Consequently, biogas technology has been identified as one of the promising options to reverse deforestation and related problems. Goldemberg and Lucon (1996) also indicated that heavy dependence on wood-fuel in less developed countries is a source of local air pollution and deforestation, and accounts a considerable portion of the GHG emissions. Hence, the solution for energy related problems include improving energy efficiency and use of technological options such as biogas.

The use of biogas technology could assist in resolving different problems that are associated with utilization of solid biomass fuels. It helps to manage animal dung and night soil effectively. The effluents from biogas digester are high grade organic fertilizer and thus increase productivity and reduce the need to expand croplands to forest areas. The reduced pressure on forest resources will also have its own positive implications on watershed management and soil conservation (Shrestha, 2010).

The process of anaerobic fermentation that changes manure to methane-rich biogas reduces GHG emissions from manures considerably. It reduces the consumption of environmentally unfriendly fossil fuels like coal for electricity generation. Thus, use of biogas replaces two important GHG sources-manure and coal combustion (Cu´ellar and Webber, 2008). Similarly, Arthur et al.

(2011) contended that biogas minimizes GHG emissions, and hence assists the world climate change mitigation efforts via capturing methane and reducing use of fossil fuels.

In Nepal, it was found that the total GHG emissions from biogas users and non users were 3.7 t and 6 t of CO_2e per household per annum, respectively. The average amount of GHG emission reduced per biogas installation was estimated to be about 2.4 t per annum (Shrestha, 2010). According to Renwick et al. (2007), the average amount of GHG emission reduction per each domestic biogas installation was estimated to be about 5 t of CO_2e per annum.

Biogas also reduces surface and subsurface water pollution as organic waste substances are locked up in biogas digesters. Urban centers solid and liquid waste disposal problems can be resolved using biogas technology. A public site visited by about 2000 individuals per day can roughly generate 60 m^3 biogas (Arthur et al., 2011). In this regard, Gebreegziabher (2007) emphasized that anaerobic fermentation in biogas digesters decomposes organic materials and wipes out pathogenic microorganisms, and thus reduces environmental pollution.

2.2 The Energy Ladder in Developing Countries with a Focus on Sub-Saharan Africa

The concept, also called the model, of ‘energy ladder’ has been utilized to illustrate the gradual transition of households from the use of traditional biomass fuels to modern fuels. It makes an analogy between household fuel choices and a ladder. Households who use traditional fuels like dung, crop residue, and fuelwood are considered to be on the lower rungs of the ladder whereas those households who use such fuels as LPG, natural gas, or electricity are assumed to be on the upper rungs of that ladder (Hosier, 2004). Thus, the ladder ranks domestic fuels in a spectrum ranging from traditional biomass fuels such as dung, crop residues and wood through kerosene and gas to eventually electricity (UNDP, 2000). Biogas energy is placed between kerosene and LPG on the energy ladder (UNHCR, 2002).

The model explains that households climb up on the ladder and replace one fuel type with another as their income increases (Leach, 1992; Mapako and Mbewe, 2004; Maconachie, 2009). However, income is not the only factor affecting energy transition. Other factors affecting household fuel choices and energy transition include: access to various fuels, cultural preferences, health impacts, level of safety, availability of government subsidies (donor funding), and access to credit to overcome the high investment costs of modern energy technologies and appliances (Masera et al., 2000; Mapako and Mbewe, 2004; O'Sullivan and Barnes, 2006).

Besides, empirical evidences on energy transition revealed that reality is more intricate than the simple energy ladder model suggests (Martins, 2005). Energy transition is seldom a unidirectional process (TERI, 2007). Households do not wholly abandon traditional fuels when they ascend the energy ladder rather they tend to utilize multiple fuels. Thus, in explaining energy transition, 'fuel stacking' or multiple fuels use model is more appropriate than the 'energy ladder model' (Masera et al., 2000; Mekonnen and Köhlin, 2008; Wuyuan et al., 2008; Jan et al., 2012). With increasing wealth, cleaner, more efficient, and more convenient fuels gradually substitute the solid fuels. Hence, moving up the energy ladder tend to happen bit by bit as the majority of low- and middle-income households utilize a combination of fuels in meeting their energy requirements (WHO, 2006) (See Figure 2).

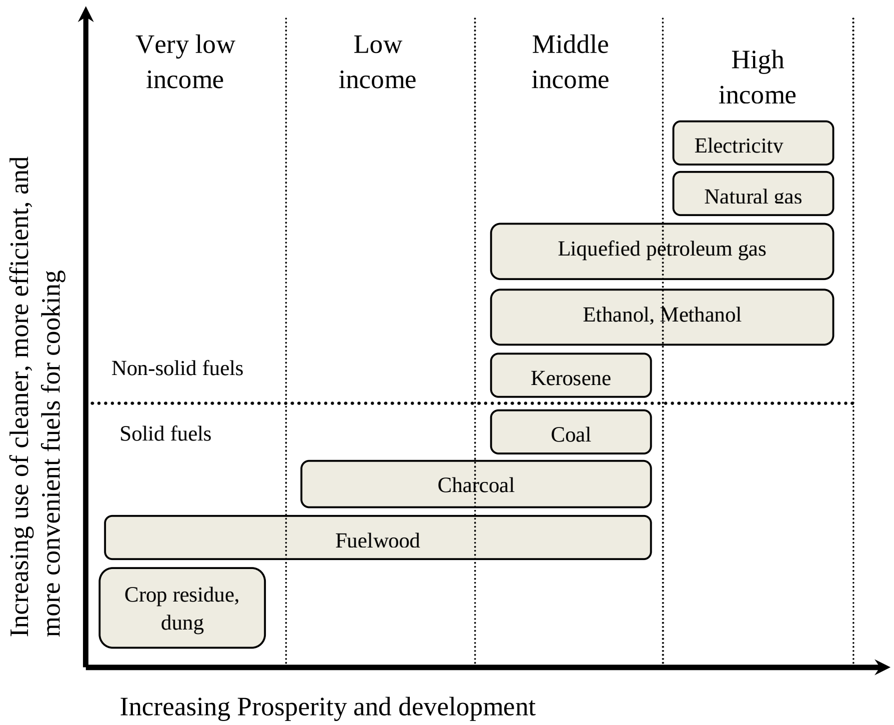

Figure 2. The energy ladder

Source: WHO, 2006

Energy is a key requirement for human life. It greatly influences all aspects of human welfare (Legros et al., 2009). Thus, access to sustainable, affordable, and modern sources of energy is decisively important to addressing many of the current global development challenges such as poverty, gender inequality, climate change, food insecurity, and inaccessibility to health care and educational services (Bazilian et al., 2010). Consequently, despite the absence of Millennium Development Goals on energy, it is underscored that the goals can never be realized without a substantial increase in quality and quantity of energy sources (N'Guessan, 2012). Hence, a key strategy in addressing the energy needs of the rural population is to accelerate moving up of the energy ladder. Theoretically, it is believed that a remarkable improvement in living standards can be achieved with small inputs of modern energy (UNDP, 2000).

However, the majority of the people in poor countries have limited access particularly to modern energy sources. As a result, they heavily rely on traditional biomass fuels and occupy the lower rungs of the energy ladder (Hosier, 2004; Mapako and Mbewe, 2004). In 2009, about 2.7 billion people (40 % of the global population) relied on traditional biomass fuels for cooking. Over 95 % of these people are either in Sub-Saharan Africa or developing Asia (IEA, 2011). These regions were indicated to be the first and second most energy-poor regions in the world, respectively (IEA, 2014).

By the year 2007, the share of total population lacking access to modern cooking fuels in Sub-Saharan Africa was 83 % (Legros et al., 2009). The figure is still high in the very recent International Energy Agency report. Around 80 % of the population in the region has still primarily relied on traditional biomass fuels for cooking. Five Sub-Saharan African countries alone, namely, Ethiopia, Nigeria, Democratic Republic of Congo, Kenya, and Tanzania roughly comprise of 50 % of the region's population relying on traditional biomass fuels for cooking. More than 50 % of the population in 42-countries of the region utilizes these fuels to meet their cooking needs and the dependence goes beyond 90 % in 23 of these countries (IEA, 2011). Even worse, access to modern cooking fuels is much lower for rural people than the urban counterpart. By the year 2007, the proportion of rural population lacking access to modern cooking fuels constituted 95 % while it was 58 % for the urban counterpart (Legros et al., 2009).

Sub-Saharan Africa is also the least electrified region in the world. In 2011, only 31.8 % of its population had access to electricity while it was 99 % for North Africa, 83 % for developing Asia, 77.6 % for Southeast Asia, 91 % for Middle East and 95 % for Latin America (See Figure 3). The region accounted about 47.7 % of the global population that live without access to electricity (REN21, 2014). Similarly, IEA (2014) reported that though there is a wide variation across the region, from the total 915 million people in the region as high as 625 million have no access to electricity. About 80 % of the people who lack access to electricity in the region reside in rural areas. The disparity in electric power distribution in the region can be understood from the fact that out of 90 GW on-grid electric-power generation capacity in 2012, roughly half of it was in South Africa.

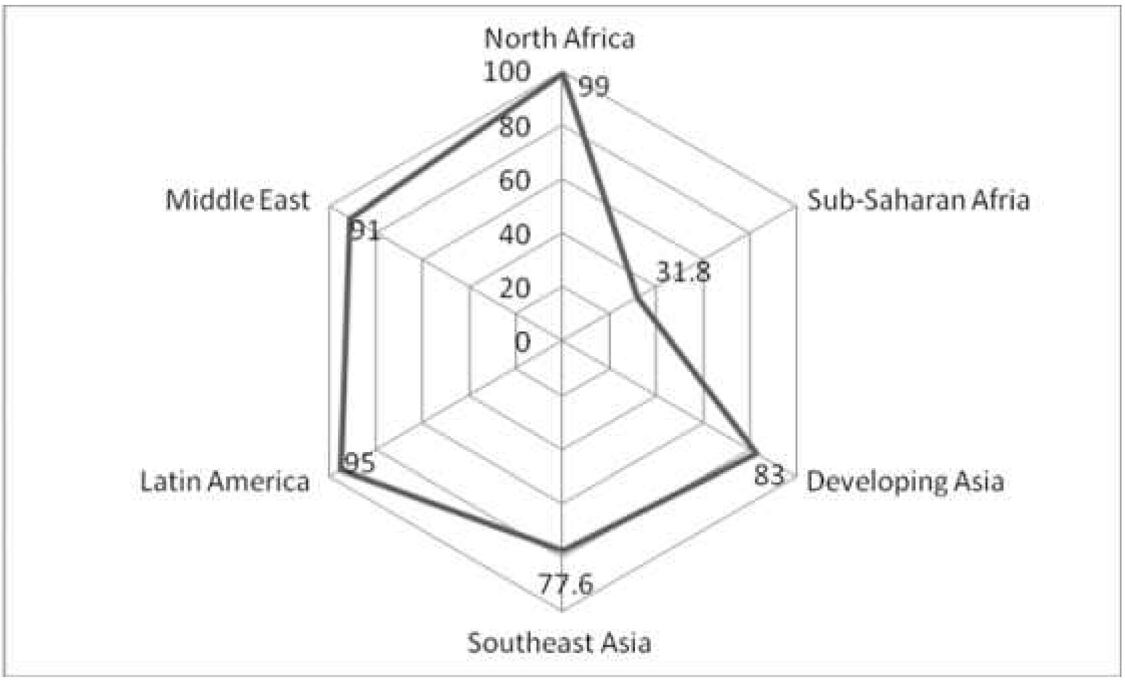

Figure 3. Share of population with access to electricity in developing regions

Source: Adapted from REN21 (2014)

Moreover, Sub-Saharan Africa is the only region in the globe where the number of people who lack access to electric power is increasing over time. But it has the largest undeveloped hydropower potential in the world (WWAP, 2014). Similarly, IEA (2014) indicated that despite the existing tremendous positive effort towards improving access to electricity, Sub-Saharan Africa is the only region in the world where the rate of population growth is outpacing that of expansion of electricity. The region has the lowest per capita electricity consumption in the globe too. Its annual per capita electricity consumption was only 535 kWh while it was 605 kWh for

South Asia, 1696 kWh for Middle East and North Africa, 1646 kWh for all developing countries, and 3044 kWh for the world average (World Bank, 2014).

It is anticipated that traditional biomass fuels will continue to be the primary cooking fuels in most rural communities in the region for some years to come. Hence, minimizing energy-poverty in this situation depends on the scale of utilizing technologies that minimize the harmful effects of traditional biomass fuels. Among others, the use of biogas technology and improved stoves was indicated to be vital to increase cooking efficiency, reduce smoke, lessen fuelwood consumption, and improve the overall safety (UNCTAD, 2010). Mulinda et al. (2013) also stated that the need to maximize the benefits of biomass resources in Africa has been justified by the low access to electricity, rapid deforestation, and the call for clean energy and environmental sustainability. This was stated to be possible among others through the use and dissemination of biogas technology.

Renewable energy technologies as a whole are important not only to obtain clean energy but also have the potential to enhance economic growth in the continent of Africa. A study on the linkage between the production amount of renewable energy and gross-domestic-product reported the existence of positive associations in four out of five geographical regions of Africa (east, west, central, north, except southern) and oil-producing and non-oil producing Africa (Abanda et al., 2012). REN21 (2014) also stated that nowadays renewable energy resources are considered not only as sources of energy, but also instruments to address various other human needs. They assist in increasing energy security; minimizing the environmental and health impacts of fossil and nuclear energy use; minimizing GHG emissions; improving gender equality, increasing job and educational opportunities; and lessening poverty.

Africa is reported to have huge renewable energy resources that many of which are under-exploited (Karekezi and Kithyoma, 2003). Various scholars pointed out the availability of high potential for the development and dissemination of biogas (a renewable energy) technology in Africa (Mshandete and Parawira, 2008; Mwirigi et al., 2014; Rahman et al., 2014; Tumwesige et al., 2014).

However, in comparison to the rest of the world, the continent generally has inadequate energy-related information (Belward et al., 2011). Developing countries still lack comprehensive and transparent methodologies to estimate energy generation potentials from their renewable energy resources (REN21, 2014). For instance, Abanda (2012) pointed out the existence of very limited research works, and scanty and scattered literature on the potentials of renewable energy resources of Cameroon. Therefore, it is difficult to quantify the overall potential of biogas and other renewable energy resources in Sub-Saharan Africa.

Nevertheless, more interestingly, there are an increasing number of household level biogas plants in the region. According to SNV (2013), over the past three years alone, the national biogas programmes in Africa were able to install a total of over 24,000 biogas plants.

2.3 The Status of Energy Resources, Consumption Patterns, and Brief Account of Biogas Technology in Ethiopia

2.3.1 The Status of Energy Resources

Ethiopia is potentially endowed with various energy resources. These energy resources include: hydropower, wind, geothermal, solar, biomass, natural gas, coal, and oil-shale (Table 1). Nevertheless, much of the stated resources are either untouched or not developed to economically optimal levels. For instance, so far the country has developed less than 5 % (roughly 2000 MW) of its total hydroelectricity generation capacity (EEPCO, 2011; FDRE, 2015).

Indeed, with the completion of the present three hydroelectric power projects under construction: the Grand Ethiopian Renaissance Dam, Ghibe III and Genale dawa III with total installed capacity of 7373 MW, the country's hydroelectric power generation capacity will grow to 9221.7 MW which will be about 20 % of the potential (MoWE, 2011). Besides, from the existing wind power potential of the country, Ashegoda, Adama I, and Adama II wind farms have already started operating and generate a total of 324 MW (MoWIE, 2015). Aluto langano geothermal plant is also under construction to upgrade its installed capacity from 7.2 to 35-70 MW (MoWE, 2011).

Table 1. Energy resource potentials of Ethiopia

S.No.	Resource Type	Unit	Potential	Remark
1	Hydropower	MW	45,000	Based on the recent national development plan documents including FDRE (2010, 2015)
2	Wind	MW	10,000	Recent studies indicate that the potential is about 100,000 MW
3	Geothermal	MW	5000	Still to be explored
4	Solar	$kWh/m^2/day$	5.2	Based on annual average
5	Woody biomass	Tonnes	1120 million	Estimated based on a 3 % forest coverage of Ethiopia with 1tree/4 m^2, and average weight of 0.2 t/tree (EREDPC, 2000 cited in Wolde-Ghiorgis, 2002)
6	Agricultural wastes	Tonnes	15-20 million	Still to be explored
7	Natural gas	Cubic feet	4 trillion	Still to be explored
8	Coal	Tonnes	>300 million	Still to be explored
9	Oil-shale	Tonnes	253 million	Still to be explored

Source: MoWE, 2011

Various assumptions and arguments are forwarded with regard to the underdevelopment of the energy sector in the country. The major assumptions and arguments include: less attention given to improve the traditional energy production, supply, and utilization; little or no attention provided to develop renewable energy; the non existence of strong energy organization; the low level of household income; and lack of capital, technical know-how, and trained man power (Woldegiorgis, 2002).

Consequently, Ethiopia suffers from a serious problem of domestic energy. This problem can be explained by the relatively very low per capita energy consumption and the dominance of traditional biomass fuel use. In 2011, the per capita total primary energy supply in Ethiopia was merely 0.4 toe while it was 0.7 toe, 4.4 toe, and 1.9 toe for Africa, OECD countries, and the world average, respectively (IEA, 2013). The same source also indicated that the annual per capita electricity consumption in Ethiopia was only 55 kWh while it was 592 kWh, 8226 kWh, and 2933 kWh for Africa, OECD countries, and the world in that order. Moreover, in 2009, the percentage of population who relied on traditional use of biomass fuel for cooking was 93 % in Ethiopia while it was 65 % for Africa, 77 % for Sub-Saharan Africa, and 39 % for the world as a whole (IEA, 2011).

Even worse, the demand for wood-fuel far exceeds the sustainable supply in Ethiopia. In 2009, the demand for wood-fuel was estimated to be 77 hm^3 whereas the sustainable supply was merely to 9.3 hm^3 (Bekele, 2011). Thus, in conditions of unaffordable and escalating prices of imported oils, inaccessibility of electricity, and increasing scarcity of wood-fuel, the option for the majority of the population would be increasing use of animal dung and crop residues for fuel which could have been otherwise used as organic fertilizer and/or animal feed. In this regard, Barnard and Christoferson (1985) rhetorically described the options that the majority could face when wood for fuel is difficult to obtain as follows. “For many, ‘the wood-fuel crisis’ is essentially over. What they have entered is a new phase in the evolution of fuel scarcity where the struggle is not to find wood, but to obtain enough dung, straw and crop stalks to cook their food and heat their homes”.

The scarcity of wood-fuel and associated problems are more severe in northern Ethiopia where most forest vegetation were lost and nearly all available areas have been converted into crop and pasture lands (Darbyshire et al., 2003). Hence, in Tigray and Amhara regions, dung fuel accounts for about 22.8 % and 20.4 % of the total energy consumption while it is almost nil, 13 %, and 12 % in Gambella, Oromiya, and the national average, respectively (WBISPP, 2004). The problem is even more severe in some specific areas. For instance, in ‘Dega’ parts of Tigray, dung fuel alone accounts as high as 36.8 % of the total energy consumption during dry season (WBISPP Tigray, 2003).

Hence, energy transition has been occurring in the reverse direction in Ethiopia and a bottom line of the energy ladder has already been reached in some areas (Leach and Gowen, 1987) (See Figure 2). Dung and crop residues, fuels of the lowest rung on the energy ladder, generate low-grade fire, less heat and more smoke thereby causing health risk and make cooking chore time consuming and less pleasant. The scarcity of wood-fuel may also force households to have fewer hot meals and adopt meals often less nutritious but can be cooked more quickly (Wright, 1993). Thus, scarcity of wood-fuel has further been deteriorating the lives of the people. It causes worsening of the household welfare through spending much productive time in search and collection of it, increased use of inferior fuels, higher wood-fuel price, and reducing agricultural productivity.

2.3.2 Energy Consumption Patterns in Ethiopia

The current energy sources of Ethiopia can be categorized into two: modern and traditional. Modern sources of energy encompass electricity and petroleum while traditional sources of energy include fuelwood, charcoal, dung, and crop residues. In 2009, traditional biomass fuels accounted for 92 % of the total energy consumption whereas modern fuels constituted the remaining 8 % (MoWE, 2011).

The household sector is the major consumer of energy in Ethiopia. It makes up 89.2 % of the total national energy consumption while the remaining 10.8 % is shared among agriculture, transport, industry, and service sectors (EREDPC and MoARD, 2002). According to MoWE (2011), in 2009, the household sector accounted 92.6 % of the total energy consumption while all other sectors together constituted only 7.4 %.

More than in any other sector, biomass fuel is important in the household sector. It makes up 98.6 % of the total energy consumption. Specifically, fuelwood, dung, crop residues, and charcoal account 81.4 %, 8.1 %, 7.8 %, and 1.3 %, respectively whereas electricity and petroleum together contribute 1.4 % of the total household energy consumption (EREDPC and MoARD, 2002). The contribution of biomass fuels is still greater in the rural households as compared to the urban counterpart. According to EREDPC and MoARD (2003), biomass fuels constitute 99.9 % of the total energy consumption of the rural households.

2.3.3 Brief Account of Biogas Technology and the National Biogas Programme of Ethiopia

There are variations among authors as to the exact time when biogas was introduced into Ethiopia. However, it seems reasonable to take the fact that Bekele (1978) wrote as he himself constructed the first biogas installation in 1962 at Ambo School of Agriculture, the later Ambo College of Agriculture. The type of model for this first installation at Ambo was a batch type digester (Eshete et al., 2006).

Based on the ways that biogas digesters are fed, biogas models may be classified into two broad groups: batch type and continuous flow type. In batch system, all the raw material is added at a time and emptied after 3 to 4 weeks of decomposition. In the case of continuous flow model type, new raw material is added on a daily basis and replacing an equivalent amount of digested residues that is discharged out (Berglund, 2006). There are many different models of continuous flow type. Nevertheless, three simple models of continuous flow type can be distinguished. These are high density plastic biogas digester model, fixed dome model, and floating drum model; each of which has its own advantages and limitations over the others (Sasse, 1988). There are also prefabricated and portable biogas digesters. They are also called "commercialized digesters". These digesters do not have exact classification. In China, based on material composition, three types of prefabricated biogas digesters are distinguished: fiber-reinforced plastic (FRP), plastic soft and plastic hard digesters (Cheng et al., 2013; 2014). The costs of these digesters were indicated to have high, low and normal, respectively. The cost of the last one is equated with the cost of concrete-made biogas digesters (Cheng et al., 2013).

Over the last two and half decades about 1000 biogas installations were constructed in different parts of the country. The sizes of these biogas digesters vary from 2.5 m^3 to 200 m^3. A wide variety of biogas models have been installed in Ethiopia including Indian floating drum, Chinese fixed dome, Camar Tech, Deenbandhu, high density plastic (Polyethylene), and LUPO fixed dome type (Yilma, 2011).

In Ethiopia, there are compelling reasons to promote biogas technology. First, the country has large livestock population particularly cattle. Second, dung is increasingly used as household fuel. Third, the soil structure and fertility has negatively been affected as it is deprived of its natural fertilizer-dung (Lucia and EEA, 1990). As there are about 35.4 million cattle in Ethiopia, 10.6 hm^3 to 14.2 hm^3 of biogas could be utilized for household cooking and lighting. Besides, about 78,000 m^3 of slurry can be available at best after generating useful biogas energy (EREDPC, 2006). Despite this opportunity, however, there are a number of barriers that hinder the expansion of the technology in the country, among which construction cost deserves mentioning.

In fact, the expense varies greatly with the type of model required, size of the installation, availability of local materials and the like. For instance, among the continuous flow type biogas models, floating drum digester is the most expensive while balloon digester is the cheapest one (Sasse, 1988; Gitonga, 1997; EREDPC, 2006). However, the cost-benefit analysis of particularly fixed dome biogas model in Ethiopia indicate that its adoption has significant positive net present value for both households who collect their own energy sources and who rely on purchasing their entire energy sources (Gwavuya et al., 2012).

Once biogas installations are built, they may fail to function for a number of reasons. Some of the major ones include: technical problems, availability of water supply, decline in the number of cows owned, change in the mode of livestock keeping, clumsy operation, and absence of demand and interest. For example, due to one or more of these reasons, 60 % of the total biogas installations visited during the national domestic biogas feasibility study were not operational (Eshete et al., 2006).

Success or failure of a model biogas installation in a given area can positively or negatively affect its further promotion in that area. According to Gitonga (1997) where the first biogas installations performed well, words of mouth from satisfied users encourage other potential users to build their own installations. Where installations failed, failure creates a negative impact on the dissemination of the technology, discouraging potential users in the process. Thus, social influence created by successfully operated biogas installations is a necessary condition for wider dissemination and acceptability of the technology.

The feasibility study on potential of domestic biogas plants in the country was initiated and conducted by SNV-Ethiopia in 2006. It was a very comprehensive study which addressed a wide range of issues including problems and functional status of previous installations, constraining factors for adoption and potential for the promotion of the technology. The study covered four major regional states: Tigray, Amhara, Oromiya, and SNNP (Figure 4). These regions are the homes of roughly 70 % of the livestock and over 70 % of the human population in Ethiopia. After assessing the financial, technical, social, and institutional dimensions for the possibility of mass dissemination and taking into account the various intervening constraints, the study reported that the potential for domestic biogas plants range from 1.1 million to 3.5 million households in the four regional states alone. The report also proposed a five years period pilot biogas programme in the four regions to the government (Eshete et al., 2006). Following the recommendation, SNV-Ethiopia in collaboration with the EREDPC, a government institution, prepared PID in 2008 (EREDPC and SNV, 2008). This finally led to the establishment of NBPE and NBPCO as well as the onset of programme implementation in the four regional states. SNV-Ethiopia was the technical advisor of the programme right from the start.

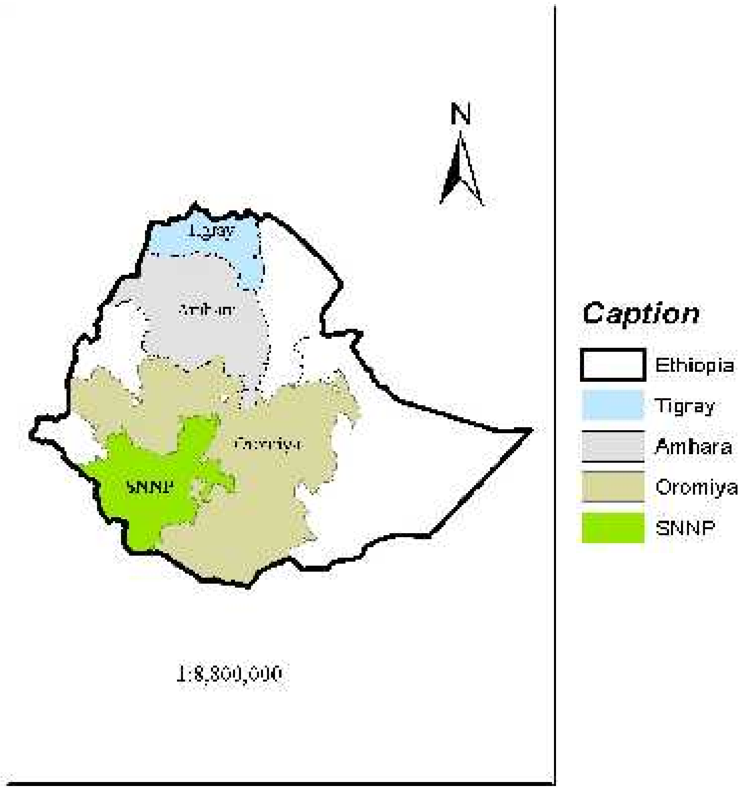

Figure 4. Regional states covered in the feasibility study for national biogas programme

The objectives of the NBPE included developing sustainable market-driven biogas sector in Ethiopia; constructing 14,000 domestic biogas plants of various digester sizes (four, six, eight, and ten cubic meters) (EREDPC and SNV, 2008), 3500 in each of the four regional states within the first phase (2009-2013) (Yilm, 2011); and ensuring the uninterrupted functions of the biogas installations to be built in the programme period. The programme commenced with standardized biogas digester model-modified Nepalese fixed dome model with local name-‘SINIDU’, meaning ready; shared costs of installations that involve beneficiary households; and new institutional structure. The financial sources for the NBPE included: an external donor (the African Biogas Partnership Programme), SNV-Ethiopia, farmers, federal government and regional governments which covered 39 %, 11.4 % (in service forms), 42 %, 4.4 % and 3.2 % of the total programme costs, respectively (EREDPC and SNV, 2008).

In 2008, for the purpose of demonstration, 98 domestic biogas digesters were built in four regional states. In the first phase of the national biogas programme (2009-2013), the country was able to construct 57.6 % (8063) of the 14,000 domestic biogas plants targeted for the period. The country is now implementing its second phase (2014-2017). Obviously, the uptake of the technology has not been progressing as intended. What makes the uptake of the technology slow needs empirical research. However, interestingly, there was a growing trend in the number of biogas installations from year to year during the first phase of the NBPE (Kamp and Forn, 2015, 2016). Still a further research is required to determine the extent that the biogas plants that have been disseminated to date in the country contribute to the sustainable rural livelihood.

2.4 Conceptual Framework

A conceptual framework could be a simple list of concepts and their likely associations or a more illustrative schematic diagram of important factors, expected relationships, and possible outcomes of the research problem. It enables the researcher to critically consider multiple facets of the research problem; identify key factors, and depict their logical interrelationships in a scheme. Thus, a thoughtfully developed conceptual framework can serve as a vital compass to assist focusing a study towards the central research problem. It also shows how the researcher conceptualizes the current problem and clarifies goals and expectations of a research (Ulin et al., 2005).

In view of the above idea, the visual representation of the conceptual framework has been developed on the basis of statement of the problem and review of related literature. Hence, the diagrammatic form of the conceptual framework that displays interrelationships among key factors and their likely outcomes is depicted in Figure 5.

Adoption and dissemination of biogas technology in a given society depends on a number of factors. Some of the major factors include: socio-demographic characters of households; economic characters of households including access to alternative sources of energy like electricity and photovoltaic; biophysical factors such as access to woody biomass, land, and water resources; legal and institutional factors such as promotion work, supports, and subsidies; private sector participation in promotion, construction, and manufacturing and supplies of appliances and spare parts; and attributes of the technology itself.

Here it should be noted that adoption of biogas technology is household selective. It requires households to have sufficient size of livestock to feed biogas digester, sufficient and reliable water sources within reasonable distances, and labour to operate the biogas installation. It also needs households either to have access to credit or sufficient own financial capital to cover the full or partial cost of biogas investment (partial in case where there is subsidy).

Thus, based on the interplay of all the aforesaid factors, households can acquire knowledge and awareness on biogas technology, evaluate its importance, and develop attitude towards using the technology, and finally may decide to adopt and start the actual use of the technology.

Once biogas technology is adopted, sustained and efficient utilization of the technology can lead to various development outcomes. Some of the major sustainable development outcomes may include: meeting energy needs, saved time, decreased workload, reduced health risk, reduced expenditure, increased income and job opportunities, increased productivity, reduced deforestation, reduced GHG emissions, improved soil fertility, reduced indoor air pollution, and improved sanitation.

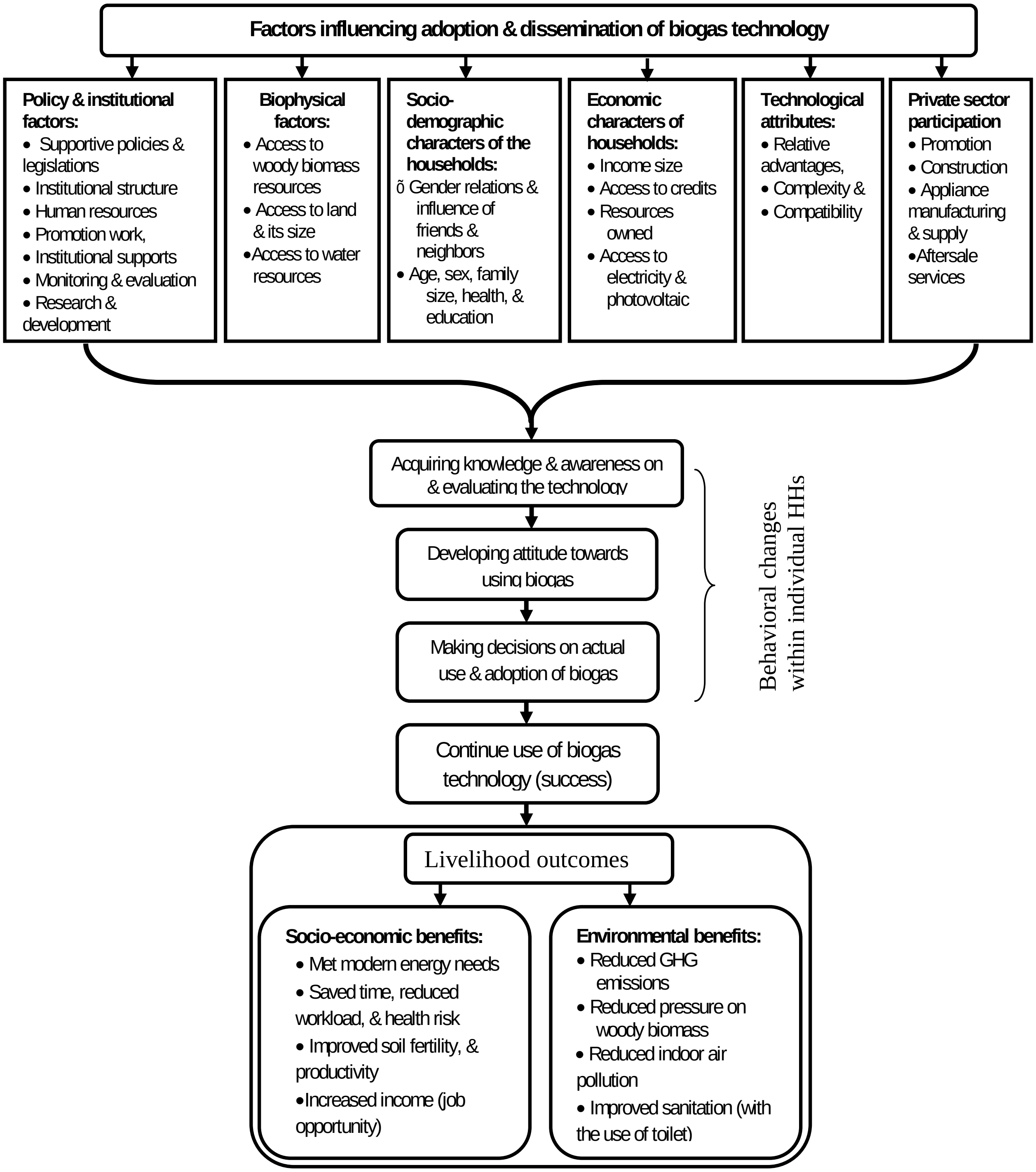

Figure 5. Conceptual framework

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Description of the Study Sites

The two sites identified for this study were *Ofla* and *Mecha woredas*[2] located in Tigray and Amhara regions, respectively (Figure 6). They were selected purposefully for being the homes of the largest number of biogas installations in their respective region during the survey time.

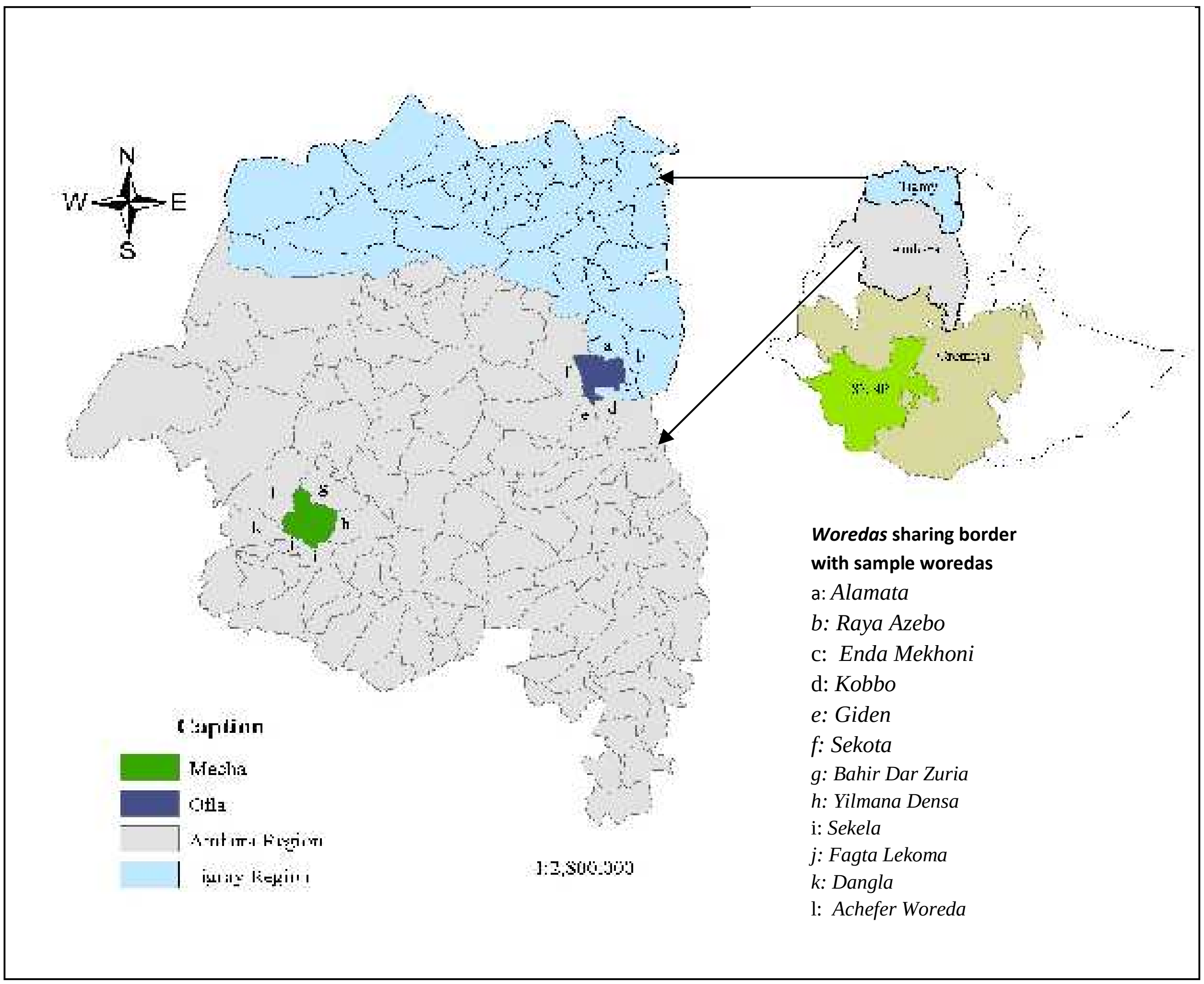

Figure 6. Location map of the study sites

***Ofla Woreda**:* It is found 628 km north of Addis Ababa City and 152 km south of Mekele Town. Its absolute location extends approximately from $12^0$15’12”N to$12^0$40’57”N latitude and $39^0$10’50”E to $39^0$35’3”E longitude. The *woreda* shares border with *Alamata* and *Raya Azebo woredas* in the east, *Enda Mekhoni Woreda* in the north, and three *woredas* in Amhara Regional State (*Kobbo* and *Giden* in the south *and Sekota in* the west) (Figure 6).

The *woreda* accommodates one of the known lakes in Ethiopia-Lake Hashenge. Based on 2007 National Census of Ethiopia, the total population of *Ofla Woreda* was 126,889. The census result also indicated that the *woreda* comprised a total of 29,571 households which gave an average household size of 4.3 persons (PCC, 2008).

Its altitude ranges from 1700 to 3288 meters above sea level. On the basis of its altitudinal range, the *woreda* lies into two local agro-ecological zones: *Dega* and *Woina Dega* [more or less equivalent to cool temperate and warm temperate zones, respectively (NMA, 2001). The *woreda* has also two rainy seasons: Summer (locally called ‘Kiremt’) and Spring (locally called ‘Belg’) with average rainfall of 625 mm and 215 mm per annum, respectively. The temperature of the *woreda* varies from 6 ^{0}C to 32 ^{0}C (Gebrehiwot, 2006).

Ofla Woreda covers an area of 1335 km^2 (Gebrehiwot, 2006). Of this, arable land accounts 18.9 %, grazing land 18.2 %, forest and bush land 33.4 %, lake 1.3 %, and waste land, settlement, and others together constitute 28.1 % of the total area (Belay, 2007). Forest land alone is indicated to have covered about 12.7 % of the total area (Admasu et al., 2011). Similar to most parts of highland Ethiopia, the basic livelihood of the *woreda* is mixed farming, i.e. crop faming and animal husbandry.

***Mecha Woreda**: Mecha Woreda* is located 535 km northwest of Addis Ababa City and 30 km southwest of Bahir Dar Town (Gebeyehu, 2011). It extends approximately from $11^0$2'10"N to $11^0$33'20"N latitude and $36^0$56'5"E to $37^0$21'52"E longitude. The *woreda* is bounded in the north and north east by *Bahir Dar Zuria Woreda*, in the east by *Yilmana Densa Woreda*, in the south by *Sekela Woreda*, in the south west by *Fagta Lekoma Woreda*, and in the west by *Dangla* and *Achefer woredas* (Figure 6).

Based on 2007 National Census of Ethiopia, the total population of *Mecha Woreda* was 292,080. The census result also showed that *the woreda* consisted of a total of 66,107 households with an average household size of 4.4 persons (PCC, 2008).

Its altitude ranges from1800 to 2800 meters above sea level. The *woreda* comprises of two local agro-ecologies: '*Dega*' and *Woina Dega*. It has an average annual rainfall of 1703 mm. Its temperature ranges from 5.7 ^{0}C to 30.6 ^{0}C. Like most parts of highland Ethiopia, the basic livelihood of the people in this *woreda* is mixed farming, i.e. crop faming and animal husbandry (Gebeyehu, 2011).

The total area of *Mecha Woreda* is about 1590.3 km^2. Its land use and land cover types include: cultivated land, cultivable in the future, grazing fields, forest (nearly all eucalyptus), bush and scrub lands, settlements and roads, and others (including water bodies, valleys, and marshy areas). They constituted 43.9 %, 18.7 %, 9.2 %, 6 %, 5.1 %, 4.1 %, and 13 % of the total area, respectively (Gebeyehu, 2011).

3.2 The Research Approaches

This study was a cross-sectional survey (Gray, 2004; Lewin, 2005). A mixed type of research approach was used. The presence of various specific research objectives and data types called for the use of both qualitative and quantitative research approaches.

3.3 Data Sources

The data inputs for the study were gathered both from primary and secondary sources. Primary data were collected using a survey conducted from June, 2013 to January, 2014. Instruments for primary data collection included: semi-structured interview questionnaires, measurement of fuel masses, key informant interviews, focus group discussions, and personal observation. Secondary data were garnered from different published and unpublished sources including books, journal articles, PID, office reports and records, magazines, and internet which were relevant to the topic under discussion. They were used as background information, to cross-validate statistical results, and support arguments. Moreover, conversion factors were also used from various secondary data sources

3.4 Sampling

The study involved both probability and purposive sampling techniques. Probability sampling was used to select the sample biogas adopter households. And purposive sampling was used to select non-adopter sample households, key informants, and focus group discussants.

The units of analysis for this study were both the biogas adopter and non-adopter households. The biogas adopter households who bought the technology a year before were used as sampling frame. There were a total of 333 such households where 235 were found in *Ofla Woreda* and the remaining 98 were in *Mecha Woreda* (National Biogas Programme Coordination Office database, 2014). The reason for selecting biogas adopters with a minimum of one year old biogas installations was to acquire clear-cut information about whether or not they utilize bio-slurry as organic fertilizer. Besides, respondents from such households were expected to have relatively better experience and familiarity with the technology's benefits and drawbacks.

Based on the general formula developed by Air University (2002), the sample size was determined to be 179. The formula was chosen from other formulae for two reasons. Firstly, it doesn't need prior research about the study population to get population standard deviation. Secondly, the formula is more appropriate if one wants to report research results in a mixture of techniques such as percentages (proportions) and means (averages) of the sample responding. The source also indicated that most survey researches use a 95 % confidence level and a $\pm 5\%$ precision level. Hence, the formula used is as follows.

$$n = \frac{NZ^2 \times 0.25}{d^2 \times (N-1) + (Z^2 \times 0.25)} = \frac{333(1.96)^2 \times 0.25}{(0.05)^2 \times 332 + (1.96)^2 \times 0.25} = \frac{319.8132}{1.7904} = 178.63 \approx 179$$

Where n=sample size required

N=total population size

d=precision level (0.05)

Z=number of standard deviation units of the sampling distribution corresponding to the desired precision level (1.96)

Then, using proportionate stratified random sampling technique (Singh, 2007) 126 biogas adopters from *Ofla Woreda* and 53 from *Mecha Woreda* were selected. Lottery method was employed for the random selection.

Among the non-adopter households, only those who owned four or more heads of cattle - potential biogas adopters (EREDPC and SNV, 2008) were included in the samples. This is because with the exception of toilet connections to some biogas digesters, cattle dung is the only source of biogas in rural Ethiopia. The total number of potential biogas technology adopters in the two study *woredas* was 46,371. Of these, 34,481 were in *Mecha Woreda* and the remaining 11,890 were in *Ofla Woreda* (*Woreda* Agriculture and Rural Development Office documents, 2014). From these potential households, one nearest neighbor for each sample biogas adopter household was chosen purposefully. Thus, the study involved a total of 358 sample households.

The main justifications behind using purposive sampling technique in selecting the sample non-adopter households were the following. In the study *woredas*, the relative sizes of biogas adopter households were quite disproportional to the sizes of potential biogas households. The number of biogas adopter households in *Ofla Woreda* was more than twofold to that of *Mecha Woreda*. To the contrary, the number of potential households in *Ofla Woreda* was nearly one-third to that of *Mecha Woreda*. Hence, purposive sampling technique assisted to avoid the occurrence of highly disproportionate sample sizes of biogas adopter and non-adopter households in each study *woreda*. Purposive sampling also helped to exclude households from remotest rural *kebeles* where the biogas programme never reached yet. Hence, the research results from these purposely selected non-adopter households should not be viewed as representative but self-illustrative.

Before the survey time, it was difficult to get precise information about which biogas adopter household has had a functioning biogas plant. Hence, based on the survey results, only 129 of the sample biogas adopter households have had functioning biogas plants. The remaining 50 sample biogas adopter households, 43 in *Ofla* and 7 in *Mecha woredas*, had a non-functioning biogas plants. The sample households with non-functioning biogas installations were labeled as non-users of the technology. Therefore, the sizes of biogas user and non-user sample households involved in the analysis of socio-economic and environmental impacts of the technology were 129 and 229, respectively.

3.5 Primary Data Collection

3.5.1 Qualitative Data Collection

Qualitative type of primary data was collected using key informant interview, focus group discussion, and personal observation.

3.5.1.1 Key Informant Interview

Key informants are individuals who are knowledgeable, open-minded, articulate, and cooperative for research interview purpose (Cole 2005; Neergaard 2007). Accordingly, prior to conducting key informant interview, key informants were identified. Interview checklists were prepared and then convenient time for interviewing was arranged for each key informant upon their consent. Hence, in this research, a total of 45 key informants, who were supposed to provide research relevant information, were purposefully selected from various administrative levels and interviewed.

At national administrative level, key informant interview was held with seven individuals. It included biogas programme manager, database officer, planning, monitoring and evaluation officer, a senior energy expert, renewable energy advisor from SNV, a renewable energy advisor from Institute of Sustainable Development, and technical advisor from Selam Technical and Vocational School. At regional administrative level, 13 key informants were used. The key informants were RBPCU coordinators, heads of mines and energy agencies, biogas technicians, biogas promotion and marketing officers, bio-slurry extension officers, biogas stove manufacturers, and a researcher on biogas *injera* stove. At *woreda* administrative level, there were 19 key informants. The key informants inculcated the *woreda* administrators, heads of *woreda* water resource offices, *woreda* mines and energy coordinators, *woreda* energy expert, heads of *woreda* agriculture and rural development offices, heads of *woreda* women's affairs offices, masons, and farmers' cooperative leaders (involved in biogas construction credit arrangements). And lastly, at *kebele* administrative level, six development agents who participated in biogas technology promotion and bio-slurry extension works were involved. Some of the key informants involved beyond the energy sector like *woreda* administrators, heads of *woreda* water resource offices, and heads of *woreda* women's affairs were members of the biogas sector steering committee.

3.5.1.2 Focus Group Discussion

Checklists were also prepared and used for focus group discussion. For the study, eight focus group discussions, four per sample *woreda*, were held. To avoid the possible cultural influences of restricting free discussion between males and females, separate groups were formed for the two sexes. The optimum size for a focus group discussion ranges from six to eight members (Bloor et al. 2001; Finch and Lewis 2003). Thus, two males' and two females' group discussions, having six or seven members per group, were formed in each sample *woreda*. To ease the task of bringing group discussants together, occasions of various social gatherings such as religious gatherings, public meetings, and public labour days were exploited. Discussions were recorded with tape recorders.

The instrument assisted to gather information about problems and consequences of wood-fuel scarcity; barriers to adoption of biogas technology, opportunities available for further dissemination of the biogas technology, weaknesses of implementing the biogas programme, and suggested solutions to improve the programme.

3.5.1.3 Direct Observation

Direct personal observation helped to generate ideas valuable to prepare leading questions for both key informant interview and focus group discussions. Besides, the appropriateness of questions prepared for semi-structured interviewing was checked, inter alia, through directly observing visible phenomena in the real ground and body languages reflected during piloting. Direct observation also assisted to acquire information about the biophysical features of the study sites, type and quality of biomass fuels gathered, current status of biogas installations, the different components of biogas installations, end-use of biogas, and use of bio-slurry.

3.5.2 Quantitative Data Collection

3.5.2.1 Semi-Structured Interview Questionnaire

Though the semi-structured interview questionnaire was also used to collect some qualitative data, it was basically utilized to collect quantitative data. Once the questionnaire was prepared and translated into the local language, first, it was evaluated by colleagues and experts. Then, the questionnaire was pretested in the actual field on a total of 30 households, 15 biogas adopter and 15 non-adopter households. Pretesting helped in improving the language, avoiding ambiguity, and refining categories. Enumerators were selected and trained about as to how to collect data and the ethics they should follow. Finally, the actual data collection was carried out in the two study sites.

The data gathered with this instrument comprised demographic characteristics, household assets and income levels, access to water, energy sources of the households, energy end-uses, types of stoves used, amount of household energy consumption by type, awareness about biogas technology, reasons for adoption or the non-adoption of biogas technology, biogas construction process, financial sources and assistance for biogas construction, availability of biogas inputs, availability of spare parts at reasonable distances, after sale services, operational status and problems faced, impacts of the technology on energy use, perceived impacts of biogas technology on health and sanitation, impacts on workload reduction and social relations, impacts on crop production and use of chemical fertilizer.

Usually getting accurate information about very sensitive issues like income of the households is challenging. Having this problem in mind, looking for appropriate technique for eliciting accurate information is definitely mandatory. Thus, utmost efforts were made to persuade the respondents about the objectives of the study and the confidentiality of the information given.

3.5.2.2 Energy Quantifications

Quantifying from the interview with rural households about the amount of biomass fuel consumption in kilogram was difficult. Hence, the amount of traditional biomass fuel consumption was requested in terms of local measurement units like the number of bundles, sacks or baskets of fuels consumed per week. The averages of these local measurements were taken. Accordingly, the average weight of a bundle of fuelwood, a sack of charcoal, a basket of dung fuel, and a bundle of crop residue was 21 kg, 18.5 kg, 10.5 kg, and 14 kg, respectively. These values helped to estimate the weekly amount of biomass fuel consumption of each sample household. The method was employed in a similar research conducted in *Chemoga Watershed*, Blue Nile Basin, Ethiopia (Bewket, 2003).

To substantiate the indigenous measurement system, actual measurements were taken on 10 % of the sample households. First, the sample households were requested whether they had collected adequate biomass fuels from each type that is enough for one week. Once the objective of measuring the masses of various biomass fuels was made clear to the sample households, the masses of various biomass fuels which exceeded the households' weekly energy consumption requirements were measured and recorded. Then, these households were requested to put the measured biomass fuels in a separate place, use only from the measured biomass fuels for a week, and keep the remaining biomass fuels for the day arranged. Next, just after a week, the masses of the remaining biomass fuels were measured and recorded. Hence, the actual weekly biomass energy consumptions were obtained by taking the difference between the two measurements.

The average monthly electricity consumptions were obtained through requesting the monthly average payments. Then using the contemporary domestic electricity consumption tariffs, the payments were converted into equivalent kilowatt hours. These values were also cross-validated through taking actual data from the monthly electricity consumption bills on 10 % of the sample user households. Besides, data on the rates of kerosene consumptions were acquired in liters. Finally, for easier comparisons between the consumptions of various fuel types, the gross weight or volumes of each fuel type were converted into equivalent heating values expressed in joules as shown Table 2.

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

Fuel type	Thermal values
Air dried fuelwood	15.5 MJ kg^{-1}
Air dried branches, leaves and twigs (BLT)	15.5 MJ kg^{-1}
Charcoal	29.0 MJ kg^{-1}
Air dried crop residue	15.0 MJ kg^{-1}
Air dried dung fuel	13.8 MJ kg^{-1}
Electricity	3.6 MJ kWh^{-1}
Kerosene	36.0 MJ L^{-1}

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

To acquire the daily amount of biogas energy consumption, the respondents were requested to report the daily average hours each of the biogas stove and/or lamp was utilized. Then, the equivalent cubic meter of biogas consumption was calculated. As indicated in the biogas PID of Ethiopia, cooking with a biogas stove consumes about 400 dm^3 of biogas per hour (EREDPC and SNV, 2008). Whereas, lighting a biogas lamp on average consumes 150 dm^3 of biogas per hour (Lam et al., 2009; Lam and ter Heegde, 2011). A cubic meter of biogas is roughly equivalent to 23 MJ (Sorensen, 2007).

3.6 Data Analysis

3.6.1 Qualitative Data Analysis

The study employed some qualitative data analysis techniques. To analyze institutional factors influencing dissemination of biogas technology, programme objectives and activities-based evaluation (Owen and Rogers 1999), content analysis, and thematic analysis techniques were used. The major programme activities indicated in PID included: promotion and marketing; training (users, promoters, and constructors); credit and private sector development; institutional support; quality control, research and development; and monitoring and evaluation (EREDPC and SNV, 2008).

3.6.2 Quantitative Data Analysis

Quantitative data analysis involved both descriptive and inferential statistics. The descriptive statistics included: averages, percentages, and Pearson’s product moment correlation (some sources categorize it as inferential statistics). Inferential statistics encompassed logistic regression and independent samples t-tests.

3.6.2.1 Analysis of Factors Influencing Adoption of Biogas Technology

To analyze the underlying factors determining households’ decisions on adoption of biogas technology, binary logistic regression model was employed. Both logistic and probit regression models are popular in the analysis of discrete binary responses (Greene, 2008). The choice between the two models is a matter of convenience and computational simplicity. Gujarati (2003) also stated the absence of compelling rationale in choosing one from the two models. However, binary logistic regression was preferred as it is easier to interpret and provides odds ratios which is lacking in probit model (Cohen et al., 2003; Orme and Combs-Orme, 2009).

Logistic regression is a probability estimation model applied when the dependent variable is binary and the independent variable is in any form of measurement scale (Cramer, 2003; Leech et al., 2005). If Y is the dependent variable, it can take values of either 1 or 0.

$$\begin{cases} Y_i = 1 & \text{if a household i own biogas plant} \\ Y_i = 0 & \text{otherwise} \end{cases}$$

Hence, the logistic regression model for estimating the probability of adopting biogas technology (P_i) is specified as follows.

$$\Pr(Y_i=1)=P_i = \frac{1}{1+e^{-Z_i}} = \frac{e^{z_i}}{1+e^{Z_i}} \qquad (1)$$

Similarly, probability of not adopting biogas technology,

$$\Pr(Y=0)=1-P_i= \frac{1}{1+e^{Z_i}} \qquad (2)$$

When dividing (1) by (2), it gives odds ratio: $\frac{P_i}{1-P_i} = e^{Z_i}$ (3)

The logit model is a logarithmic transformation of the odds ratio.

$$L_i=nl(\frac{P_i}{1-P_i}) = Z_i = \sim + \ {}_1X_2 + \ {}_1X_2 + ... + \ {}_kX_k + £_i$$

Where L_i is the log of the odds ratio; e is the base of natural logarithms; α is a constant; X_1, X_2, …, X_k are explanatory variables; $\beta_1, \beta_2, …, \beta_\kappa$ are estimated parameters corresponding to each explanatory variable; k is number of explanatory variables; and ε_ι is the random error.

When using logistic regression, the data were checked for the existence of multicollinearity. No serious problem was found. According to Gaur and Gaur (2009) a value of variance inflation factor (VIF) greater than five reveals the existence of multicollinearity. However, the maximum VIF value for this study was 3.3. Outliers were also checked using box plots and in residual statistics. Analyses were made with and without the outliers. As there were no significant differences in the two outputs, outliers were not removed. For the analysis of the logistic regression, continuous independent variables were transformed into standardized (z) values. According to Elliott and Woodward (2007), large values of continuous variables can cause odds ratios and β coefficients to be small and make it difficult to interpret. Thus, for logical comparison purposes among odds ratios of various continuous variables, all of them were transformed into standardized values.

Variables explaining adoption of biogas technology: The households' decisions on adoption of biogas technology were expected to be the outcomes of interactions of multiple factors. Based on examination of various related studies (Bhatia, 1990; Bhat et al., 2001; Mwirigi et al, 2009; Walekhwa et al. 2009; Kabir et al., 2013; Qu et al., 2013), the major determinants influencing adoption of biogas technology revolve around 1) demographic, 2) social, 3) economic, 4) institutional and 5) biophysical factors. However, the relative importance of each factor varies over space depending on the specific social, economic, and environmental settings (Bekele and Drake, 2003). Therefore, selection of plausible explanatory variables involved both examination of the existing related literature and field observations and experiences. Accordingly, below is list of explanatory variables used and descriptions of presupposed influences. Definitions of the variables are also shown in Table 3.

Age: 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 accumulations and have lower economic status than the old farmers. Hence, the age of the household head was expected to have either positive or negative influence on adoption of biogas technology.

Sex: The use and management of household energy is primarily the duty of women in Ethiopia (EREDPC and SNV, 2008). But men dominantly control the household resources (Lim et al., 2007) and often make final decisions both at household and community levels in the country (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 level: 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 passed through greater number of schooling years were anticipated to have a greater probability of adopting biogas technology.

Household size: Large household size may mean having sufficient labour required to manage and operate biogas technology. Or it may mean greater pressure on the household resources. Thus, household size was hypothesized to have either positive or negative influence on adoption of biogas technology.

Cattle size: The primary input for biogas digesters in Ethiopia is cattle dung. That is why the NBPE targeted rural households with four or more heads of cattle (EREDPC and SNV, 2008). Thus, the number of heads of cattle, expressed in cow equivalent, was expected to have positive influence on adoption of biogas technology.

Household income: Forty-two percent of the total cost of biogas installations in Ethiopia was planned to be covered by the farmers either through own income sources or loans (EREDPC and SNV, 2008). Thus, the probability of adoption of biogas technology was hypothesized to be increasing with the household income.

Access to credit: Given biogas technology requires relatively high initial investment, having access to credit was supposed to have positive influence on adoption of the technology.

Size of farmland: Households with larger size of farmland were supposed to have better income and larger backyard to closely locate the biogas units-biogas digester, livestock-barn, and garden of fruits and/or fodder-lawn (Walekhwa et al., 2009). Hence, it was hypothesized to have positive influence on adoption of biogas technology.

Number of planted Trees: This was supposed to have either positive or negative influence on adoption of biogas technology. Having more numbers of planted trees may mean less problem of household energy and hence, less motivation to adopt biogas technology. Conversely, having higher number of planted trees may mean having better cash to be able to finance biogas installation. Besides, adoption of the technology is a matter of getting cleaner and modern source of energy.

Distance to fuelwod sources: The opportunity cost of collecting fuelwood increases with increasing distance to its sources away from home (Guta, 2014). Thus, distance to the main fuelwood source away from home was expected to have positive influence on adoption of biogas technology.

Distance to water sources: For daily feeding of the biogas technology, the source of water was suggested to be within a walking distance of 20 minutes to 30 minutes away from home (Eshete et al., 2006; EREDPC and SNV, 2008). Therefore, distance to water source from home was expected to have negative influence on adoption of biogas technology.

Sufficiency and reliability of water sources: Availability of sufficient and reliable water source was expected to positively influence adoption of biogas technology.

Distance to the market: Distance to the market from household's home was expected to have a negative influence on adoption of biogas technology. Having closer market was supposed to assist farmers to get spare parts easily and increase their social interactions and shared information.

Electronic media: Possession of electronic media, namely, radio and television increases farmers' awareness and understanding about the benefits of biogas technology. Hence, it was predicted to have positive influence in households' decisions on adoption of biogas technology.

Electricity connection: Electricity connection was expected to have negative influence on adoption of biogas technology.

***Woreda* (geographical location):** There was larger number of biogas adopters in *Ofla Woreda* than *Mecha Woreda*. Thus, households in *Ofla Woreda* were supposed to have better adoption behavior than the households in *Mecha Woreda*.

Table 3. Definition of independent variables supposed to explain adoption of biogas technology in Ethiopia and the variables' expected signs of association with the dependent variable

Variable	**Type**	**Description**	**Expected sign**
Age (AgeHHH)	Continuous	Age of the household head	±
Sex (SexHHH	Categorical	Sex of the household head: Female =1; male=0	±
Education (EduHHH)	Continuous	Household head's educational level in years of schooling	+
Household size (SizeHH)	Continuous	Total number of people in the household	±
Heads of cattle (HeadsCatt)	Continuous	Household's total number of cattle in cow equivalent**	+
Total income (Tincome)	Continuous	Total annual income of the household in $[3]	+
Access to credit (AccCredit)	Categorical	Having access to credit=1; Otherwise=0	+
Farmland size (SizeFarm)	Continuous	Household's total farmland owned in hectare	+
Planted trees (PlanTrees)	Continuous	Household's total number of planted trees	±
Distance of fuelwood source (DistWood)	Continuous	Walking distance of the main fuelwood source from home in minutes	+
Distance of water source (DistWater)	Continuous	Walking distance of the main water source from home in minutes	-
Sufficiency and reliability of water source (Suff&rWater)	Categorical	Having sufficient and reliable water source=1; Otherwise =0	+
Distance to the market (DistMkt)	Continuous	Walking distance of the nearest market from home in minutes	-
Electronic media (ElecMedia)	Categorical	Have radio and/or television=1; Otherwise=0	+
Electricity connection (ElecCon)	Categorical	Having electricity connection=1; Otherwise=0	-
Geographic location (*woreda*)	Categorical	*Ofla*=1; *Mecha*=0	+

*** Heads of cattle ownership was measured in cow equivalent where, cow=1; ox=1.25 cow equivalent; bull= 1.25 cow equivalent; immature male=0.75 cow equivalent; heifer=0.63 cow equivalent; and calf= 0.25 cow equivalent (Njuki et al., 2013)*

3.6.2.2 Analysis of the Socio-Economic Impacts of Biogas Technology

In addition to the various descriptive statistics used, the statistical tools employed in this part included independent sample t-tests and Pearson's product moment correlation coefficients. The independent sample t-test was used to compare mean values of energy consumptions between biogas user and non-user households, time spent on various household activities between the two sample groups, and between men and women members of the sample households. Pearson's product moment correlation coefficient was employed to see the strength of the association between weekly total energy consumptions and household sizes as well as between weekly per capita energy consumptions and household sizes.

3.6.2.3 Analysis of the Environmental Benefits of Biogas Technology

To compute the GHG emission reductions, only the three most potent GHGs, namely, CO_2, CH_4, and N_2O (Yu et al., 2008) were considered. The GWP of these gases over a 100 years' time-horizon that were revised in the fourth assessment report into adjusted ratio to 1, 25, and 298, respectively (IPCC, 2007), were utilized in this study. For all sources of N_2O, dependable emission factors are still lacking (IPCC, 1996). Yet, its incorporation in the analysis can provide a highlight about the emission of this very powerful GHG.

To quantify the GHG emissions and emission reductions, the default emission factors were taken from IPCC (2006) as shown in Table 4. Hydroelectricity being a clean source of energy (Akella et al., 2009) was not included in the analyses.

Table 4. GHG emission factors in mg MJ^{-1} by fuel type

Fuel type	CO_2 (mg MJ^{-1})	CH4 (mg MJ^{-1})	N_2O (mg MJ^{-1})
Fuelwood	112,000	300	4
Charcoal	112,000	200	1
Dung fuel	100,000	300	4
Crop residue	100,000	300	4
Biogas	54,600	5	0.1
Kerosene	71,900	10	0.6

Sources: IPCC, 2006

The mass of GHG emissions from the combustion of the use of a given fuel types 'a' in CO_2e were calculated as follows:

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

$$= \sum_{i=1}^{n} (C_i (EF_{CO_2} + 25 \times EF_{CH_4} + 298 \times EF_{N_2O})$$

Where E_a= GHG emissions in kg from the combustion of fuel type 'a'; n= total number of sample households; Ci= amount of fuel consumed by a sample household 'i'; EF_{CO_2} = CO_2 emission factor for fuel type 'a'; EF_{CH_4} =CH_4 emission factor for fuel type 'a'; EF_{N_2O} =N_2O emission factor for fuel type 'a'; GWP=Global warming potential for the GHG indicated

If k is the number of non-users of biogas households, then the amount of GHG emissions in CO_2e in kg from the combustion of fuel type 'a' would be:

$$E_{a1} = \sum_{i=1}^{k} C_i (EF_{CO_2} + 25 \times EF_{CH_4} + 298 \times EF_{N_2O}) = \sum_{i=1}^{229} C_i (EF_{CO_2} + 25 \times EF_{CH_4} + 298 \times EF_{N_2O})$$

For the sample biogas user households, it would be:

$$E_{a2} = \sum_{i=k+1}^{n} C_i (EF_{CO_2} + 25 \times EF_{CH_4} + 298 \times EF_{N_2O}) = \sum_{i=230}^{358} C_i (EF_{CO_2} + 25 \times EF_{CH_4} + 298 \times EF_{N_2O})$$

Thus, the quantities of GHG emission reductions resulted from the use of biogas energy were obtained through computing the difference in GHG emissions between sample biogas user and non-user households.

While calculating the GHG emission reduction potential of biogas technology, the problem of leakages and other means of gas releases should be taken into account. Emission of methane from unintentional leakages due to some process disturbances or unforeseen events ranges from 0 % to 10 % of the total methane volume generated (IPCC, 2006). To be on the safe side, in this particular study, 10 % of the methane generated was assumed to be emitted.

The average daily minimum biogas generation values of the two digester sizes (6 m^3 and 8 m^3), i.e., 1.2 m^3 (EREDPC and SNV, 2008) was taken for two reasons. Firstly, 25 (19.4 %) of the sample biogas user households had either functioning biogas stoves or lamps only. Secondly, as high as 45 (34.9 %) sample biogas user households possessed less than the recommended heads of cattle (amount of dung input) for their digester sizes.

The average annual emission of methane from the biogas digesters was computed as follows:

$$E_{CO_2e} = YG \times P_{CH_4} \times GWP_{CH_4} \times R$$

Where, E_{CO_2e} = *average annual emission of methane from the biogas plants in kg of* CO_2e*; YG= yearly average estimated biogas generation from the two digester sizes (6* m^3 *and 8* m^3*) in kg, where the daily average biogas generation= 1.2* m^3 *(EREDPC and SNV, 2008); and 1*m^3 *biogas=0.7 kg (Pathak et al., 2009);* P_{CH_4} = *volume fraction of methane content in biogas which* *is about 60 % (Eshete et al., 2006; EREDPC and SNV, 2008);* GWP_{CH_4} *= GWP of methane in* CO_2e *which is 25 (IPCC, 2007); and R= Average estimated rate of emission of methane from the biogas digesters which is about 10 %.*

To estimate GHG emission reduction from the reduced use of DAP and Urea[4] that resulted from the use of bio-slurry, three cases were considered. These were: i) emission rate from new fertilizer plants that employ the latest available technologies (IFA, 2009); ii) the current world average emission rate (IFA, 2009); and iii) emission rate from fertilizer plants that dominantly use coal for synthesizing ammonia (Li et al., 2012).

Table 5. Amount of energy input and GHG emissions during the production of chemical fertilizer under different cases

Fertilizer type	Energy input ($MJ\ kg^{-1}$)			GHG emissions ($kg\ CO_2e\ kg^{-1}$)		
	New plants (i)[a]	Global average (ii)[a]	Plants that use coal (iii)[b&c]	New plants (i)[a]	Global average (ii)[a]	Plants that use coal (iii)[b]
Urea	21.3	26.5	71.7	0.7	1.0	11.4
DAP	2.2	8.5	12.1	0.2	0.6	0.5

Sources: [a] IFA, 2009; [b]Li et al., 2012; [c]Yang and Chen, 2012

To determine the benefits of biogas technology in reducing the depletion of woody biomass, a hectare of tropical forest is estimated to give 145 t to 253 t of fuelwood (Specht et al., 2015). To quantify the fertilizer benefits of bio-slurry, 13 kg of solid bio-slurry is considered to have approximately the same quantity of nitrogen available in a kilogram of Urea. And 11 kg and 24 kg of solid bio-slurry roughly consist of the same quantity of nitrogen and phosphorus present in a kilogram of DAP, respectively (Barfuss et al., 2011). The daily average fresh dung input requirements for 6 m^3 and 8 m^3 biogas digesters are 45 kg and 60 kg, respectively (EREDPC and SNV, 2008). Fresh dung contains about 20 % solids of which microbial digestion removes about 20 % of the solid matters (Lichtman, 1983).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Socio-Economic Profiles of the Sample Households

4.1.1 Sex and Age Composition

Male-headed and female-headed sample households accounted 334 (93.3 %) and 24 (6.7 %), respectively. The male-headed biogas adopter and non-adopter sample households constituted 163 (91.1 %) and 171 (95.5 %), respectively while the female-headed ones accounted 16 (8.9 %) and 8 (4.5 %), in the same order. The male-headed sample biogas user and non-user households were 120 (93 %) and 214 (93.4 %), respectively while the female-headed ones were 9 (7 %) and 15 (6.6 %), in the same order.

The age of the sample household heads ranged from 25 to 82 years old with an average of 47.8 years. The average ages of the sample biogas adopter, non-adopter, biogas user, and non-user household heads were 47.5, 48.1, 48, and 47.7 years, in the same order. There was statistically insignificant age difference between the sample biogas adopter and non-adopter household heads. There was also statistically insignificant age difference between the sample biogas user and non-user household heads.

The population pyramid of the sample population is shown in Figure 7. Irrespective of some irregularities with the shape of the population pyramid, the shape created with the trend lines typically reflects the population characteristics of developing countries. It is wider at the base and sharply narrows up towards the apex (Caselli et al., 2006). The male and female population of the sample households were 1173 (53.2 %) and 1033 (46.8 %), respectively. At the country level too, the male population is slightly greater than the female population. The male and female population of Ethiopia constituted 50.5 % and 49.5 %, respectively (PCC, 2008).

The young (0-14 years), economically active (15-64 years), and old (≥ 64 years) age groups accounted 860 (39 %), 1313 (59.5 %), and 33 (1.5 %), respectively. These gave a dependency ratio of 68 %. At country level, the young, economically active, and old age groups accounted 45 %, 51.8 % and 3.2 %, respectively. This gave the dependency ratio of the country to be 93 % (PCC, 2008). Hence, the dependency ratio of the sample population is lower than the national level. The possible reason could be associated with the purposeful selection of economically better off farmers with four or more heads of cattle. These households are likely to have more hired labour that lowers the dependency ratio.

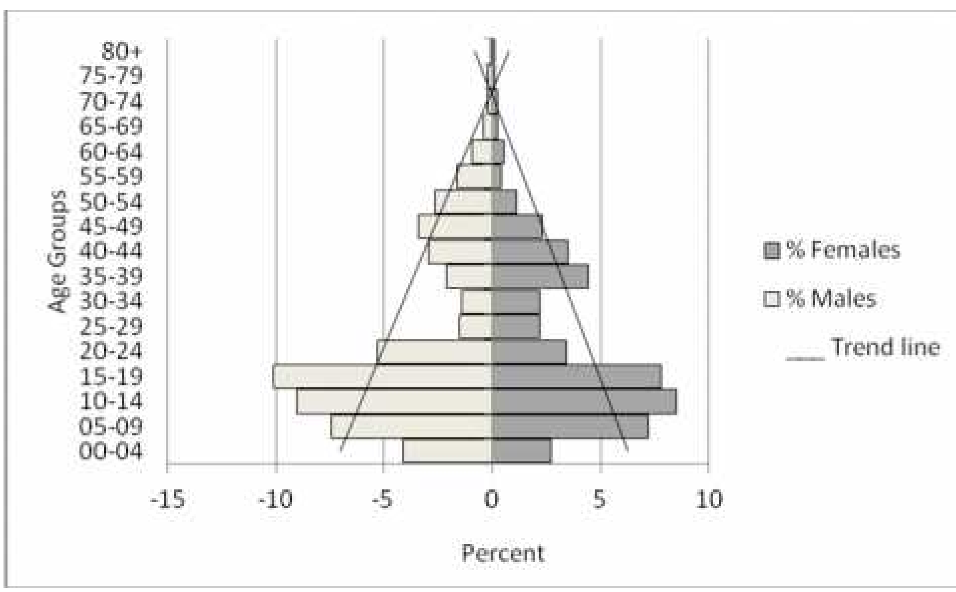

Figure 7. The population pyramid of the sample households

4.1.2 Household size

The household sizes of the sample households ranged from two to thirteen with an average size of 6.2 persons. This average is much higher than the national level which is 4.7 persons (PCC, 2008). One possible reason for this difference can be the operational definition used to define the term ‘household’ in this study. A household was defined to include hired labour and/or relative(s) who shared a single meal regularly.

The average household sizes of the sample biogas adopter, non-adopter, biogas user, and non-user households were 6.4, 5.9, 6.4, and 6 persons, respectively. The mean difference between the households sizes of the biogas adopter and non-adopter sample households was statistically significant at $p<0.01$. A significant ($p<0.05$) mean difference was also obtained between the sizes of sample biogas user and non-user households.

4.1.3 Educational Level

Educational levels of the sample household heads in years of schooling varied from zero to sixteen with an average of 2.9 years. In a study conducted in *Basona* and *Sodo Zuriya woredas of Ethiopia*, Ayele (2009) also found an average education level of the household heads less than three year of schooling. Illiterate (who not able to read and write) and literate sample household heads constituted 94 (26.3 %) and 264 (73.7 %), respectively.

The average educational levels of the sample biogas adopter and non-adopter household heads in years of schooling were 3.7 and 2, respectively. Significant ($p<0.01$) mean differences were obtained between educational levels of the sample biogas adopter and non-adopter household heads.

4.1.4 Livestock

The sample households possessed various livestock types: cattle, sheep, goats, donkeys, horses, mules, pigs, chicken, and bee hives. The total cattle size (in cow equivalents), sheep, goats, horses, mules, pigs, chickens, and bee hives owned by the sample households were 2396, 1827, 464, 360, 39, 44, 21, 1110, and 263, respectively. The average cattle size of the sample households in cow equivalents was 6.7. The average cow equivalents of the sample biogas adopter, non-adopter, biogas user, and non-user households were 7.2, 6.2, 7.6, and 6.2, in the same order. There were significant ($P<0.01$) mean differences in cattle sizes between the sample biogas adopter and non-adopter households, and between biogas user and non-user households.

4.1.5 Farmland size

The average farmland size of the sample households was 0.9 ha. This is slightly higher than the national level. While the per capita farmland size of the sample population was 0.15 ha, the national level was indicated to be 0.11 ha (FDRE, 2005).

The average farmland sizes of the sample biogas adopter, non-adopter, biogas user, and non-user households were 1.0 ha, 0.8 ha, 1.1 ha, and 0.8 ha, respectively. There was significant ($p<0.05$) mean difference between the farmland sizes of biogas adopter and non-adopter sample households. Significant ($p<0.01$) mean difference was also found in farmland sizes between the biogas user and non-user sample households.

4.1.6 Household Income

There was great variation in income size of the sample households. Income size of the sample households ranged from 307.8 $ to 6681.3 $ with an average of 1907.8 $. The average annual income of the sample biogas adopter, non-adopter, biogas user and non-user households in the in 2013/14 production year were 2192.2 $, 1623.2 $, 2298.9 $, and 1687.5 $, respectively.

Significant ($p<0.01$) mean differences were found between both average incomes of the sample biogas adopter and non-adopter, and between biogas user and non-user households.

Even if households with four or more heads of cattle were included in the sample, the per capita income of the sample households is lower than the national level. The Gross Domestic Product (GDP) per capita of Ethiopia is indicated to be 380 $ (World Bank, 2014) whereas the per capita income of the sample households is about 310 $.

4.2 Factors Affecting Households' Decisions in Biogas Technology Adoption

4.2.1 Reasons to Invest on Biogas Technology

The sample households had various reasons for adopting biogas technology. Anderson (2002) stated that decisions that involve allocation of resources include consideration of multiple alternatives and reasons. Hence, the reasons given for adoption of biogas technology included: energy, economic, social, health, and environmental aspects. Faster and more convenient biogas stoves and brighter biogas light were among the reasons for adopting biogas technology to 157 (87.7 %) and 148 (82.7 %) of the respondents, respectively (Figure 8). In connection with this, Surendra et al. (2014) stated that the primary uses of biogas technology in developing countries are cooking and lighting. Eshete 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. Children are taking care of feeding the biogas digesters to get brighter lighting in the evening. As a result, the interest on biogas plant vanishes when the biogas lamps stopped operating. In this context, the need for biogas lighting had to be number one reason. The possible justification for it to take the second level can be associated with electricity connections. Among the sample biogas adopters, 35 (19.6 %) of them have electricity connections.

The existence of government subsidy was the third most important reason for adopting biogas technology to 123 (68.7 %) of the respondents. In Bangladesh, subsidy was indicated to be a reason for 90 (60 %) of the respondents in taking a decision to adopt biogas technology (Kabir et al., 2013). The other important reasons for adoption of biogas technology in descending order of importance include: saves time and reduces workload 116 (64.8 %); reduces health risks and associated costs due to smokeless stove and toilet connection 94 (52.5 %); better quality bio-slurry for fertilizer 88 (49.2 %); reduces expenditure on energy 41 (22.9 %); and existence of credit arrangement 21 (11.7 %) (Figure 8). Credit arrangement was particularly important in Tigray Region where cement and PVC pipe were given in credit form to all biogas adopters. The amount of cement and PVC pipe were predetermined based on digester size.

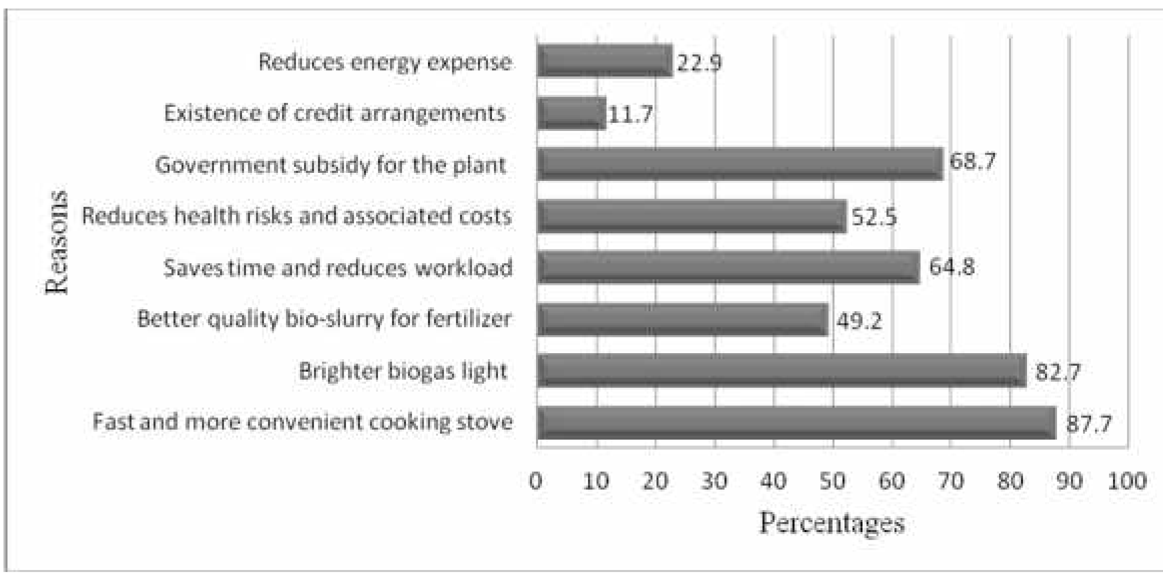

Figure 8. Biogas adopters' reasons that led them to invest on biogas technology

4.2.2 Factors Influencing Adoption of Biogas Technology

The results of analysis of the binary logistic regression model indicated that the model reasonably fitted with the observed data. The complete model comprising the full number of predictors was found to be statistically significant, where χ^2(df=20) =250.57 and p<0.001.

The model correctly predicted 82.70 % of the biogas adopters, 84.90 % of the non-adopters, and 83.80 % of the overall sample households. A non-significant value ($p > 0.05$) of the Hosmer and Lemeshow test is one rule of thumb in validating 'goodness of- fit' of the logistic model (Tarling, 2009; Pallant, 2011). Hence, the test statistics were chi-square=10.30, degree of freedom=8 and p-value= 0.25. The Cox and Snell R-squared and Nagelkerke R-squared values, which merely mimic the R-squared value in linear regression (Pallant, 2011) were 50.3 % and 67.1 %, respectively. The Cox and Snell R-squared is often an underestimate. Hence, it is the Nagelkerke R-squared value which is often reported in researches (Leech et al., 2005). Therefore, Nagelkerke R-squared value 67.1 % is fairly adequate in supporting the quality of the model. According to Kabir et al. (2013), a pseudo R^2 value of 15 % was labeled to be robust and was claimed not affecting the quality of the model.

Among the sixteen independent variables included in the model, eight variables in the main effects and four pairs of variables in the interaction effects had statistically significant ($p\leq0.1$) influence on adoption of biogas technology (Table 6). Sex of the household head, educational level, number of heads of cattle, access to credit, distance to the main fuelwood source, total annual income, number of planted trees, geographical location (*Woreda*) were all found to be significant ($p\leq0.01$) variables. Besides, the interaction effects of age of household head by educational level, age of household head by number of planted trees, household size by heads of cattle, and farmland size by number of planted trees were significant ($p\leq0.1$). Age of the household head, household size, farmland size, distance to the main source of water, sufficiency and reliability of water source, having radio and/or television, electricity connection, and distance to the nearest market were found statistically insignificant ($p>0.1$) factors (Table 6). The results of the analysis revealed that considerations of socio-economic characteristics of the households and bio-physical conditions are critically essential in promoting adoption and dissemination of biogas technology. Several development programmes having the aim of promoting a new technology tend to give greater emphasis to the technical dimensions of the technology (Kabir et al., 2013). However, socio-economic features of the target population are also equally important in promoting new technologies such as biogas.

Table 6. Binary logistic regression model results for the factors influencing adoption of biogas technology in northern Ethiopia

Variables	Parameter Estimate	Standard Error	Wald	P-Value	Odd Ratio
AgeHHH	0.166	0.190	0.763	0.382	1.180
SexHHH (Female=1)	-2.560	0.706	13.146	0.000***	0.077
EduHHH	1.101	0.231	22.689	0.000***	3.008
SizeHH	0.065	0.197	0.109	0.741	1.067
SizeFarm	0.258	0.385	0.448	0.503	1.294
HeadsCatt	0.688	0.218	9.971	0.002***	1.990
Tincome	0.680	0.226	9.083	0.003***	1.974
DistWater	-0.177	0.175	1.024	0.311	0.838
Suff&rWater	-0.105	0.511	0.042	0.838	0.901
ElecMedia (yes=1)	-0.281	0.355	0.626	0.429	0.755
AccCredit (yes=1)	2.189	0.428	26.151	0.000***	8.925
DistWood	0.518	0.178	8.451	0.004***	1.679
PlaTrees	4.160	0.540	59.337	0.000***	64.074
ElecCon	0.406	0.498	0.664	0.415	1.501
DistMkt	-0.150	0.197	0.579	0.447	0.861
Woreda (*Ofla*=1)	-6.831	1.049	42.433	0.000***	0.001
AgeHHHbyEduHHH	0.387	0.203	3.633	0.057*	1.473
AgeHHHbyPlaTrees	-0.410	0.204	4.042	0.044**	0.664
SizeHHbyHeadsCatt	0.484	0.197	6.059	0.014**	1.622
SizeFarmbyPlaTrees	-0.899	0.181	24.650	0.000***	0.407
Constant	4.655	0.912	26.072	0.000	105.161

****, **, and * significant at pá0.01, 0.01<pá0.05, and at 0.05<pá0.1, respectfully. –2 Log likelihood =245.72; Omnibus tests of model coefficients (¡^{2}=250.57 and p=0.000); Hosmer and Lemeshow test (¡^{2} =10.30, df =8 and p= 0.25); Pseudo R-Squareds (Cox and Snell R^2=50.30 % and Nagelkerke R^2 =67.10 %); Percentage of correctly predicted biogas adopters=82.70; Percentage of correctly predicted non- adopters =84.90; and Overall percentage of correctly predicted sample households=83.80.*

Sex of the household head: The sex of the household head was found to have negative and a statistically significant (p<0.01) relation with the households' decision on adoption of biogas technology. Female-headed households appeared to have lesser probability of adopting biogas technology than the male-headed households. Inverting the odds ratio value when it is less than one would make it easier to interpret (Pallant, 2011). Accordingly, inverting odds ratio of sex (0.077) gave the fact that female-headed households were less likely to adopt biogas technology by a factor of 12.99 as compared to the male-counterpart. This seems to indicate that males dominantly control the households' resources and decisions. The result is supported by the findings of a study conducted in Ethiopia on adoption of caster bean production under contractual agreement within the biofuel-supply chains (Negash and Swinnen, 2013). Abebaw and Haile (2013) also obtained similar result on a study of membership for agricultural cooperatives in Ethiopia. It is true that in most cases men control the household resources in Ethiopia (Lim et al., 2007). It is also men who primarily made final decisions both at household and community levels (EREDPC and SNV, 2008). However, a different result was obtained by Kabir et al. (2013) in which female-headed households were found to have more favorable biogas technology adoption behaviors than the male-headed households. Contrary to this result, in the same document, it was described that males mostly dominate the decision process over the household matters in Bangladesh.

Educational level: Educational level was among the vital factors that contributed to the adoption of biogas technology. It was found to have a statistically significant positive ($p<0.01$) influence on adoption of biogas technology. The probability of adoption of biogas technology increases by a factor of 3.01 as the household head's educational level increases by one more year of schooling. The result is consistent with the findings of Kabir et al. (2013) and Mwirigi et al. (2009) who obtained positive association between educational status of household heads and adoption of biogas technology. As stated in Surendra et al. (2014), lack of education is among the most critical factors that limits the dissemination of biogas technology in economically less developed countries. To establish biogas technology as a viable and long lasting option, it is quite essential to educate the people about the socio-economic, health, and environmental benefits of the technology. Landi et al. (2013) also revealed that Africa being an emerging continent from the agricultural-based economy, there is generally limited access to education and important information. Consequently, new renewable energy technologies are not accepted easily because of lack of the basic knowledge and understandings about the operations and benefits of the new technologies.

Heads of cattle: Cattle dung is the primary input for biogas digesters in Ethiopia. Consequently, the NBPE has targeted households with a minimum of four heads of cattle. Four heads of cattle are supposed to produce a minimum of 20 kg dung daily input needed to feed the minimum size biogas digester of the programme (EREDPC and SNV, 2008). Hence, with this principle in mind, only potential biogas adopters were included in the sample. However, still heads of cattle was found to be a significant ($p<0.01$) factor that positively affected adoption of biogas technology. For each additional unit of cow or cow equivalent, the likelihood of adopting biogas technology increases by a factor of 1.99. The result is consistent with the findings of Walekhwa et al. (2009) and Kabir et al. (2013) in which cattle size was reported to have a significant positive association with that of adoption of biogas technology.

Therefore, though the surveyed households have the minimum number of cattle required to feed the smallest digester size (4 m^3), the number of cattle is yet a significant factor. The possible justification for this can be the lack of *injera*[5] stove with the current biogas model at hand. *Injera* baking is estimated to be consuming about 50 % of the total household energy consumption (Gebreegziabher, 2007). Thus, households with a lesser number of cattle may not have sufficient cattle dung required both for feeding the biogas digester on daily basis and for *injera* baking. Hence, upgrading the existing model of biogas technology to include *injera* stove is supposed to reinforce adoption of biogas technology.

Total annual income: A statistically significant positive association ($P<0.01$) was found between the total annual income and adoption of biogas technology. The analysis gave an odds ratio of 1.97 (Table 6). Thus, when the households' income increases by 1.0 $, the adoption of biogas technology increases by a factor of 1.97. It shows the capital intensive nature of the technology. The result is in line with Mwirigi et al. (2009), Walekhwa et al. (2009), and Kabir et al. (2013). In all these cases, a positive significant association between adoption of biogas technology and income level was reported. Therefore, despite the existing subsidy, household income is still one of the significant factors determining adoption of biogas technology in the study sites.

Access to credit: The result revealed that access to credit is a significant factor. It is likely to increase households' decision on adoption of biogas technology by a factor of 8.93, given other factors remain the same. Access to credit enables the poor to be able to afford adoption of biogas technology. Provision of subsidy to biogas construction is a temporal solution but to scale up adoption and dissemination of biogas technology over a wider market, access to credit is quite essential (Ghimire, 2013). Adoption studies on improved maize (Feleke and Zegeye, 2006) and potato (Abebe et al., 2013) varieties in Ethiopia showed similar statistically significant positive associations between access to credit and adoption of those improved crop varieties.

Distance to the main fuelwood source from home: As it was hypothesized, a significant positive association ($p<0.01$) was found between distance to the main fuelwood source and adoption of biogas technology. The opportunity cost of gathering fuelwood increases with the increasing distance of its source away from home (Heltberg et al., 2000; Guta, 2014). As the scarcity of fuelwood worsens, households have to collect fuelwood from further sources and utilize more and more proportion of dung and crop residues (Teketay, 2001). The result is consistent with the findings of Beyene (2010) in which distance to the forest was found to have a significant positive association with the probability of purchasing fuelwood. Hence, with the increasing scarcity and time spent on collection of fuelwood, there seemed an increased opportunity to adopt or purchase biogas technology. Beyene and Koch (2013) reported that the likelihood of purchasing fuelwood decreases with distance from the market. However, based on the result of group discussions, the rural households rarely purchase fuelwood loads from the market. Instead, they often purchase either big standing tree(s) that are warped and less suitable for construction or clipped branches left during the preparation of logs cheaply.

Number of planted Trees: The number of household planted trees was identified to be a significant ($p<0.01$) factor that positively influence adoption of biogas technology. With a unit increase in the number of planted trees the odds of adopting biogas technology increases by a factor of 64.07. Planted trees have become important source of cash for the rural households (Mekonnen et al., 2007; Bazezew et al., 2013). Income from the sales of planted trees particularly from eucalyptus trees accounted on average one-quarter of the total annual cash of the households (Mekonnen et al., 2007). A moderate (Urdan, 2005) positive correlation (+0.49) was also obtained between the number of planted trees and annual income at 99 % level of confidence. Thus, the greater the number of planted trees a household owns the more likely to have better source of cash so as to finance biogas installation. Indeed, one may argue that the larger the number of planted trees a household owns the lesser problem of fuelwood and the lesser tendency to adopt biogas technology. However, Bewket (2003) found out a statistically insignificant association between the number of planted trees and the amount of fuelwood consumption. The possible justification provided was that households preferred getting some more cash from the sale of trees to utilizing them more for fuelwood. Moreover, Gebreegziabher and van Kooten (2013) conducted a research to check whether planting more trees represent greater use of fuelwood. The conclusion was that households utilized less of the exogenous tree species like eucalyptus and more from indigenous planted tree species such as *A. ethbaica*. Thus, eucalyptus trees were likely to be kept for sale or for non-fuel purposes.

Geographical location (*Woreda*): Geographical location (*Woreda*) of the households was found to be a statistically significant ($p<0.01$) factor that influenced households' decision on adoption of biogas technology. Due to larger number of biogas installations in *Ofla Woreda*, initially it was expected that households in *Ofla Woreda* were better in biogas technology adoption features than *Mecha Woreda*. However, the results of the logistic regression model indicated that households in *Mecha Woreda* were found to have more favorable biogas technology adoption characteristics than those households in *Ofla Woreda*. With the exception of educational levels, the mean values of the continuous variables which significantly affected adoption of biogas technology, namely, heads of cattle, annual income, distance to the main fuelwood source from home, and number of planted trees were found to have significant ($p<0.001$) mean differences between the two w*oreda*s. *Mecha Woreda* was quite better off in heads of cattle, annual income, and number of planted trees than *Ofla Woreda*.

Interaction effects between a few pairs of explanatory variables

Age of household head by educational level: Age of the household head in the main effects was found insignificant ($p>0.1$). However, the interaction effect of age and educational level of the household head was expected to have a positive influence on adoption of biogas technology. More likely, as the age of the household head increases, the household's capital accumulation also increases. At the same time, as age increases, a person becomes less flexible and more resistant to accept new ideas and technologies (Walekhwa et al., 2009). Therefore, an increase in the educational level with the age of the household head is likely to raise one's awareness and understanding about new technologies which in turn increases the probability of biogas technology adoption. Accordingly, the results of the interaction effect of age of the household head and educational level was found to be significant ($p\leq0.05$) that positively influence adoption of the biogas technology. Hence, an increase in educational level with the age of the household head can speeded up the probability of adoption of biogas technology.

Age of household head by number of planted trees: Age of the household head in the main effects was found insignificant ($p>0.1$). However, intuitively, as age of the household heads increases, the household's number of planted trees also increases. This in turn increases the household's liquid capital through the sale of planted trees or decreases the problem of household energy (fuelwood). At the same time, as age increases, people become more stiff and resistant to accept new innovations (Walekhwa et al., 2009). Therefore, it was difficult to predetermine the result of the interaction effect of the two variables on adoption of biogas technology. Nevertheless, the result of the analysis (Table 6) showed that the interaction effect of age of the household head and the number of planted trees was found to have a significant ($p\leq0.05$) negative association with the adoption of biogas technology. More likely, older people are less flexible and more resistance to new changes and technologies. Thus, when the older people possess larger number of planted trees, they may prefer maintaining the preexisting status quo of using fuelwood to using the planted trees as a source of cash to finance the technology.

Household size by heads of cattle: When household size was used as a standalone variable, it was found insignificant ($p>0.1$). However, presence of sufficient household-labour power, which is denoted by the household size, is vital both for the biogas digester construction process and post-construction management activities. As part of cost sharing, the NBPE demand potential biogas adopters to: (a) present sufficient building materials including stones, gravels, and sands; and (b) excavate pit for the biogas digester that is required to be situated below the earth's surface (Eshete et al., 2006). After the completion of the construction, household-labour is also required for feeding the biogas digester daily as well as taking care of the cattle (livestock) to ensure sustained digester feeding. Thus, the interaction effect of household size and heads of cattle was expected to have positive influence on adoption of biogas technology. Accordingly, the result of the interaction effect of the two variables was found significant ($p\leq0.05$) that positively influence adoption of biogas technology. A unit increase in the combined effect of household size by the heads of cattle increases the probability of biogas technology adoption by a factor of 1.53.

Farmland size by number of planted trees: Farmland size was found insignificant ($p>0.1$) in the main effects. Nevertheless, the interaction effect of farmland size and number of planted trees was expected to have a significant influence on adoption of biogas technology. The rural households primarily derive their income from the farmland. Hence, possession of larger farmland size represents higher income to be able to finance installation of biogas technology. Having larger farmland size also allows someone to have larger number of planted trees. In this regard, the household survey showed a strong (Urdan, 2005) positive correlation (+0.70) between the size of farmland and number of planted trees. However, possession of larger number of planted trees may mean having more cash that increases probability of adoption of biogas technology or it may mean having less problem of energy that can discourage adoption of the technology. Thus, it was difficult to predetermine the sign for the interaction effect. However, the result of the analysis showed a significant ($p<0.01$) negative association between the interaction effect of the two variables on adoption of biogas technology. Therefore, a unit increase in the combined effect of farmland size and number of planted trees decreases the probability of adoption of biogas technology by a factor of 2.46.

The spatial variations of biogas technology adoption factors

Geographical location (*Woreda*) of the households was one of the significant ($P<0.01$) variables influencing adoption of biogas technology. This result can be attributed to the discrepancies in socio-economic and environmental settings between the two study sites- Ofla and *Mecha* w*oredas* (Figure 6). Among the ten continuous variables included in the model (Table 7), significant ($p<0.01$) mean differences were obtained in seven variables, namely, household size, farmland size, heads of cattle, annual income, distance to the main water sources, distance to fuelwood sources, and number of planted trees. Except age of the household head, educational level, and distance to the main water and fuelwood sources, in the rest variables, *Mecha Woreda* had greater mean values than the *Ofla Woreda*. *Mecha Woreda* had also a significantly ($p<0.01$) greater mean annual household income than *Ofla Woreda*. The mean annual household income in *Mecha Woreda* was 2659.8 $ while it was 1591.5 $ in *Ofla Woreda*.

The proportion of sample household having electricity connection, access to credit, sufficient and reliable water sources, and electronic media (radio and/or television) in *Ofla Woreda* were 29.4 %, 76.2 %, 87.7 %, and 57.1 %, respectively; while they were 2.8 %, 67.0 %, 86.8 %, and 72.6 % in *Mecha Woreda*, in the same order. Thus, there is a great variation in the proportion of sample households having electricity connection between the two *Woreda*s.

Table 7. Mean differences of the continuous variables between *Ofla* and M*echa woredas*

Continuous variable	*Ofla*	*Mecha*	Grand mean
Age of the household head (years)	48.0	47.5	47.8
Education level of the household head (years)	3.0	2.5	2.9
Household size (number)	5.9	6.8	6.2**
Farmland size (hectare)	0.6	1.7	0.9**
Heads of cattle (cow equivalent)	5.9	8.5	6.7**
Annual income ($)	1591.5	2659.8	1907.8**
Distance to water source (minutes)	12.2	6.9	10.6**
Distance to fuelwood source (minutes)	23.4	12.5	20.25**
Number of planted trees	256.2	934.5	457.0**
Distance to the market (minutes)	66.9	69.2	67.6

*** represents statistically significant differences in mean values between Ofla and Mecha woredas at p <0.01. (T-test was used to check differences in means.)*

The results of the analysis of the logistic regression executed by splitting the data based on *Woreda* provided some further insights. The model correctly predicted 82.10 % of the overall sample households in *Ofla Woreda* and 85.80 % in *Mecha Woreda*. The proportion of variance in adoption of biogas technology accounted by the set of predictor variables were 64.50 % and 71.80 % (Pseudo Nagelkerke R-squares) in *Ofla* and *Mecha woredas*, respectively.

Among the fifteen independent variables, while eight of them were statistically significant in *Ofla Woreda*, only four were significant in *Mecha Woreda* (Table 8). In *Ofla Woreda*, sex, educational level, access to credit, and number of planted trees were significant at $p<0.01$; heads of cattle, total annual income, and distance to the main source of fuelwood at $p<0.05$; and farmland at $p<0.1$. In *Mecha Woreda*, access to credit and number of planted trees were significant at $p<0.01$; educational level at $p<0.05$; and annual income at $p<0.1$. Hence, all the four significant variables in *Mecha Woreda* were also significant in *Ofla Woreda*. The only discrepancies were on the significance levels of education and total annual income.

Sex of the household head was found to have a statistically significant ($p<0.01$) negative association with adoption of biogas technology in *Ofla Woreda*. In this *Woreda*, female-headed households had a lesser probability of adopting biogas technology than the male-headed households. While in *Mecha Woreda*, female-headed households were not at all present both in the samples and sampling frame. The result of group discussions in the *Woreda* indicated that there is a scarcity of building stone, gravel, and sand in nearby areas. Consequently, it is particularly difficult for females and female-headed households to collect and transport these building materials from the distant areas using pack animals. In some cases, due to the absence of small size stone at reasonable distances, there is a need to even split big boulders which is difficult for the females. Therefore, despite the fact that females, the primary cooks, benefit more from the biogas installations, there were no female-headed biogas adopter households in the *Woreda* during the survey time.

Table 8. Factors influencing adoption of biogas technology by *woreda*

Woreda	Variables	Parameter Estimate	Standard Error	Wald	P-Value	Odd Ratio
Ofla Woreda	SexHHH (Female=1)	-3.042	0.749	16.493	0.000***	0.048
	AgeHHH	0.145	0.203	0.511	0.475	1.157
	EduHHH	0.761	0.239	10.153	0.001***	2.141
	SizeHH	0.030	0.234	0.016	0.898	1.030
	SizeFarm	1.376	0.762	3.261	0.071*	3.960
	HeadsCatt	0.638	0.294	4.715	0.030**	1.893
	Tincome	0.771	0.312	6.122	0.013**	2.163
	DistWater	-0.220	0.194	1.295	0.255	0.802
	Suff&rWater	-0.112	0.629	0.032	0.858	0.894
	ElecMedia (yes=1)	0.099	0.418	0.056	0.813	1.104
	AccCredit (yes=1)	2.208	0.513	18.525	0.000***	9.097
	DistWood	0.495	0.192	6.651	0.010***	1.640
	PlaTrees	5.119	0.837	37.359	0.000***	167.086
	EleCon	-0.029	0.519	0.003	0.956	0.972
	DistMkt	-0.064	0.231	0.076	0.782	0.938
	Constant	6.069	1.132	28.754	0.000	432.110
Mecha Woreda	AgeHHH	0.160	0.475	0.113	0.737	1.173
	EduHHH	1.391	0.550	6.402	0.011**	4.019
	SizeHH	0.218	0.336	0.420	0.517	1.244
	SizeFarm	-0.675	0.426	2.511	0.113	0.509
	HeadsCatt	0.621	0.388	2.560	0.110	1.861
	Tincome	0.814	0.436	3.475	0.062*	2.256
	DistWater	-0.592	0.555	1.138	0.286	0.553
	Suff&rWater	-0.224	1.037	0.047	0.829	0.800
	ElecMedia (yes=1)	-0.991	0.815	1.481	0.224	0.371
	AccCredit (yes=1)	2.335	0.849	7.570	0.006***	10.327
	DistWood	1.188	1.021	1.353	0.245	3.280
	PlanTrees	2.508	0.590	18.094	0.000***	12.283
	EleCon	1.449	2.027	0.511	0.475	4.257
	DistMkt	-0.706	0.459	2.365	0.124	0.494
	Constant	-4.025	2.293	3.081	0.079	0.018

****, ** and * significant at $p \leq 0.01$, at $0.01 < p \leq 0.05$ and at $0.05 < p \leq 0.1$, respectfully. –2 Log likelihood =182.88(Ofla) and 65.05(Mecha); Omnibus tests of model coefficients (χ^2=81.90 and p=0.000(Mecha) and (χ^2=166.47 and p=0.000(Ofla)); Hosmer and Lemeshow test (χ^2 =11.38, df =8 and p= 0.18 (Ofla) and (χ^2 =4.00, df =8 and p= 0.86 (Mecha)); Pseudo R-Squareds (Cox and Snell R^2=48.30 % (Ofla) and 53.80 %(Mecha); and Nagelkerke R^2 =64.50 % (Ofla) and 71.80 % (Mecha)); Percentage of correctly predicted biogas adopters=79.40 (Ofla) and 88.70 (Mecha); Percentage of correctly predicted non- adopters =84.90(Ofla) and 83.00 (Mecha).; and Overall percentage of correctly predicted sample households=82.10 (Ofla) and 85.80 (Mecha).*

Size of farmland was found to be statistically significant ($p<0.1$) in *Ofla Woreda* while it was insignificant in *Mecha Woreda*. A unit increase in the size of farmland in *Ofla Woreda* was likely to increase adoption of biogas technology by a factor of 3.96 (Table 8). This result was consistent with the findings of Mwirigi et al. (2009) in which size of farmland was identified to be a significant ($p<0.01$) factor that positively affected adoption of biogas technology in Kenya. The size of farmland was found insignificant in *Mecha Woreda* where its size is more than double to that of *Ofla Woreda*. The per capita size of farmland in *Mecha Woreda w*as 0.26 hectares while it was only 0.10 hectares in *Ofla.* The per capita size of farmland in *Mecha Woreda* is also over twofold to that of the national average 0.11 hectares (Eshete et al., 2006). There was a significant ($p<0.01$) mean difference in the per capita size of farmland between the two study sites at 99 % confidence level. Hence, the result seemed to indicate the fact that the size of farmland significantly influences adoption of biogas technology to a certain threshold size above which it is likely to become less important.

Heads of cattle and distance to the main fuelwood source were found significant ($p<0.05$) in *Ofla Woreda* only. A unit increase in the variables was likely to increase the probability of adoption of biogas technology by a factor of 1.89 and 1.64, respectively. In both variables, there were significant ($p<0.01$) mean differences between the two *Woreda*s. The mean values of heads of cattle in *Ofla* and *Mecha* w*oreda*s were 5.93 and 8.50, respectively. The average walking distances to the main fuelwood sources in *Ofla* and *Mecha woredas* were 23.39 and 12.46 minutes, respectively. There were variations in the primary sources of fuelwood in the two *Woreda*s. In *Ofla Woreda*, the primary source of fuelwood for 157 (62.3 %), 56 (22.2 %) and 39 (15.5 %) of the sample households were planted trees, naturally grown vegetations and purchasing. In *Mecha Woreda*, the main source of fuelwood for 104 (98.1 %) and 2 (1.9 %) of the sample households were planted trees and purchasing, respectively. Hence, as high as 56 (22.2 %) of the sample households in *Ofla Woreda* still met their fuelwood demand primarily through collecting from naturally grown vegetations (communal scrub lands, government protected forests, and naturally grown vegetations around homesteads and farmlands).

4.2.3 Reasons for Not Adopting the Technology

The survey results indicated that 176 (98.3 %) of the heads of the non-adopter sample households have some awareness about biogas technology. Regardless of the existing constraints, 170 (95 %) of the non-adopter sample households have the interest to invest on biogas technology in the future. Door to door preaching has been the primary biogas technology promotion strategy utilized in the NBPE. This promotion tool has targeted only at those households who own four or more heads of cattle. Possession of four or more heads of cattle was indicated to be sufficient to feed the minimum recommended digester size (EREDPC and SNV, 2008). Therefore, possession of the minimum recommended heads of cattle, having some awareness about biogas technology, and interest to invest on biogas technology by the majority of the non-adopter sample households are opportunities for further promotion of the technology.

The majority of the non-adopter sample respondents seemed to have a ‘wait and see’ principle. In this regard, Kabir et al. (2013) indicated that neighbouring households to the biogas adopters have the opportunities to carefully observe the nature, durability, benefits, and limitations of the biogas installations. The reasons provided for not adopting biogas technology by 128 (71.5 %) of the respondents included problems faced by their biogas adopter friends, neighbours and relatives. Specifically, 55 (30.7 %) of the non-adopter respondents revealed the absence of regular maintenance, follow up, and supervision services. The other 36 (20.1 %) indicated problem of supply of spare parts particularly biogas lamps. Still the other 22 (12.3 %) pointed out the existence of user training gaps. And lastly, the remaining 16 (8.9 %) said due to poor performance of biogas stoves, many of the biogas adopters utilize only biogas lamps. Hence, improving such institutional related problems can increase adoption of biogas technology. As stated in EREDPC and SNV (2008), a satisfied user from the proper functioning of biogas installation can serve as the best advocator of the technology.

The other important reason provided for not adopting biogas technology by 121 (67.6 %) of the respondents was related to the problem of human and/or animal labour power required for the construction of the biogas digester. Among these, 77 (43 %) of the respondents said they lacked pack animals to transport construction stones, gravel, and sand. The remaining 44 (24.6 %) said they had shortage of human labour to collect construction materials and dig the digester pit. In this regard, group discussants requested the government to supply sand for construction with reasonable prices. Similarly, key informants emphasized the need to solve the problem of supply of sand through facilitating contractual agreement between vehicle owners and group of potential adopters.

Financial constraint was another important reason given for not adopting biogas technology by 108 (60.3 %) of the respondents. Financial status is one of the most critical and frequently mentioned factors that determine adoption of biogas technology (Walekhwa et al., 2009). Thus, improving the household income and arranging credit facilities can boost adoption of biogas technology. The other vital reason forwarded by 71 (39.7 %) of the respondents was the absence of biogas *injera* stove. Improving the existing biogas model with addition of *injera* stove can be an impetus to the adoption and dissemination of biogas technology.

4.3 Institutional Factors Influencing Biogas Technology Disseminations

4.3.1 Institutional Structure

The institutional structure designed for the implementation of NBPE extends only from federal to regional administrative levels (Figure 9). At the federal level, under the Ministry of Water, Irrigation, and Electricity, there is Alternative Energy Technology Development and Promotion Directorate. Below this directorate, there comes a semi-autonomous office, NBPCO. The directorate performs regulatory activities and coordinates programme stakeholders. NBPCO carries out the daily routine coordination and programme management activities. In between the directorate and NBPCO, there is NBPSC, which is composed of seniors from major biogas programme stakeholders where the Directorate's Director was the Chairperson and the NBPCO manager is the Secretary. Since 2012, NBPCO has become directly accountable to the State Minister for the Ministry of Water and Energy (at the moment renamed as Ministry of Water, Irrigation, and Electricity), in order to empower the programme office better. Therefore, the current Chairperson for the NBPSC is the State Minister.

Based on key informant interview, the NBPSC currently has eleven members. In addition to the aforesaid Chairperson and the Secretary, the members include two senior energy experts from the Ministry, a representative from SNV-Ethiopia, a representative from Institute of Sustainable Development, a representative from Ministry of Finance and Economic Development, and heads of the regional Mines and Energy agencies from the four biogas programme implementing regions. Besides, as stipulated in the PID, a representative from Ministry of Agriculture and Rural Development (currently the ministry has been divided into Ministry of Agriculture and Natural Resources Development and Ministry of Fisheries and Animals), a representative from

Ministry of Health, a representative from Environmental Protection Authority (currently reformed into Ministry of Environment, Forestry and Climate Change), a representative from Micro-finance Institutions, and a representative from private sector was supposed to be there. But most likely because of their repeated absence, they were no longer regarded as members of the NBPSC. However, these stakeholders were supposed to play key roles in development and dissemination of biogas technology. For example, the agricultural sector was supposed to manage and ensure proper utilization of bio-slurry. Involvement of Ministry of Health was supposed to follow up sanitation and proper constructions of shelters for biogas digester connected toilets.

The committee is responsible for setting an overall direction for the development of biogas sector and for providing advices on various biogas related matters, such as policy, annual plans, selecting partner organizations, links with donors, quality standards and guides, and programme evaluation. The committee is supposed to arrange regular meetings twice a year or more when the need arises. However, interview with some of the committee members indicated that the committee rarely meets as per the schedule. It has never been involved in programme evaluation in the field. Indeed, it was pointed out that whenever the committee meets, it forwards valuable ideas for the improvement of the programme.

The NBPCO carries out the daily routine coordination and programme management activities under NBPSC. The programme office gets technical and advisory support from SNV-Ethiopia which provides various capacity building services, such as training, technical advices, networking, and partnership building services to both the NBPCO and its regional branches.

At the regional administrative level, mines and energy agencies are in charge of regulatory issues and guardians of the programme. Under the regional energy agencies, there is also RBPSC. The committee is composed of a representatives from Mines and Energy Agency (chair person), the RBPCU manager (secretary), a representative from Bureau of Finance and Economic Development, a representative from non-government organizations working in the region, a representative from regional micro-finance institutions, a representative from biogas stove manufacturers, and a rural households' union representative. This steering committee is supposed to carry out similar tasks as that of the national committee (EREDPC and SNV, 2008). The problem lies with its functionality. Ninety percent of the regional level key informants indicated that the committee was not as such active. In any case, under this regional biogas steering committee, the RBPCU performs the routine coordination activities as well as the operational and financial management aspects of the programme.

Below the regional administrative level, only the Mines and Energy sector has increased its institutional structure to the *woreda* administrative level. Even this Mines and Energy sector is organized under the *woreda's* Office of Agriculture and Rural Development. To realize implementation of the biogas programme, the RBPCU utilizes *woreda* mines and energy personnel as focal persons. Thus, *woreda* mines and energy office is acting as the extension of the biogas institutional structure and delivers programme implementation activities. Besides, whenever the RBPCU plans to start programme implementation in a new *woreda*, awareness raising workshops about the technology and the mode of dissemination are known to be given. It was indicated that the workshops involve *woreda* administration cabinet members. The cabinet members include heads of sector offices, *woreda* mines and energy personnel, development agents and rural *kebele* leaders. The cabinet members were labeled as *woreda*-level biogas sector steering committee, also known as *woreda* multi-stakeholder platform members. The *Woreda* Administrator is the Chairperson and the head of the *Woreda* Water Resources office is the Secretary. The *Woreda* Mines and Energy office is under the *Woreda* Water Resources office.

Nevertheless, the biogas steering committee was not that much functional at the *woreda* level either. Two basic reasons were identified for this. First, at *woreda* administrative level, there are always peak time or governing seasonal tasks done in campaign such as soil and water conservation campaign, parasitic insect elimination campaign, rural road construction campaign, fertilizer and better seed distribution season. The seasonal tasks made the cabinet members busy in organizing and leading the campaigns. Secondly, the cabinet members were changed frequently. Therefore, even if biogas was discussed as a single component of the various *woreda* issues among the cabinet members, there was always a tendency of ‘Let’s hear from the horse’s mouth’. The members could say almost nothing about the programme and the technology because they were not involved in monitoring and evaluation aspects.

Hence, it is the focal persons of the *woreda* Mines and Energy office that shoulder nearly the entire burden of the implementation of the programme. However, the implementation wing of this programme could not be as effective as it was planned, for at least two reasons. First, in the institutional structure of w*oreda* Mines and Energy sector, there are only two employees, namely, one coordinator and one energy expert. They are responsible for the implementation of all programmes related to mines and energy of any type and report to the higher administrative hierarchy. So it is automatic to see implementation of biogas programme as a single component of the diverse mines and energy related duties carried out in the *woreda* sub-sector. Even in some cases, the heads of the *woreda* water resources offices may assign one of the two biogas programme focal persons to the water resource projects (irrigation projects) as observed in *Ofla*

Woreda. Secondly, the RBPCU does not have a direct 'chain of command' or regulatory power over the *woreda* focal persons. Thus, when problem occurs during programme implementation in the *woreda*, the only option for the RBPCU is to report the case to the regional mines and energy agency. This has created a problem in the programme implementation by delaying for some days, weeks or even months, before getting corrective legal measures.

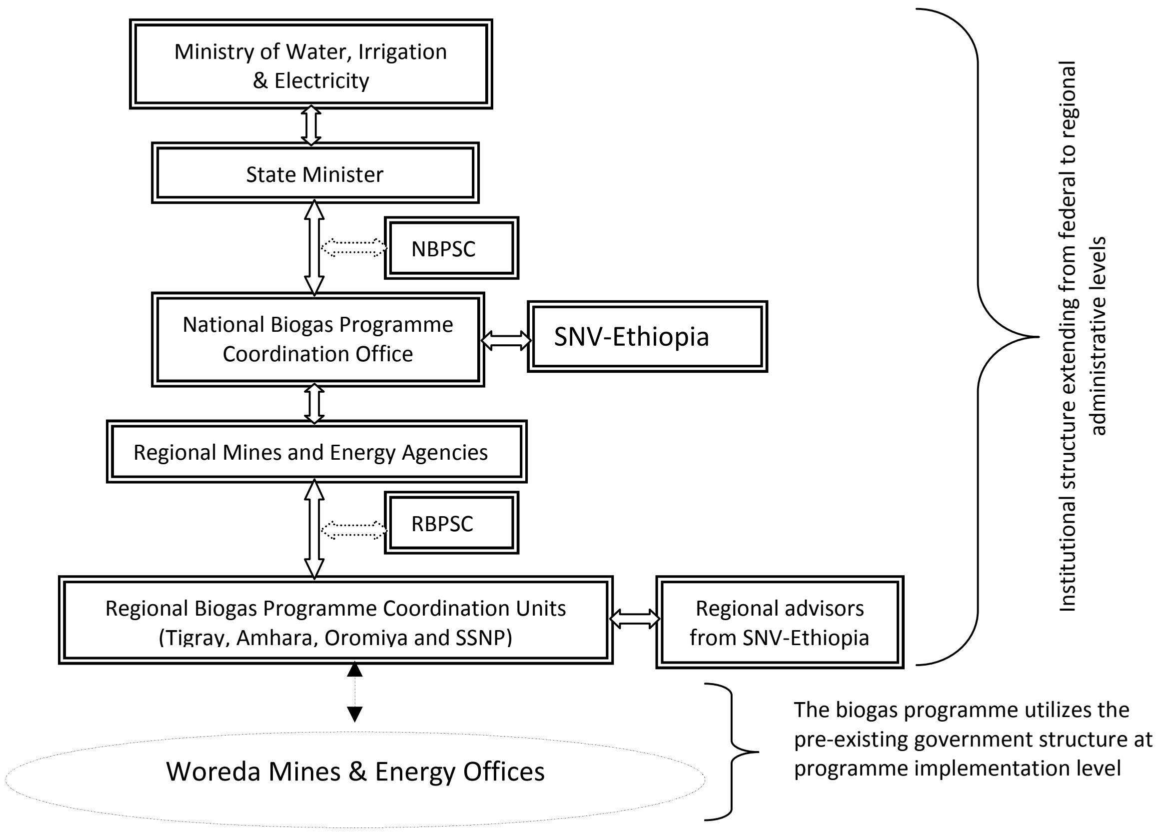

Figure 9. Institutional structure of the national biogas programme of Ethiopia

Key informants at various administrative levels were asked whether the existing institutional structure is suitable and appropriate for development and dissemination of biogas technology. The majority (84.6 %) of the informants at national and regional levels believed that the institutional structure had to be expanded to implement the programme at *woreda* level. The programme implementing level was indicated to be weakly organized for two reasons: human resource gaps and the indirect ‘chain of command between *woreda* mines and energy office and the RBPCU.

4.3.2 Human Resources

Adequate size and quality of human resource is a prerequisite for the successful implementation of biogas programme. However, the overall full-time staff size of the biogas programme in Ethiopia is sixty-two. At NBPCO, there are only eleven staff members: five technical and six supportive staff. The staff include: 1) a programme coordinator; 2) two chief biogas engineers; 3) a database manager; 4) a planning, monitoring and evaluation officer; 5) a general service provider (purchasing and logistics); 6) a finance and administration officer; 7) a secretary and cashier; 8) a messenger and cleaner; and 9) two drivers. Even the second biogas engineer and a planning, monitoring and evaluation officer were added in the staff in 2012.

The chief biogas engineers are supposed to be involved in development of quality control standards, development of programme strategies, and development and provision of training. According to key informants, during the first one or two years of programme implementation, when various training and workshops were urgently needed in all four biogas programme implementing regions, the size of technical staff, particularly the number of chief engineers, was too small to give efficient service. This can be evidenced from the very low numbers of biogas installations in the first two year of programme implementation period. The numbers of biogas plants constructed in 2009, 2010, 2011, 2012 and 2013 were 30, 731, 1641, 2511, and 3150, respectively. It was indicated that the planning, and monitoring and evaluation officer was rarely involved in monitoring and evaluation in the field, due to work burden at the office.

In the RBPCU, there are also technical and supportive staff members. The technical staff members encompass: 1) regional programme coordinators (one for each region); 2) chief biogas engineers (one for each region); 3) promotion and marketing officers (one for each region); 4) bio-slurry extension officers (one for each region); and 5) twelve biogas technicians (three for each region).

The regional chief biogas engineers assist the national chief biogas engineers in developing quality control standards, programme strategies, and training, as well as providing technical advisory services to the biogas technicians. Regional promotion and marketing officers engage in planning how and when to use various promotion and marketing tools, distribute manuals and pamphlets, and coordinate stakeholders participating in biogas promotion and marketing activities. The biogas technicians deliver various construction materials, like dome pipes, PVC pipes, and appliances to *woreda*s; training masons; following up biogas construction; and carry out quality control supervision on a sample basis. Bio-slurry extension officers coordinate all bio-slurry related extension services and trainings.

Considering the number of biogas programme implementing *woreda*s and rural *kebeles* in each region, the distance between regional office and each *woreda* and rural *kebeles* in each region, and the presence of only one or two focal persons at *woreda* level even without a direct 'chain of command' with the regional office, the size of technical staff at the regional administrative level is also low. For instance, in Tigray and Amhara regional states, there were 27 and 33 biogas programme implementing *woreda*s, respectively, and hundreds of rural *kebeles* in a region. Hence, three biogas technicians in a region were supposed to deliver their intended professional services to all these *woreda*s and rural *kebeles*. As the key informant interviews revealed, the biogas technicians were supposed to work in the field for 75 % of the weeks in a month.

Therefore, distributing biogas appliances and other biogas construction materials to *woreda*s, giving technical assistances, making quality control visits on regular basis, and travelling long distances from the regional office to various *woreda*s including the remotest ones can hardly be effectively handled.

All key informants at both *woreda* and regional administrative levels revealed existence of serious human resources gaps at implementation level (*woreda* level). Here, it should be noted that in the absence of institutional structure for biogas programme, talking about human resource at *woreda* level may seem strange but it refers to the *woreda* focal person(s). If the human resource gap at *woreda* level is solved, the existing staff size at regional level could be adequate. Author's observation in Tigray Regional State, *Ofla Woreda*, showed that due to the presence of only a single individual in the *woreda*'s Mines and Energy Office, it was the regional biogas technicians who paid salary to the masons, after checking the quality and completion of the biogas construction on a sample basis. It is therefore unlikely that these biogas technicians will have sufficient time to effectively get involved in other duties, such as aftersale supervisions. Thus, the human resources gap at the programme implementation level needs due consideration.

4.3.3 Promotion and Marketing

According to regional biogas promotion and marketing officers, the biogas sector employed various promotion tools: electronic media (radio, television, and documentary films), printed materials (user manuals, calendar posters, and pamphlets), and door-to-door promotion (words of mouth). However, the most effective and frequently used type of biogas technology promotion tool is door-to-door promotion. In support of this, 146 (81.6 %) of the sample biogas adopters indicated that orientation was their first and major source of information, and for 19 (10.6 %) it was their neighbors and friends. In door-to-door biogas promotion type, *woreda* mines and energy personnel, development agents, rural *kebele* administrators, masons as well as biogas users were known to be involved. For each biogas installation, there is 5.13 $ incentive to be given to the one who convinced the potential user to adopt and use the technology. This incentive was believed to be the primary reason that made the tool being the most effective one.

4.3.4 Institutional Supports

4.3.4.1 Subsidies and Credit Arrangements

The NBPE has allocated a flat rate financial subsidy of 256.25 $ which is given in kind per biogas installation. The subsidy is given irrespective of the variations in digester size, location, inflation, and income status. With regard to the need for allocation of subsidy, it was pointed out that high initial investment cost of biogas technology has remained a principal obstacle for adoption and widespread use of the technology by the rural households (Bensah and Brew-Hammond, 2010; Arthur et al., 2011). Hence, provision of financial incentives such as soft loans and subsidies are among the recommendations made for the success of biogas technology dissemination programmes (Winrock International 2007).

The subsidy was devoted first to cover predetermined rate of payment for masons, and then the remaining money was used to purchase biogas appliances and other construction inputs until the subsidy is used up. However, frequent fluctuations, mostly increment of the prices of various biogas construction materials, such as cement, biogas appliances, and PVC pipe, have posed their own negative repercussions on the dissemination of biogas technology for at least two reasons. First, as clearly indicated in the PID under risk assumptions (EREDPC and SNV, 2008), continual rise of prices of biogas construction materials definitely increases the technology's initial investment cost and reduces its affordability and hence, adoption and dissemination. Secondly, it creates suspicion among biogas adopters as to whether the government subsidy is being received in its entirety. In a difference of a few days or weeks in the adoption of biogas technology, households are requested to pay various amounts of money for differences between prices of the total purchases and the subsidy. The problem is particularly related to cement which cannot be purchased in bulk and stored over a year.

As indicated earlier, arrangement of soft loans is another mechanism that assists in reducing the backlash effects of high initial investment costs on biogas dissemination. As pointed out in the PID, microfinance institutions were supposed to be participating in the provision of credit for biogas construction. However, according to key informants at national and regional administrative levels, micro-finance institutions particularly in Tigray and Amhara regional states showed less interest in providing credits for financing biogas constructions for various reasons. The reasons included: 1) having rules to provide loans on immediate profit-making jobs while biogas is not such type; 2) fearing repayment problem; 3) having less encouraging information on operational rates of biogas installations; and 4) believing in the need to prepare special regulation for biogas loans.

Hence, Tigray Regional Government arranged its own solution and provided cement and PVC pipes on credit through farmers' cooperatives to all biogas users, to be repaid over three years. This credit scheme helped the region to have better uptake of biogas technology than the Amhara Region. In the first biogas programme period (2009-2013), Tigray constructed a total of 1992 biogas digesters whereas Amhara Region constructed 1892. In Amhara Region, it was stated that farmers who are members of the farmers' cooperatives can take credit for biogas construction through the cooperatives.

4.3.4.2 Manuals and User Guidelines

For the success of biogas programme implementation, various manuals, guidelines, pamphlets, and calendar posters were prepared. The manuals and guidelines included: 1) construction manuals; 2) quality control standards and formats; and 3) biogas utilization guideline.

The availability of detail user guidelines can contribute a lot to the long-lasting utilization and continuous operation of the biogas system. However, the distribution of these user guidelines which could be used as references in case of doubts or difficulties in operating or maintaining the biogas system were very much limited. Among the surveyed biogas adopter households, 82 (45.8 %) households did not get any written material on biogas. More specifically, 38 (71.7 %) of the sample households in *Mecha Woreda* and 44 (34.9 %) in *Ofla Woreda* did not obtain user guideline. In the absence of a reference material, biogas adopters may fail to operate or maintain the biogas system and make the potential clients retreat from its adoption. Nevertheless, the biogas adopters had the potential to utilize the user manuals effectively. Among the surveyed biogas adopter households, 150 (83.8 %) of the household heads had minimum of reading and writing skills. Even among those 29 (16.2 %) of the illiterate household heads, 27 (93.1 %) had at least one literate family member with a grade 5 or higher educational level. Hence, a detail user guidelines written in local language, comprising step-by-step techniques of operating and maintaining the biogas plant, having pictorial depiction and principles of do’s and don’ts, should either be provided to all users timely or presented at a reasonable price.

4.3.4.3 Mason and Biogas User Training

For successful implementation of a new programme involving new technology and new approach, the provision of training was indicated to be a key requirement (EREDPC and SNV, 2008). Consequently, diverse training, such as mason training, biogas users' training on how to operate and do minor maintenance, bio-slurry utilization training, supervisor training, refresher training for masons and supervisors, and biogas technician training were given to the different groups of actors involved in the implementation of NBPE.

Mason training was seen as a priority requirement for the implementation of the programme (EREDPC and SNV, 2008). Thus, a total of 1022 biogas masons with previous masonry or plumbing experiences were screened, trained, and certified in the programme period. Although the plan was to develop 20 private biogas construction enterprises in the programme period (EREDPC and SNV, 2008), according to the key informants, none were created within the period. However, given creating market-driven biogas sector is one of the major objectives of the biogas programme, the need to develop private biogas sector is critically important.

Measuring the skill of the masons and effectiveness of the trainings offered definitely need independent research. However, the skill of the masons can be reflected in the quality of the biogas installations. In this respect, surveyed biogas adopters were asked whether the masons were skillful in constructing the biogas plants. While 154 (86 %) of the respondents said they were skillful, the remaining 25 (14 %) said not skillful. The justification for the latter incorporates the following: 1) cracking of domes and cracking and/or fracturing of inlet pits, outlet tanks, and slabs (Figures 10 and 11) due to use of impure sand and incorrect cement-sand ratio; 2) bio-slurry outflow before fermenting or inflow of bio-slurry back to the digester; 3) failure to function after the completion of construction and unable to identify the problems; 4) improper plumber work and problem of gas leakage; 5) the inability to make it functional, after doing the laborious emptying and plastering of the digesters; 6) improper orientation given to feed the digester with full of inlet pit everyday and the plant failed to operate as a result; and 7) improper site selection, where either the bio-slurry flows to neighbors' yard or digesters are installed in front of the houses, which makes it difficult for biogas users to use biogas toilet connections.

Figure 10. Cracking/fracturing of an outlet tank and slabs

Figure 11. Fracturing of slabs

A problem like the use of impure sand could be the result of carelessness and irresponsibility. Other problems such as the outflow of bio-slurry before fermenting, the improper ratio of cement and sand and failing to identify where the problems lie, could be the result of skill gaps in taking measurements and other basic skills. Thus, masons with such irresponsible behavior or skill gaps should be identified as early as possible before ruining a number of biogas installations through establishing communication network with biogas adopters and closer follow-up and supervision.

The following pictures of biogas installations can also substantiate the existence of skill gaps with some masons. Some biogas plants have been constructed at improper sites where boulders can slide down easily and damage the installations (Figure 12). The mason training manual recommends that the top part of the dome should also be equal to the ground surface level (MoWE 2010a). However, some biogas installations were found to have dome casts high above the ground level (Figure 13). Surprisingly, a few biogas plants have toilet seats where the PVC pipes protrude above the concrete surface (Figure14a and b).

Figure 12. Improper biogas installation site selection

Figure 13. Dome cast high above ground surface

Figure 14a. Examples of improperly built toilet seats

Figure 14b. Examples of improperly built toilet seats

Biogas user training is also an essential requirement that equips the farmers to be able to properly operate the biogas plants and resolve minor maintenance problems. As indicated in the PID, the plan was to provide user training twice during the pre- and post-construction periods (EREDPC and SNV, 2008). However, with the exception of provision of a simple orientation/instruction for a few minutes (10’ to 15’) by masons and/or supervisors, biogas user training was neither given uniformly across all biogas implementing regions, nor to all biogas user households. In Tigray Regional State, user training was given more often to three members of a biogas user household whereas in Amhara Regional State it was given only to a single household member, mostly to the head. So in a culture where women and children are almost exclusively responsible for cooking, provision of user training to household heads, dominantly males, as observed in Amhara Region, can contribute little to the proper and continuous utilization of the biogas installations. The budget for user training was known to be given on unit biogas installation basis. As key informant revealed, the problem with the provision of user training at the right time was associated with the matter of commitment at the regional mines and energy agency and the RBPCU.

In addition, 61 (34.1 %) of all the surveyed households did not get user training. Indeed, provision of user training was quite better in Tigray Region than in Amhara. Among the surveyed households in the *Mecha Woreda* of the Amhara Region, as high as 31 (58.5 %) did not get any user training while in the *Ofla Woreda* of the Tigray Region only 30 (23.8 %) got no user training. Moreover, of the total sample biogas user households, only 11(6.1 %) got both the pre- and post-construction user trainings. With no doubt, the provision of these pre-planned user training types at the right time are critically important to the sustainable utilization of the biogas installations at least as further in time as the presupposed service years of the technology. The use of dung mixed with chaffs and leaving dung stored in the inlet pit for later digester feeding can also show user training problems (Figure 15 and 16).

Figure 15. Dung mixed with chaffs ready for digester feeding

Figure 16. Dung stored in the inlet pit for later use has got dried

Training on the utilization of bio-slurry was lacking the necessary attention. One of the main reasons for this could be lack of belongingness on the part of the agricultural sector towards the biogas programme or the biogas projects. Most likely, this tendency came as a result of the non-involvement of the sector during biogas programme development. At the initial stage, more attention was given to the energy benefit aspects of biogas technology. The agricultural sector was not involved in preparation of the PID (EREDPC and SNV, 2008). Besides, the sector was not regarded as a member of the regional biogas steering committee. As a result, the bio-slurry extension component of the biogas programme was not given to be led and guided under the sector's institutional structure. So this should also be reconsidered, otherwise the existing regional bio-slurry extension component of the RBPCU would remain nominal and inactive.

Therefore, apart from the regular duty of promoting compost preparation and utilization to the entire public, no special attention was given to bio-slurry utilization and training in the sector. Even, as observed in *Ofla Woreda*, there seemed be a conflict of interest between biogas programme unit and the agricultural and rural development office. In GTP I, there was a target to boost up smallholder-farmers' productivity to about twofold by the end of the plan period (FDRE, 2010). In connection with realizing this grand plan, the woreda's agriculture and rural development office compel every household who own farmland to buy at least the minimum predetermined amount of chemical fertilizer that is proportional to the size of their farmland. This situation interferes with the promotion of bio-slurry utilization and discourages biogas owners who effectively utilize bio-slurry for fertilizer.

The Institute of Sustainable Development, a local non-governmental organization, provided bio-slurry training to about 800 biogas users in all the four biogas programme implementing regions. The interviewee indicated that the trainings focused on model and influential farmers so that knowledge and experiences were believed to be shared among biogas users.

4.3.4.4 Maintenance Services

Absence of follow up and maintenance service was one of the major problems identified to the failures of many of the biogas installations constructed prior to the establishment of NBPE (Eshete et al., 2006; EREDPC and SNV, 2008). So to solve this problem in the newly established NBPE, quality management is designed to be one of the basic programme activities. Quality management, as indicated in the PID, comprises control of construction qualities and maintenance service (EREDPC and SNV, 2008). In the 15-point tri-party agreement among biogas user, mason, and the programme unit, the mason was required to give a two-year maintenance service guarantee for the structural part and a one-year guarantee for appliances and pipelines. One of the enforcement mechanisms designed for this purpose was withholding 10.25 $ from the subsidy allocated per unit biogas installation. So this money is supposed to be given to the mason after two years of free maintenance services upon the approval of the biogas users for the service gained.

However, maintenance service was not given as intended for the following reasons. Firstly, it is only the masons who signed the aforesaid tri-party agreement. However, some masons give the duty of fitting biogas pipelines to plumbers on agreement to pay 5.13 $ to 10.25 $. Because masons with previous plumber work experiences tend to work on fittings while masons with previous masonry experiences tend to work on the structural parts of the biogas plants. Actually, it is good for the biogas pipelines to be fitted by experienced plumbers. But at the same time, it is this part of the biogas installation that needs repeated maintenance services. Whenever the biogas installation got any problem on the pipelines, the plumbers were not willing to give maintenance service whereas the masons in some cases failed to identify and solve the problem. It may be this skill gap that made some masons to give pipeline fitting duties to the plumbers. Even in conditions where the masons did the entire cement and pipelines work, the masons more often did not give immediate maintenance services as they were busy in constructing new biogas plants in further rural *kebeles*. In this regard, a regional advisor from SNV-Ethiopia revealed that masons have not yet seen the construction of biogas plants as a business. As a result, they don't visit biogas plants after the completion of construction. In fact, mention has to be also made to the positive social relations created between some masons and the biogas users which morally compel the masons to give maintenance service at any cost of time and distance.

Secondly, greater attention seems to be given to the number of biogas installations. In free-grazing system where cattle are roving during the day time, possessing a minimum of four heads of cattle is recommended to adequately feed a 4 m^3 biogas digester (EREDPC and SNV, 2008). However, when the sample biogas adopters were asked whether there was change in the number of cattle after adoption of biogas, it was found that a biogas household started with a single head of cattle in *Ofla Woreda*. The reason given was that being a *kebele* female representative, she was supposed to help in biogas promotion activities. Besides, all the surveyed biogas digesters in *Ofla Woreda* were 6 m^3 in size. To be able to adequately feed 6 m^3 digester size, possessing a minimum of six heads of cattle, which on average are supposed to produce 45 kg dung, is recommended (EREDPC and SNV, 2008). However, practically in this *Woreda*, households were expected to have a minimum of four heads of cattle to have got the installation of this digester size. As indicated in PID, four heads of cattle are supposed to produce 20-40 kg of dung which is sufficient only to feed the smallest (4 m^3) biogas digester. Besides, the *woreda* mines and energy focal persons were given around 25.62 $ per biogas installation. So it is more likely to push the masons to finish a biogas installation within 15 days as per their commitment indicated in the tri-party agreement. Here, this is not to criticize the incentives given, but it is to say incentives should be as per the number of functioning biogas plants too.

Third, withholding 10.25 $ as an enforcement mechanism is too small to morally attract the masons given dispersed locations of biogas plants and frequent operation problems resulting from lack of user training. Fourth, despite the tri-party agreement, there was no practical legal enforcement mechanism to compel masons to give timely maintenance service. This was evidenced by the fact that some masons left the construction of biogas plants before finishing, for financial reasons. As a result, some biogas plants remained incomplete for one or more years. The payment for masons varies from 123 $ to 146.1 $, depending on digester size and distances.

A question was raised to supervisors and programme coordinators about the measures taken in such circumstances. They revealed that though they explained the possibility to take the case to the courts, they didn't do that due to shortage of personnel to follow up the cases. Instead, they explained payments to masons were given progressively as per the stage of construction. So if a mason fled away at certain stage, the mason could easily be substituted by another mason and the payment for the remaining construction stages could be shifted. This progressive payment is also mentioned in the tri-party agreement. However, the surveyed incomplete biogas plants remained unfinished for 14 to 24 months. One possible reason for this could be progressive payments were not put into practice. Therefore, for a variety of reasons, of the total 179 surveyed biogas plants, only 129 (72.1 %) were operating where as the remaining 50 (27.9 %) were not operating. Of the 129 functioning biogas plants, only 96 (74.4 %) have both functioning stoves and biogas lamps. The rest have either functioning stoves or biogas lamps. Thus, of the total surveyed biogas plants, only 96 (53.6 %) have had both functioning stoves and lamps. The problems with non-functioning biogas plants included: 1) problems on pipelines (leakages, loosen valves, blockage by bio-slurry); 2) cracking of domes; 3) incomplete construction from the beginning due to masons fled away; 4) shortage of appliances; 5) demolished by task force due their construction on illegal sites (*Ofla Woreda*); 6) biogas users own problems; 7) improper site selection (bio-slurry flows to neighbor); 8) flow of bio-slurry before fermenting; 9) backflow of bio-slurry to the outlet tank; and 10) over-feeding.

The respondents were asked about the efforts made to get maintenance services. Thus, the responses included: 1) applied many times but obtained not more than lip service [22 (44 %)]; 2) tried nothing [12(24 %)]; 3) masons and/or supervisors came but unable to repair [4(8 %)]; and 4) repaired but failed to operate again [2(4 %)].

Despite the better trainings given, the problem of maintenance services was found to be more serious in *Ofla Woreda* than in *Mecha*. Out of the total 50 surveyed non- operating biogas installations, 43 were found in *Ofla Woreda*. In terms of proportions, while 43 (34.1 %) of the surveyed biogas plants failed to operate in *Ofla Woreda*, only 7 (13.2 %) failed to operate in *Mecha Woreda*. For various reasons, nine out of forty-three non-operating biogas plants remained incomplete for 14 to 24 months in *Ofla Woreda*. One major justification for this could be absence of maintenance service. There is only one focal person in the *woreda*. Therefore, the problem of maintenance service needs urgent action. Focus group discussants also emphasized on three issues for immediate improvement in the programme: maintenance service, user training, and availability of spare parts. Hence, one solution may be to assign a standby biogas technician who can give immediate maintenance and advisory services in each *woreda*. The other solution, which is even more cost-effective, could be the provision of on-the-spot intensive maintenance training to a few, may be three, educated, wise, and committed farmers per rural *kebele*. In support of the latter, mentioning a specific case may be very helpful. In *Mecha*

Woreda, a biogas owner requested about the existence of maintenance service. He had a blockage of the pipeline and asked the mason for maintenance service. While the mason was repairing, he attentively followed how the mason did repair and observed the necessary tools used for repairing. Then afterwards, he repairs not only his own but neighboring biogas plants too. He was asked how he was able to learn how to repair in such a short time. His reply was he has a grain mill and exercises doing some minor maintenance on it.

4.3.4.5 Supervision Services

Closer supervision and follow up is quite essential to control quality of construction, verify adherence to the standardized design, confirm compliance of measurements to the standards set, check proper operation of the biogas installations, and consider complaints on maintenance and other services. Accordingly, the NBPE prepared four types of quality control forms: quality control Stage One (QC1) and Stage Two (QC2), to be filled in by focal persons, construction completion quality control form (CCf) to be filled by regional biogas technicians, and 'after sales services' quality control form to be filled by regional or federal supervisors. QC1 was expected to be filled before and during construction. Starting from site selection, planning, and layouts, QC1 helped to follow up the various stages of construction and check quality and sufficiency of construction materials presented. QC2 was filled immediately after completion of construction (MoWE, 2010b).

The surveyed biogas adopters were asked about how often supervisors visited their biogas plants after the completion of construction. Accordingly, 123 (68.7 %) replied they were visited at least once whereas the remaining 56 (31.3 %) said no supervisor came at all. Among the former, 34 (27.6 %) of the plants were visited once, 46 (37.4 %) visited twice, 24 (19.5 %) visited thrice, and the remaining 19 (15.4 %) visited four or more times. Concerning the benefits obtained from supervisors' visits, 86 (69.9 %) replied that they obtained advices, maintenance services, and motivation. The remaining 37 (30.1 %) said they obtained nothing. It was also pointed out that supervisors mostly come without any maintenance tools. Hence, they can only maintain the type of problems requiring no maintenance tools.

In the PID, it was indicated that supervisions would be carried out on sample basis (EREDPC and SNV, 2008). If this is so, the proportion of visited biogas plants could be quite enough. But supervisors seemed to be directed towards the operating ones. This is because the proportion of visited non-operating biogas plants out of the total non-operating biogas plants was 29 (58 %) whereas the proportion of visited operating biogas plants out of the total operating plants was 94 (72.9 %). Hence, if supervision is not done on random basis, there will not be more chance for those non-operating biogas plants to get solutions. For instance, in *Ofla Woreda*, based on information obtained from the surveyed biogas owners, the entire seven biogas plants constructed in *Adishmbereket Tabiya (Kebele)* remained incomplete. Four of these installations were among the surveyed ones. Had there been supervision on random sample basis, these biogas plants might get solution. Based on personal observation, in rural *kebeles*, where there were many non-operating biogas plants, such as *Adishmbereket* in the *Ofla Woreda* and *Bachima* in *Mecha Woreda*, there were no new uptakes at all. *Bachima Kebele* was the first *kebele* where domestic biogas was introduced in *Mecha Woreda*. Unfortunately, as informants indicated, because of improper sand used for the construction, six out of eight biogas plants failed to function and remained unattended.

4.3.5 Supplies of Spare Parts

Availability of biogas spare parts within reasonable distance is a decisive factor for dissemination of biogas technology. Spare parts for biogas technology are commonly used as spare parts for pipe water installations or other construction and are widely available on the market. Those spare parts which are solely used for biogas technology are not available as needed. Biogas stoves have started to be produced by private manufacturers in the regional capitals. Walta Workshop in Mekele Town and Munic Engineering Plc in Bahir Dar Town are two of the biogas stove producers. After attending workshops at Selam Technical and Vocation Training Center in Addis Ababa and being given the required biogas stove model by NBPE, they are now producing and selling biogas stoves when ordered. They also produce and sell reducers, dome pipes, and templates. But the biogas lamp and all its accessories, and pressure gauges are imported by the government.

Two basic problems were raised by group discussants with regard to spare parts, particularly biogas lamp glasses and mantles. First, the spare parts are not available at all times in the *woreda* offices. So farmers were requested to wait until they come from the regional or federal offices. Second, sometimes the *woreda* offices are closed for field or other reasons. For those farmers coming from the remotest parts of the *woreda*, it is very tiresome. In *Ofla Woreda*, due to the shortage of the right biogas mantle type, biogas users commonly buy and use mantles originally meant for kerosene lamps. These mantles purchased from private shops were indicated to be less durable as compared to the ones given at the *woreda* office. Thus, owing to shortages of spare part only, operation of 7 (3.9 %) of the surveyed biogas plants were interrupted. Key informants at various administrative offices admitted the existence of spare part supply problems in the first two years of programme implementation period but the problems were solved afterwards. Even it was pointed out that the spare parts were given freely at the *woreda* offices. However, in reality, may be because of the problem of distribution or failure to request for the spare parts from the regional or federal offices at the right time, there were complaints about the shortages of supplies of spare parts.

Therefore, instead of even giving the spare parts freely but demanding farmers to travel long distances to the *woreda* offices, it would be better to put the spare parts at each rural *kebele* office and sell them to the farmers with reasonable prices. Especially during peak cropping seasons, farmers may not have enough time to travel a long distance to the *woreda* offices to get spare parts. Besides, as per the group discussants, sometimes, farmers get offices closed; and the other time, they are told the temporal unavailability of spare parts. The involvement of the private sector, wholesalers and retailers, in the supply of spare parts can solve the problem for good.

4.3.6 Monitoring and Evaluation

Monitoring and evaluation was also planned to be carried out in the programme period. Two types of monitoring and evaluation were mentioned: internal or external ones. Monitoring and evaluation was planned to be done twice in the programme period by external consultants (EREDPC and SNV, 2008). However, only the mid-term review was conducted in August and September 2011 by an external consultant recruited by the African Biogas Partnership Programme. The mid-term review had three focus areas. The first focus area was to determine the status of the programme in terms of four dimensions: expectations, efficiency, efficacy and partnership mapping. It was presented by the NBPCO of Ethiopia. The second area was programme implementation assessment using strength, weakness, opportunity and threat

(SWOT) analysis system. It was done in the workshop that involved programme stakeholders. The third area was to evaluate whether the programme was developing towards sustainability in relation to market development, enabling economic environment, and responsive policy. So the mid-term review was a workshop-based assessment. Moreover, as a component of monitoring and evaluation, user survey was also planned to be conducted annually. However, there wasn't any done to this survey time. Hence, the numbers of operating and non-operating biogas plants were not known correctly at national level.

4.3.7 Research and Development

Research and development is one of the major activities designed to be implemented in the national biogas programme, with the aim of ameliorating the programme, reducing the costs, and maximizing the benefits of the technology. For practical purposes, the activity's budget share and potential research areas were mentioned in the PID. The document also pointed out that capable research institutions, biogas companies, and consulting firms were supposed to be involved in the research, monitoring and evaluation endeavors of the biogas programme (EREDPC and SNV, 2008).

However, key informant interview with various individuals indicated the absence of well-coordinated research and development activities. Despite the existence of various research trials, both at private and institutional levels, they were fragmented and lacked continuity. For instance, institutionally there was an attempt to replace stones with interlocking soil blocks but this failed and was interrupted. In Amhara Region Biogas Programme Coordination Unit, there was an attempt to develop a biogas lamp, but it was not developed further. An *injera* stove was also developed by a private researcher in Amhara Region and three *injera* stoves were given to farmers for piloting purpose. The stove enabled baking 23 *injera* at a time, after saving gas for three days. However, the research has still continued for further improvement. In the Tigray Region, an *injera* stove and a clamp, a biogas lamp accessory, were also developed by Mesfin Industrial Engineering and Walta Workshop, respectively, but both technologies were not upgraded for consumption.

Nevertheless, failure to use biogas technology for baking *injera* and the short lifespan of biogas lamps, due to the frequent breakage of glass of biogas lamp and the burning of mantle, were indicated to be among the major bottlenecks that retard adoption and dissemination of biogas technology. Baking *injera* was estimated consuming about 50 % of the total household energy consumption (Gebreegziabher 2007). Consequently, the adoption and use of biogas technology has never fully replaced the utilization of traditional biomass fuels. Sample biogas adopters were asked a very general question about what to be improved in the overall biogas programme of Ethiopia. Accordingly, among other things, 124 (69.3 %) of the respondents suggested the introduction of an *injera* stove. Focus group discussants also emphasized the need to introduce *injera* stove. Besides, improving the durability of biogas lamps through research and development is a critical requirement for further dissemination of biogas technology. The frequent interruption on the use of biogas lamps resulting from lamp glass breakage and the burning of mantles together with their unavailability on the local market, not only discourages the biogas users but also the potential adopters.

4.3.8 Policy Support

The energy policy of Ethiopia, which was formulated in 1994, comprises various policy objectives, general policy directions, priorities, and main policy issues. These policy components spin around more or less similar ideas. Among eight policy objectives, four of them have supportive implications in addressing the modern energy needs of the rural households. These policy objectives are: 1) to ensure the gradual shift of the society's energy sources from traditional to modern fuels; 2) to resolve problems encountered in the process of development, supply, and utilization of energy resources; 3) to regulate and facilitate the development and supply of different energy resources; and 4) to give utmost effort towards the development of indigenous energy resources (TGE, 1994).

About 95 % of the population in Ethiopia relies on traditional biomass fuels for cooking (CSA and ICF International, 2012; Sanbata et al., 2014). Such high dependence on traditional biomass fuels over centuries coupled with rapid population growth has contributed to the fast declining of the woody biomass stock (Wolde-Ghiorgis, 2002). Hence, it is quite appropriate to have an energy policy objective that ensures the gradual shift of energy sources from traditional to modern fuels. It is also essential to resolve the unsustainable exploitation of woody biomass; regulate and direct the development and supply of various energy resources and give emphasis to the development of indigenous energy resources.

Among the indigenous energy resources, hydropower, a resource which is indicated to be the most available and dependable source of electricity, with a relatively low cost of generation per unit power, has received the highest priority of development. The development and use of other indigenous energy resources such as solar, wind, and geothermal are also encouraged, provided that their costs of investment are competitive. With regard to biogas technology, no mention was made in the document. Given biogas technology was introduced into Ethiopia about three decades before the formulation of the energy policy (Bekele, 1978); the prevalence of an energy problem in the country; and the relatively high cattle population in the nation by African standards, the policy document amazingly fails to acknowledge the role of biogas technology.

Nevertheless, biogas being one of the indigenous renewable energy sources, its development is implicitly encouraged. The document underscored the need to ensure that energy production and utilization are in harmony with the environment. This policy statement has also an embedded supportive implication to the development of biogas technology. Because biogas is an environmental-friendly technology that improves the soil fertility by the use of bio-slurry, lessens deforestation, and reduces GHG emissions (Arthur et al., 2011). Still the policy document underlined the need to develop the rural energy in coordination with the agricultural and the overall rural development (TGE, 1994). This policy statement also latently supports the development and dissemination of a multi-purpose biogas technology.

In a nutshell, the energy policy document of Ethiopia has the following strengths and limitations. The strengths encompass: 1) it provides priority attention to development and use of indigenous energy resources; 2) it emphasizes the need to bring energy transition from use of traditional fuels to modern fuels; 3) it underscores the need to develop energy resources in harmony with the environment and ecological settings; and 4) it underlines the need to develop the rural energy in coordination with the agricultural and the overall rural development. The limitations include: 1) it has not yet been updated with the dynamic realities for a solid two decades; 2) it does not exhaustively identify domestic energy resources including biogas; 3) it fails to clearly propose the need to promote decentralized modern energy systems including biogas; 4) it vaguely proposes the need to provide alternative energy sources to various energy consuming sectors without clearly listing alternative energy types; and 5) it proposes the involvement of private investors in the development and supply of energy resources without having a clearly stated policy instruments (incentives). In general, the country does not have Household Energy Master Plan. The menu for choosing energy options is not yet well developed. Biogas technology for example is dependent on the availability of donor support.

Even in relatively recently developed national documents, biogas is missing in the renewable energy lists. No single mentioned is made in documents like Energy Proclamation (Proc. No. 810/2013) of Ethiopia (FDRE, 2013) and the four successive national development plans: Sustainable Development and Poverty Reduction Programme (2002/03-2004/05), Plan for Accelerated and Sustained Development to End Poverty (2005/06-2009/10), GTP I (2010/11-2014/15), and GTP II (2015/16-2019/20) (FDRE, 2002; 2005; 2010; 2015). However, the inclusion of biogas technology in the country's renewable energy list, in a document like energy policy and other applicable documents, is undoubtedly important for its promotion and development. It would serve as a signal to the existence of government attention to the technology, so that the stakeholders could give the necessary attention towards its development.

4.4 The Socio-Economic Impacts of Domestic Biogas Technology

4.4.1 Source and End-Use of Household Energy

Regardless of the differences in accessibility, households' choices, and the amount consumed, a variety of household energy sources are utilized in the study areas. These energy sources are: fuelwood, charcoal, dung, crop residues, electricity, kerosene, biogas, solar panels, dry cells and candles. The feasibility study on domestic biogas programme in Ethiopia also described the utilization of all these fuel types at different scales in the country (Eshete et al., 2006). Fuelwood was utilized by the entire sample households. Its primary source for 261 (72.9 %) of the sample households was own planted trees. The other principal sources of fuelwood for 37 (10.3 %), 17

(4.7 %), 2 (0.6 %), and 41 (11.5%) of the sample households were communal scrub lands, government protected woodlands, naturally grown vegetation around farmlands, and purchasing, respectively. As a primary source, fuelwood collection was practiced only in *Ofla Woreda*. In this *Woreda*, 56 (22.2 %) of the sample households principally collect fuelwood from communal scrub lands, government protected woodlands or naturally grown vegetation around farmlands. Whereas, 157 (62.3 %) and 39 (15.5 %) of the sample households obtained fuelwood from own planted trees and purchasing, respectively. In *Mecha Woreda*, with the exception of some isolated stands of trees around homesteads and farmlands, one does not see much naturally grown vegetation. Therefore, the primary sources of fuelwood for 104 (98.1 %) and 2 (1.9 %) of the sample households in the *Woreda* were own planted trees and purchasing, respectively. The latter were compelled to purchase fuelwood due to the loss of their planted trees for an irrigation development project in the *Woreda*. In relation to the use of planted trees, Bewket (2003) stated that the scarcity of wood for cooking and other purposes has compelled the households in Chemoga Watershed to plant more trees.

Dung fuel was utilized by 91 (70.5 %) of the biogas users and 228 (99.6 %) of the non-users. Similarly, Gebreegziabher (2007) found that almost all (99.5 %) of the surveyed households in Tigray Region utilize dung as a source of fuel. Therefore, the use of biogas energy is an important step forward that has assisted 38 (29.5 %) of the biogas users to be able to fully abandon the direct combustion of an air dried dung fuel.

Crop residue was utilized by 40 (31 %) of the biogas users and 63 (27.5 %) of the non-users. The dominant types of crop residue utilized for fuel were stalks of maize (including its cobs) and sorghum. The consumption of this fuel type inevitability varies with the type of crops grown every year. Damte et al. (2012) also found that 35 % of the households surveyed in four regional states of Ethiopia, namely, Oromiya, Amhara, Tigray, and SNNP were utilizing crop residue for fuel.

Electricity connection was enjoyed by 19 (14.7 %) of the sample biogas users and 58 (25.3 %) of the non-users. Most of the electricity users 74 (96.1 %) were in *Ofla Woreda*, specifically in the suburb parts of Korem Town. Kerosene was utilized by 16 (12.4 %) of the sample biogas users and 150 (65.5 %) of the non-users. Solar panels were used by 10 (7.8 %) of the biogas users and 10 (4.4 %) of the non-users. Battery lamps were used by 6 (4.7 %) of the biogas users and 57 (24.9 %) of the non-users. In a nutshell, the proportions of biogas user and non-user sample households by sources of their household energy are shown in Figure 17.

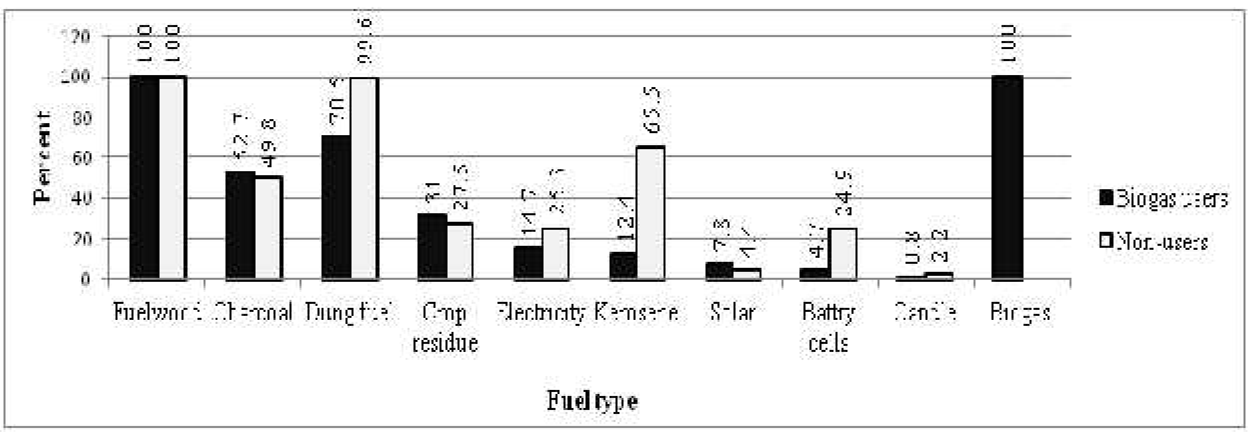

Figure 17. Percentage share of the sample households utilizing the fuel

Each of the aforesaid fuel types is utilized for one or a combination of the following end-uses: baking *injera* and bread, cooking *wot* and others, boiling water, lighting, space heating, and charging electronics (Table 9). The type of fuels regularly utilized for baking *injera* and bread by both biogas user and non-user households were fuelwood, dung, and crop residue. Merely 1 (0.8 %) and 4 (1.7 %) of the biogas user and non-user sample households utilized electricity for baking *injera* and bread, respectively. In this regard, Gebreegziabher et al. (2012) stated that in most cases lighting is the principal end-use of electricity. Only a few families in large urban centers utilize it for cooking purpose. Besides, for piloting purpose, a sample household got a biogas stove for baking *injera* from a private researcher. However, the technology has not yet been developed for wider dissemination.

The biogas user and non-user sample households substantially differed in the type of fuels utilized for cooking *wot*, boiling water, and lighting. For these end-uses, biogas has turned out to be an important source of energy for the biogas users. Specifically, 123 (95.3 %) and 110 (85.3 %) of the biogas users utilized biogas energy for cooking and lighting purposes, respectively, while 227 (99.1 %) and 148 (64.6%) of the non-users made use of fuelwood and kerosene for these purposes, in the same order (Table 9).

Table 9. Percentages of sample biogas users and non-users by end-uses of various fuel types

Type of fuels	Baking (*injera* and bread)		Cooking *wot* and others		Boiling Water		Lighting		Space heating		Charging electronics		Use the fuel for any end-use	
	Biogas users	Non-users	Biogas users	Non-users	Biogas users	Non-users	Biogas users	Non-users	Biogas users	Non-users	Biogas users	Non-users	Biogas users	Non-users
Fuelwood	100.0	99.6	52.7	99.1	51.9	98.7	-		0.8	2.2	-	-	100.0	100.0
Charcoal	-	-	47.3	49.3	47.3	49. 3	-	-	6.2	4.4	-	-	52.7	49.8
Dung	70.5	99.1	23.3	80.8	17.1	44.1	-	-	-	-	-	-	70.5	99.6
Crop residue	31.0	27.5	13.2	21.0	17.1	24.9	-	-	0.8	0.4	-	-	31.0	27.5
Electricity	0.8	1.7	-	1.7	-	0.9	14.7	25.3	-	-	14.0	24.0	14.7	25.3
Kerosene	-	-	0.8	1.7	0.8	1.7	12.4	64.6	-	-	-	-	12.4	65.5
Solar	-	-	-	-	-	-	4.7	4.4	-	-	7.8	3.9	7.8	4.4
Battery lamp	-	-	-	-	-	-	4.7	24.9	-	-	-	-	4.7	24.9
Candles	-	-	-	-	-	-	0.8	2.2					0.8	2.2
Biogas	0.8	-	95.3	-	93.8	-	85.3	-	-	-	-	-	100	-

4.4.2 The Status of Household Energy Consumption in the Study Areas

The consumption quantities of various household energy types have been computed with the exceptions of solar panels, battery lamps, and candles. Thus, excluding these three fuel types, the weekly total energy consumption of the entire surveyed households was about 428,574.7 MJ. Of this, traditional biomass fuels made up 389,577.5 MJ (90.9 %) of the total energy consumption. Fuelwood and dung alone constituted 352,540.6 MJ (82.3 %) of the total household energy consumption. Unlike the national level where fuelwood is the leading fuel being consumed (Teketay, 2001; EREDPC and MoARD, 2002; CSA and ICF International, 2012), its consumption is outpaced by dung fuel in the study sites. Fuelwood accounted 151,392.4 MJ (35.3 %) while dung fuel constituted 201,148.3 MJ (46.9 %) of the weekly total energy consumption of the surveyed households (Figure 18). The result is consistent with the findings of Gebreegziabher (2007) in which the mean annual dung fuel consumption (1364.6 kg ≈18831.3 MJ) exceeded that of fuelwood (624.3kg ≈ 9676 MJ). Therefore, this finding indicates the prevalence of severe problem of fuelwood in the study areas. However, coincidentally, this is an opportunity for further promotion biogas technology. Based on the feasibility study on the national domestic biogas programme of Ethiopia (Eshete et al., 2006), households having a minimum of four heads of cattle can adequately feed at least the minimum recommended domestic digester size (4 m^3).

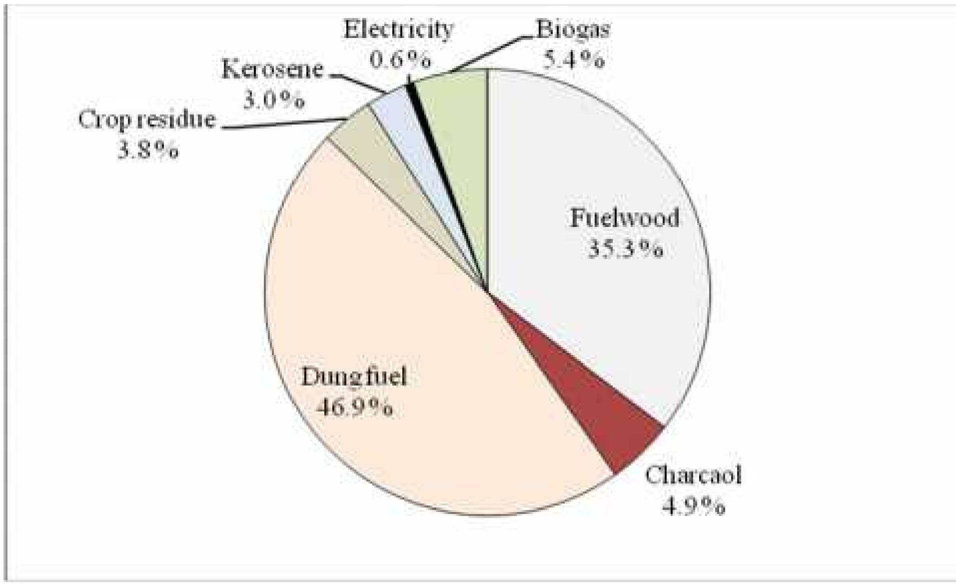

Figure 18. Percentage share of various fuel types in the household energy mix in the study areas

Among the modern fuel types, biogas came to be the most consumed energy in the household energy mix. It constituted 23,275.8 MJ (5.4 %) of the surveyed households' weekly total energy consumption. Its consumption exceeded the combined consumptions of kerosene and that of electricity (Figure 18).

In the surveyed households, the weekly total energy consumptions ranged from 425 MJ to 2440 MJ, with an average of 1197.1 MJ. Given other factors remain the same, the amount of energy consumption increases with the size of the households. A strong (Urdan, 2005) positive correlation (+0.567) was obtained between weekly total household energy consumption and household size at $p<0.01$ significant level. But a strong negative (-0.604) correlation was found between the weekly per capita energy consumption and household size at $p<0.01$ significant level. The result implies that cooking large meals is more energy efficient than cooking small meals. The scatter diagram showing the correlation between weekly total household energy consumption and household size is displayed in Figure 19.

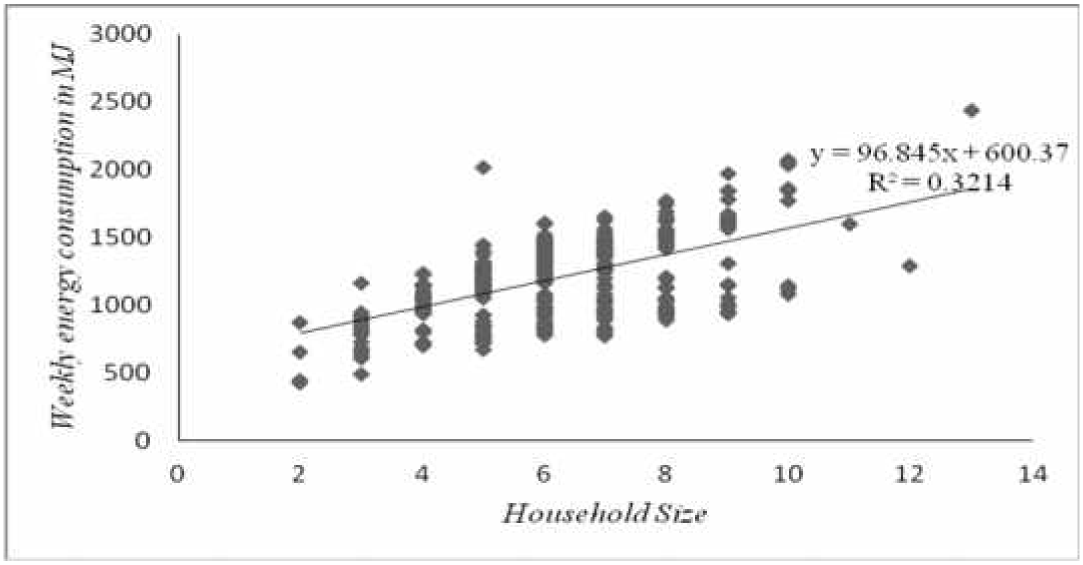

Figure 19. Correlation scatter diagram between weekly total household energy consumption in MJ and household size

The weekly average per capita energy consumption of the entire sample households was 203.1 MJ. On daily basis, it gave 29 MJ which is less than the national average, i.e., 32.1 MJ (WBISPP Amhara, 2002; WBISPP Oromiya, 2002; WBISPP Tigray, 2003). The amount was also lower than the daily per capita energy consumptions of the rural households in Zimbabwe (34.4 MJ) and Botswana (44.8 MJ) but higher than that of Kenya (25.3 MJ) (African Development Bank, 1996 cited in Karekezi and Kithyoma, 2002). Therefore, the result indicates the prevalence of energy poverty in the study sites. Even the amount would have been smaller if the study had not purposely focused on better off farmers who have adopted the technology or have the potential to be able to adopt biogas technology.

4.4.3 The Impacts of Biogas Technology on Rural Household Energy Consumption

The weekly average per capita energy consumptions of biogas user and non-user households were compared. Accordingly, the weekly average per capita energy consumption of the biogas user households was found significantly ($p<0.01$) lower than that of the non-user households.

The former had a weekly per capita energy consumption of 158.8 MJ whereas the latter had 228.1 MJ (Table 10). These variations certainly resulted from the use of an energy efficient biogas technology. Consequently, the biogas user sample households were able to save a total of 2,989,406.2 MJ or 192.9 t of fuelwood equivalents annually. This has a shadow price[6] of about 17,885.9 $. A similar study in Northern China also stated that households with biogas digesters were capable of reducing domestic energy consumption by 10.2 % (1305.2 MJ) on per capita basis than those households without biogas digesters (Ding et al., 2012).

The use of biogas technology remarkably reduced the consumptions of fuelwood, dung fuel, and kerosene. In all these three fuel types, the biogas users' weekly average per capita consumption was significantly ($p<0.05$) lower than that of the non-user households. The weekly average per capita fuelwood, dung fuel, and kerosene consumptions of the biogas user households were 65.6 MJ, 42.5 MJ, and 0.8 MJ, respectively whereas for the non-user households, they were 71.8 MJ, 127.9 MJ, and 9.6 MJ, in the same order (Table 10). Thus, the use of biogas technology enabled the surveyed biogas user households to be able to reduce the total consumption of fuelwood by 17.2 t, dung fuel by 267.4 t, and kerosene by 10,538.9 liters ≈65.87 barrels per annum, provided one barrel equals 160 litres (Twidell and Weir, 2006). The use of biogas in Sirsi, India, enabled 85 % of the surveyed households to be able to fully replace all other cooking fuels, dominantly fuelwood (Bhat et al., 2001).

Had there been *injera* stove with the biogas technology, traditional biomass fuel consumption would have been reduced further. According to Gebreegziabher (2007), baking *injera* roughly consumes 50 % of the total household energy consumption. Therefore, if the biogas technology is scaled up to include *injera* stove, most if not all traditional biomass fuels are likely to be substituted by biogas energy. Indeed, there is an attempt of developing a biogas stove for *injera* which is under a pilot-testing. It will be a breakthrough if it is upgraded to a public consumption level.

Table 10. Weekly per capita energy consumption of biogas users and non-users by fuel type in MJ

Sample type	Fuelwood	Charcoal	Dung fuel	Crop residue	Kerosene	Electricity	Biogas	Total
Biogas users	65.6	11.5	42.5	7.2	0.8	0.9	30.3	158.8
Non-users	71.8	10.0	127.9	7.3	9.6	1.5	-	228.1
T-test values	p<0.05	p>0.1	p<0.001	p>0.1	p<0.001	p>0.1	-	p<0.001

Separate analyses for *Ofla* and *Mecha woredas* also gave essentially similar results with that of the combined *woredas*. Both in *Ofla* and *Mecha woredas*, the weekly average per capita energy consumptions of the biogas user households were significantly (p<0.01) lower than that of the non-user households. In *Ofla Woreda*, the weekly per capita energy consumptions of the biogas user and non-user sample households were 160.6 MJ and 227.8 MJ, respectively while in *Mecha Woreda*, they were 155.9 MJ and 229 MJ, in the same chronology (Table 11). More specifically, the use of biogas energy significantly (p<0.05) reduced the weekly per capita consumptions of fuelwood, dung fuel, and kerosene in *Ofla Woreda*. Consumptions of these fuels were reduced by 10.7 MJ, 80.5 MJ, and 7.0 MJ on weekly per capita basis, respectively. While in *Mecha Woreda*, significant (p<0.01) reductions were obtained in the consumptions of dung fuel and kerosene alone. Their weekly per capita consumptions declined by 94.1 MJ and 13.6 MJ, respectively (Table 11).

Thus, the weekly average per capita fuelwood consumptions of the biogas user and non-user households were significantly different in *Ofla Woreda* only. One of the possible justifications for this could be the differences in the sources of fuelwood between *Ofla* and *Mecha woredas*. As a primary source, fuelwood collection from naturally grown vegetation was practiced only in

Ofla Woreda. Hence, it seemed that the use of biogas energy enabled the households to be able to abandon or minimize the need to travel long distance in search of fuelwood.

Table 11. *Woreda* variations in the weekly per capita energy consumptions in MJ between biogas user and non-user sample households by fuel types

Woreda	Sample type	Fuelwood	Charcoal	Dung fuel	Crop residue	Kerosene	Electricity	Biogas	Total
Ofla	Biogas users	61.4	12.3	47.6	5.5	1.1	1.4	31.3	160.6
	Non-users	72.1	11.2	128.0	6.4	8.1	2.0	-	227.8
	Woreda	68.6**	11.5	101.5*	6.1	5.8**	1.8	10.3	205.6**
Mecha	Biogas users	73.1	10.0	33.3	10.4	0.4	0.1	28.6	155.9
	Non-users	70.8	6.8	127.4	9.9	14.0	0.1	-	229.0
	Woreda	71.8	8.2	86.6**	10.1	8.1**	0.1	12.4	197.3**

*** and * Significant at $p<0.01$ and $p<0.05$*

4.4.4 The Benefits of Biogas Technology in Improving Health and Sanitation

The majority [110 (85.3 %)] of the sample biogas users realized that the utilization of biogas technology highly reduced the problem of health through the declined use of traditional biomass fuels. The biogas user respondents were requested to choose from the list of energy-related health problems which they assumed declined following the adoption and use of biogas technology. Accordingly, eye diseases, respiratory problems like coughing and asthma, headaches, back pain resulting from heavy load of traditional biomass fuels, injury mishap during fuel collection, and burning accidents were the health problems that were reported decreasing by 87 (67.4 %), 54 (41.9 %), 39 (30.2), 28 (21.7 %), 11 (8.5 %), and 2 (1.6 %) of the respondents, respectively. The result is in line with the findings of Laramee and Davis (2013) in which it was reported that 75 % of the respondents in Tanzania realized the health improvements due to shifting from the use of fuelwood or kerosene to biogas cooking.

Besides, as per the group discussants, the use of biogas lamps reduces the need for some students to rent dormitories in the town for the purpose of studying with electric light. Students who rent dormitories commonly take cooked food in bulk for a week or so from their parents. In the absence of any food preservation facilities, the food gets moldy within two or three days. As a result some students face serious health problems that can occasionally lead to school dropping. Moreover, the use of biogas lamp is a great relief for those students who used to study at home with kerosene lamps. While studying with kerosene lamp, the lamp needs to be brought closer. Otherwise, it will be too dim to read. When it is brought closer, eye irritation and inhaling kerosene soot are inevitable. Moreover, the need to feed the biogas digester daily assists in maintaining the sanitation of the livestock barn through daily collection of dung. This promotes the health of the livestock and reduces possibility of transmittable diseases from the livestock to humans.

Furthermore, the installations of biogas technology gave an opportunity for the majority of biogas user households to have biogas digester-connected toilets. In currently-working biogas model of NBPE, the PVC- pipe is already in place for possible toilet connection with the biogas digester. Thus, it is up to the interest of the biogas users to have constructed the toilet seats and shelters and utilize the toilet connections (Eshete et al., 2006). Consequently, among 123 (95.4 %) biogas user households who owned toilets, 108 (87.8 %) had biogas digester-connected toilets with concrete seats while the rest 15 (12.2 %) utilized pit-toilets with wooden-seats. One of the justifications given for not using digester-connected toilet by the latter was feeling not comfortable to use bio-slurry, if connected. Amongst the non-user sample households, 152 (66.4 %) had toilets to which 113 (74.3 %) had wooden seats and the rest 39 (25.7 %) had concrete seats. Of the latter, as high as 29 (74.4 %) had biogas-digester connected toilets which continued to be used after the biogas plants stopped operating. Thus, they are likely to be abandoned sometime soon unless the plants are repaired again within reasonably short period of time. Concerning to toilet roofs and walls, both biogas user and non-user sample households utilized nearly the same materials. Toilet walls were dominantly made of wood while roofs were covered with iron sheets, grass, plastics or eucalyptus leaves. Therefore, the installations of biogas digesters enabled the biogas user households to have comparatively larger number and better quality toilets than the non-user households. This in turn minimizes the practice of random defecations and possible transmission of contagious diseases.

4.4.5 The Benefits of Biogas Technology on Workload Reduction

The effect of biogas technology on workload reduction was determined based on the estimated weekly average hours spent on various household activities. The household activities which were thought to be influenced by the use of biogas technology were included. These were: 1) collecting wood-fuel and preparing for use (collecting fuelwood, splitting fuelwood, making charcoal, and purchasing fuels) ; 2) collecting dung, feeding the biogas digester and/or making dung cakes; 3) collecting crop residue for fuel; 4) fetching water; 5) cooking food; and 6) cleaning utensils and kitchen. Besides, livestock care and fodder collection which were thought to have some influence on the use of biogas technology were also considered. According to Keizer (1994), the main reproductive activities of women which were believed to have closer link with the use of biogas technology included collection of cooking fuels, cooking food, cleaning pots, and feeding the biogas digester. Though not included in the time measurement, herding, collecting fodder, and lighting were also mentioned to have some influence on the use of biogas technology. Thus, based on the survey result, the weekly mean hours spent on various household activities and their differences between biogas user and non-user households are shown in table 12.

Table 12. Estimated weekly average hours spent on various household activities by biogas user and non-user households

S.No.	Household activity	Biogas users (a)	Non-users (b)	(b-a)
1	Collecting wood-fuel and preparing it for use	4.0	4.6	0.6*
2	Collecting dung, feeding the biogas digester and/or making dung cakes	5.5	4.9	-0.6**
3	Collecting crop residue for fuel	0.2	0.1	-0.1
4	Fetching water	8.8	6.3	-2.5**
5	Cooking food	19.0	31.8	12.8**
6	Cleaning utensils and kitchen	4.5	7.6	3.1**
	Total	42.0	55.3	13.3**

*** and * represent statistically significant differences in mean values between biogas user and non-user households at p <0.01 and 0.01<p<0.05, respectively. (T-test was used to check differences in means.)*

Even if the use of biogas technology involved carrying out a few extra duties such as fetching water, mixing dung and water, and feeding the biogas digester, the technology generally assisted in reducing the overall household workload by 13.3 hours per week (1.9 hours per day) at p<0.01 significant level. Specifically, the average times taken for cooking food, cleaning utensils and kitchen, and collecting wood-fuel and its preparation for use were reduced by 12.8 hours, 3.1 hours, and 0.6 hours per week, respectively (Table 13). The time saved through the use of the technology was devoted partly to leisure time, schooling, agricultural activities, and other income generating activities. In relation to this, the feasibility study for national domestic biogas programme in Ethiopia indicated that the utilization of biogas technology can on average lessen the overall household workload by two to three hours per day (Eshete et al., 2006). In a similar study in Nepal too, the use of biogas technology enabled the biogas user households to cut back the time required for household activities on average by three hours per day than the non-user households (Singh and Maharjan, 2003). The possible justification for the slightly less time saved from the use of biogas in this particular case study could be related to the functional status of the biogas plants. No all biogas plants work with full capacities. Among other things, 25 (19.4 %) of the biogas plants had either a non-functioning stoves or lamps. However, saving an average of about 1.9 hours daily from the use of biogas technology is yet significant.

Besides, the average hours taken for livestock care and fodder collection were compared between the sample biogas user and non-user households. Consequently, while there was a non-significant mean difference in the time spent on livestock care, there was a significant ($p<0.01$) mean variation in the times spent on fodder collection. The weekly average hours devoted to livestock care by the biogas user and non-user households were 22.8 and 23.9, respectively. The weekly average hours spent on fodder collection were 3.7 and 2.3, in the same order. However, the total hours spent on these two closely-related activities by the sample biogas user and non-user households were found statistically insignificant. Hence, it is possible to state that the use of biogas technology has little effect in the combined time spent on livestock care and fodder collection. In connection with this, Katuwal and Bohara (2009) empirically showed that the daily average times spent on fodder collection and livestock caring slightly increased (by 0.7 and 2.8 minutes, respectively) following adoption of biogas in Nepal.

None other than cultural reasons, most of the routine household activities were carried out by women and children. In the sample biogas user and non-user households, women and children together covered 5305.9 hours (97.9 %) and 12,457.9 hours (98.6 %) of the weekly total hours devoted to different household activities, respectively. In comparison to daughters, the participation of sons was also very much limited (Table 13). Nevertheless, the utilization of biogas technology significantly ($p<0.05$) increased the involvement of men in the household chores. In the sample biogas user households, men accounted 10.3 % of the total hours spent on various household activities whereas in the non-user sample households, they covered only 6.9 % of the time (Table 13).

Table 13. Weekly total hours spent on various household activities by gender between sample biogas user and non-user households

Household activities	Biogas users						Non-users				
	Gender	Wife	Husband	Daughter	Son	Total	Wife	Husband	Daughter	Son	Total
Collecting wood-fuel and preparing for use	Hours	214.0	97.7	91.2	109.0	511.9	447.4	170.3	220.0	204.6	1042.3
	%	41.8	19.1	17.8	21.3		42.9	16.3	21.1	19.6	
Collecting dung, feeding digester and/or making cakes	Hours	324.1	9.2	322.7	52.3	708.3	584.8	0	507.7	27.1	1119.6
	%	45.8	1.3	45.6	7.4		52.2	0	45.3	2.4	
Collecting crop residue for fuel	Hours	10.8	0	7.5	1.8	20.1	15.7	0	10.7	3.0	29.4
	%	53.6	0	37.3	9.0		53.4	0	36.5	10.1	
Fetching water	Hours	761.4	4.6	331.2	42.6	1139.8	961.3	1.7	438.3	38.4	1439.7
	%	66.8	0.4	29.1	3.7		66.8	0.1	30.4	2.7	
Cooking food	Hours	1491.1	2.3	756.4	204.2	2454.0	4582.6	11.7	2402.8	272.8	7269.9
	%	60.8	0.1	30.8	8.3		63.0	0.2	33.1	3.8	
Cleaning utensils and kitchen	Hours	286.7	0	262.9	36.2	585.8	870.7	0	774.9	95.2	1740.8
	%	49.0	0	44.9	6.2		50.0	0	44.5	5.5	
Total	Hours	3088.1	113.8	1771.9	446.1	5419.7	7462.5	183.7	4354.4	641.1	12,641.6
	%	57.0	2.1	32.7	8.2	100	59.0	1.5	34.5	5.1	100

Thus, in addition to the time saved through the use of energy efficient biogas stoves and declined time spent on collection of traditional biomass fuels, men's increased involvement in the household activities with the use of biogas technology further contributed to women's workload reduction. In this regard, Bajgain and Shakya (2005) stated that the user-friendliness of biogas stoves increases the involvement of men in cooking. As a result, the traditionally feminized role of cooking is changing into where men are ever more involved in cooking. Katuwal and Bohara (2009) also described that as the utilization of biogas technology significantly reduces the time needed for various domestic activities, women become the primary beneficiaries of the technology.

The utilization of biogas technology significantly ($p<0.01$) increased women's average time spent on fetching water, and collecting dung, feeding the biogas digester, and/or making dung cakes. However, the technology significantly ($p<0.05$) and overwhelmingly reduced women's average time spent on cooking food, cleaning utensils and kitchen, and collecting wood-fuel and its preparation for use. Whereas, men's average time spent on cooking food, and collecting dung, feeding the biogas digester and/or making dung cakes significantly ($p<0.01$) increased with the use of biogas technology.

As per the group discussants, biogas stove is faster and easier to use than the solid fuel stoves. As a result, male students (sons) have started cooking their own breakfast before leaving for the school. Consequently, they do no more wait their mothers or sisters for the preparation of their breakfast, specifically when mothers or sisters are busy in other duties. Otherwise, in the absence of biogas technology, the involvement of sons in cooking food is largely limited to attending the fire while some food is being cooked. The significantly higher involvement of the sons in collecting dung, feeding the biogas digester and/or making dung cakes can be related to their motivation with the use of the technology particularly with the brighter biogas light. Concerning to the involvement of the husbands in the household activities, as it is clearly shown in Table 13, it was limited to some selected chore types. Nevertheless, among the household chores they involved, the husbands' average time spent on collecting dung, feeding the biogas digester, and/or making dung cakes was significantly ($p<0.01$) higher for the biogas user households than the non-user households. In this regard, the group discussants specified that the husbands have better involvement in mixing water and dung, and feeding the biogas digester provided that the dung is already collected and put in the inlet tank; selecting and cutting warped tree stands and chopping them down for easy transportation; in splitting wood for fuel; extracting water from well water in the compound (if any); and to a small extent in cooking food.

4.4.6 The Benefits of Biogas Technology to the Agricultural Sector

The use of biogas technology can positively influence the development of the agricultural sector in various ways. Among others, the use of bio-slurry as organic fertilizer can immensely boost agricultural production. Of the total sample biogas user households, 118 (91.5 %) utilized bio-slurry for fertilizer whereas the remaining 11 (8.5 %) did not. Similarly, in a field survey conducted in four major regional states of Ethiopia, namely, Tigray, Amhara, Oromiya, and SNNP, nearly an equivalent proportion of bio- slurry users were reported. Among 71 biogas user sample households, 91.6 % were found using bio-slurry for fertilizer (Eshete, 2011).

The justifications given by non-users of bio-slurry included:

- lack of awareness and clear understandings about its fertilizer quality;
- there was no much accumulated bio-slurry (Some biogas plants did not function with their full capacities);
- the farmland is too far to transport the bio-slurry;
- shortage of labour and time to transport to the farm; and
- purchasing chemical fertilizer is obligatory and hence, no need of carrying bio-slurry to distant place (this was reported in *Ofla Woreda* only).

When asked what they did with the bio-slurry, the replies were either they used it as fuel after drying or buried it or left it unattended. However, the cost-benefit analysis of biogas technology in rural Ethiopia indicated that effective utilization of the bio-slurry significantly increased the benefits of the technology and shortened its payback periods (Gwavuya et al., 2012). Therefore, there should be utmost efforts in encouraging and promoting the utilization of bio-slurry among all the biogas user households.

Among 118 sample bio-slurry users, 104 (88.1 %) of the respondents realized that bio-slurry has superior fertilizer qualities than the fresh manure, 12 (10.2 %) replied not sure; and the other 2 (1.7 %) perceived as it has the lesser qualities than that of the fresh manure. The relatively superior qualities of bio-slurry included the following. As high as 104 (88.1 %) of its users perceived it increases crop yield better than the one grown with the fresh manure; 97 (82.2 %) replied it lessens weeds; 25 (21.2 %) said it minimizes unpleasant odour; 27 (22.9 %) realized it is more fragile and easier to apply; 4 (3.4 %) said it reduces pests; and the rest 1 (0.9 %) said it prevents immediate wilting during prolonged dry time. In support of this, the results of various preliminary field trials on the fertilizer qualities of bio-slurry over different cereal crops, specifically on wheat, barley, and *teff* showed that bio-slurry increased yields by about 50 % to more than 100 % (Eshete, 2011). Besides, in a similar study in Tanzania, as high as 95 % of the sample biogas users considered bio-slurry to be a better-quality fertilizer than both the fresh manure and chemical fertilizers. Furthermore, Seadi et al. (2008) listed the qualities of bio-slurry over that of the fresh manure. It boosts crop yield through readily available nutrients; it has less or no unpleasant odour; it harbors no or less weed seeds; and it consists no toxic substances to the crops.

Bio-slurry was applied on a wide variety of crops: cereals, garden, fodder crops, oil crops, and pulses. As high as 112 (94.9 %) of its users applied it for cereal crops such as on maize and *teff*; 75 (63.6 %) utilized it for garden crops like vegetables and fruits; and 26 (22.0 %) for fodder crops. Still a very small proportions, 5 (4.2 %) and 4 (3.4 %) of the bio-slurry users applied it on pulses and oil crops, respectively. EREDPC and SNV (2008) also stated the application of bio-slurry over a range of crop types including vegetables, fruits and others. Moreover, Eshete (2011) specified experiences of application of bio-slurry over a wide variety of crops: tree fruits, vegetables, cereals, and fodder.

Amid the sample bio-slurry user households, 113 (95.8 %) had bio-slurry pits. The number of pits ranged from one to four where 52 (46 %) had one, 54 (47.8 %) had two, and the remaining 7 (6.2 %) had either three or four pits. Though possession of a minimum of two bio-slurry pits is suggested to be able to alternately use one after the other, maintain the nutrient quality of the bio-slurry, and allow it curing itself from any potential pathogen for a while (Eshete et al., 2006; Ejigu, 2010), nearly half 57 (48.3 %) of the bio-slurry users had either none or only one bio-slurry pit.

The bio-slurry was utilized either in wet or dried forms. Among the bio-slurry user households, 73 (61.9 %) utilized it in dried form, 7 (5.9 %) in wet form either by directly pouring it onto the plant roots or directing it to flow to the farm yard, and 38 (32.2 %) in both dried and wet forms. In the case of using bio-slurry in dried form, it was either stored alone to let it dry in a pit or open field or made compost. While 77 (65.3 %) of the sample bio-slurry users made compost out of it (Figure 20 and Figure 21), the other 34 (28.8 %) stored and let it dry alone (Figure 22 and Figure 23). During storage, 74 (62.7 %) of the bio-slurry users covered it either with straw, soil, leaves, grass, sheds or a combination of these (Figure 20). Whereas, the rest 37 (31.4 %), which excluded those using it in wet form, did not cover or make shelter to the stored bio-slurry. However, the need to cover and/or make shelter to the stored bio-slurry is critically important to avoid or minimize loss of volatile nutrients such as nitrogen (Eshete et al., 2006; Ejigu, 2010).

Figure 20. Compost making in pits from bio-slurry and other organic matters covered with straw

Figure 21. Compost making in an open field from various organic matters without any cover

Figure 22. Drying bio-slurry alone in pits without any cover

Figure 23. Bio-slurry partly drying up in an open field and partly flowing to the grass

Though the majority of the sample biogas users recognized the superior fertilizer qualities of bio-slurry over that of the traditional manure, only 43 (36.4 %) of the bio-slurry users reduced the amount of chemical fertilizer being purchased. These households were able to reduce a total of 3200 kg of both DAP and Urea in 2013/2014 production year and save a total of 2293.44 $. This was only about one-tenth of the total 32,600 kg of both DAP and Urea purchased by the entire sample biogas user households in the production year. Therefore, it is possible to say that the majority of the biogas user households have not yet effectively utilized the bio-slurry for fertilizer purpose. Similarly, Laramee and Davis (2013) reported insignificant variations in the use of chemical fertilizer between biogas user and non-user households in Tanzania. Indeed, the group discussants raised an important issue with regard to the role of bio-slurry. The use of bio-slurry enabled the biogas user households to at least avoid the need to constantly increase the dose of chemical fertilizer application that resulted from the repeated cropping and ever rising deterioration of the soil fertility.

Besides, as the group discussants revealed, the use of smokeless-biogas energy promotes people's health and so does their agricultural productivity. Part of the time-saved through the use of biogas technology has been devoted to agricultural activities. The growing of fodder crops using bio-slurry was as well indicated to have its own positive contribution to the improvement of livestock production. Furthermore, the need to feed the biogas digesters daily implies daily cleaning of the livestock barn and promotion of livestock health and productivity.

4.5 The Environmental Benefits of Domestic Biogas Technology

4.5.1 Benefits of Biogas Technology in Reducing GHG Emissions

4.5.1.1 Emission Reductions from the Declined Use of Traditional Biomass Fuels and Kerosene

The use of biogas energy enabled the biogas user households to be able to reduce the consumptions of various traditional biomass fuels and, in turn, emissions of GHGs. The average amounts of GHG emission reductions obtained through the reduced use of dung fuel, kerosene, and fuelwood were 2.7 t, 182 kg, and 45 kg of CO_2e per digester per annum, respectively (Table 14). The main justification for the highest GHG emission reduction from the use of dung fuel is, obviously, the shift in its role from direct combustion in air-dried form to an input for the biogas digester. In relation to this, Lansche et al. (2011) stated that for every unit of heat energy conveyed to the cooking pot, the biogas system released 45 % lower GHG in CO_2e than the dung combustion system.

Table 14. Average annual GHG emissions and emission reductions in kg of co_2e from the use of various fuels by biogas user and non-user sample households

Fuel type	Emissions in kg CO_2e		Emissions reduced (a-b)
	Non-users of biogas (a)	Biogas users (b)	
Fuelwood	2670.3	2625.2	45.1
Charcoal	338.2	391.6	-53.4
Dung fuel	4141.6	1461.0	2680.6
Crop residue	255.5	249.9	5.6
Kerosene	202.2	20.5	181.7
Biogas	0.0	513.7	-513.7
Total	7607.8	5261.9	2345.9

The utilization of biogas energy and the subsequent declined use of traditional biomass fuels and kerosene resulted in a significant ($p<0.01$) GHG emission reductions. Both the average yearly household level and per capita GHG emissions from the combustions of household fuels were significantly ($p<0.001$) lower for the biogas user households than the non-user households. The average annual GHG emissions of the biogas user and non-user households were 5.3 t and 7.6 t CO_2e. Thus, neglecting the possible biogas leakage problem, the technology assisted in reducing GHG emission by about 2.3 t of CO_2e per digester annually.

However, 10 % of the biogas generated was assumed to be escaped to the atmosphere. Thus, the average annual emission of methane from the biogas plants would be 460 kg of CO_2e. Hence, the net annual average GHG emission reductions per unit biogas installation would be 1.9 t of CO_2e. The resulting value is less than the findings of Katuwal and Bohara (2009) (4.5 t), Laramee and Davis (2013) (6.4 t), and Pathak et al. (2009) (9.7 t) but greater than that of Zhang et al. (2013)

(1.3 t). The main justification for this variation could be the absence of country specific emission factors. In case of the last one, the first reason can be the use of different emission factors. The other reason could be the incorporation of construction materials and transport fuels needed for biogas installations.

In China and India, biogas is a well-developed technology, and so is the efficiency of the biogas stoves. The efficiency of biogas stoves in China was reported to be about 60 % (Gregory, 2010; Li et al., 2009). In India too, the average efficiency of biogas stoves was indicated to be 57.4 % (Smith et al., 2000). Whereas, for Ethiopia, due to the less quality of stove manufacturing, the efficiency of biogas stoves is much less than these values. For example, to determine the efficiencies of sample biogas stoves and lamps taken from different countries including Ethiopia, laboratory tests were conducted in 2007with SNV funding in China, India, and the Netherlands. The test results confirmed the poor efficiency of the biogas stoves made in Ethiopia. The average thermal efficiency of biogas stoves of Ethiopia was reported to be 46.4 % while it was 60.5 % for India (Khandelwal and Gupta, 2009).

Therefore, for the entire sample biogas user households, the GHG emission reduction was about 243.3 t of CO_2e per annum. In Tigray and Amhara regional states alone, 7000 domestic biogas digesters were planned to be built in the first phase (2009-2013) of NBPE (EREDPC and SNV, 2008). Had all these digesters been constructed and properly operated, there would have been a total GHG emission reduction of about 13,202 t of CO_2e per annum. As indicated in Moges et al. (2010) the value of carbon abatement at the global market ranges from 10 $ to 20 $ t^{-1}. Taking the minimum carbon reduction value alone, there would have been yearly revenue of about 132,020 $ for the regions. Even the stated average reduction can generate huge hard currency of carbon financing if the technology is embraced under the scheme of Clean Development Mechanism.

4.5.1.2 Emission Reductions from the Practice of Better Manure Management

The practice of manure management also influences the rate of GHG emissions. Both the daily collection of cattle dung for feeding the digesters and toilet-connections to the digesters help controlling emissions of GHGs. Unless the sample biogas user households have large number of cattle that their dung exceeds the daily feeding requirements of digesters, most cattle dung is fed into the digesters on a daily basis. This practice obviously holds back emission of GHG like methane in the digesters. Besides, biogas installations enabled the biogas user households to possess better quality toilets than the non-user households. As high as 123 (95.4 %) of the biogas user sample households possess toilets. Of these toilets, 108 (87.8 %) were connected to the biogas digesters while the rest 15 (12.2 %) own pit latrines. Among the non-user sample households, only 152 (66.4 %) had toilets. These toilets were all in all pit-latrines with either concrete or wooden seats. Relative to the practice of random defecations, the use of pit latrines can help in reducing contagious diseases. But they don't help in controlling the release of methane from the anaerobic fermentation of human excreta. In this regard, Yu et al. (2008) stated that through collection of livestock and human manure for the production of biogas, emission of GHG like methane can be controlled.

4.5.1.3 Emission Reductions from the Reduced Use of Chemical Fertilizer.

Among the sample biogas user households, only 43 (36.4 %) reported that the use of bio-slurry helped to reduce the quantity of chemical fertilizer that they used to purchase. Even these households reduced only 1.6 t of DAP and 1.6 t of Urea in 2013/2014 production year. This roughly accounts one-tenth of the total chemical fertilizer (17.7 t of DAP and 14.9 t of Urea) purchased and utilized by the sample biogas user households in this production year.

However, the production of chemical fertilizer, particularly Urea, is an energy-intensive process (Gellings and Parmenter, 2004; IFA, 2009; Chen and Chen, 2011; Vaneeckhaute et al., 2013). Besides the requirement of energy to fuel the production process, natural gas is a key raw material for the creation of ammonia (Gellings and Parmenter, 2004; IFA, 2009). Thus, the quantity of GHG emission reductions gained from the existing meager substitution of chemical fertilizer by bio-slurry cannot still be disregarded. As shown in table 15, the total amount of GHG emission reductions gained from the stated decrease of chemical fertilizer ranged from 1.4 t to 19 t of CO_2. If the country purchases chemical fertilizer from companies that employ the latest technologies, a minimum of 1.4 t of CO_2 emission reductions could be gained. If it purchases from fertilizer companies that dominantly utilize coal to synthesizing ammonia, like the case in China, the emission reductions gained could be as high as 19 t. However, the country purchases chemical fertilizer on tender basis (Tadesse, 2015; Endeshaw, 2016). Hence, tender winners may vary over time, and so are the fertilizer industries and their energy inputs. Thus, based on the global average emission factors, about 2.6 t of CO_2 could be reduced from the stated amount of chemical fertilizer forgone.

Table 15. GHG emission reductions from the production of chemical fertilizers forgone due to the use of bio-slurry

Fertilizer type	Total chemical fertilizer reduced (kg)	Total energy saved (MJ)			Total CO_2 emissions reduced (kg)		
		New plants (a)	Global average (b)	Plants that use coal (c)	New plants (a)	Global average (b)	Plants that use coal (c)
Urea	1600	34,080	42,400	114,720	1120	1600	18,240
DAP	1600	3520	13,600	19,360	320	960	800
Total	-	37,600	56,000	134,080	1440	2560	19,040

In China, as compared to the non-user households, the utilization of bio-slurry helped the user households to reduce the use of chemical fertilizer by about half. While the biogas user households on average used 185.5 kg ha^{-1} of chemical fertilizer, the non-user households used 376.4 kg ha^{-1} (Ding et al., 2012). There are only a few reports that claim bio-slurry can fully replace the use of chemical fertilizer (Kocar, 2008; Gautam et al., 2009; Katuwal and Bohara, 2009; Li et al., 2012; Vaneeckhaute et al., 2013). Hence, had there been proper utilization of bio-slurry, the sample biogas user households could have reduced the use of chemical fertilizer by at least half. This, in turn, could have given an additional 10.8 t of CO_2 emission reductions and relieved the biogas user households greatly from the purchase of expensive chemical fertilizer.

Therefore, to ensure the proper management and utilization of bio-slurry by the biogas user households, the concerned bodies should give the necessary attention. Particularly, the NBPCO - responsible for the dissemination of biogas plants, Ministry of Agriculture and Natural Resources-responsible for the supply and proper utilization of agricultural inputs, and the Ministry of Environment, Forestry and Climate Change-responsible for the well-being of the environment should coordinately work and give the necessary attention towards the better result.

4.5.2 Benefits of Biogas Technology in Reducing Depletion of Woody Biomass

The use of biogas technology assists in reducing depletion of woody biomass in two aspects: a) improving efficiency of energy use, and b) replacing wood-fuel and other energy sources with biogas energy.

a) Improving efficiency of energy use: Owing to the use of an energy-efficient biogas technology, the yearly per capita energy consumption of the biogas user households was lower than that of the non-user households. The former has a yearly per capita energy consumption of

8.3 GJ whereas the latter had 11.9 GJ. As a result, the sample biogas user households were able to save a total of 192.9 t of fuelwood equivalents per annum. Based on the feasibility study on domestic biogas potential of Ethiopia, in Tigray and Amhara regional states alone, 330,952 to 994,707 households were indicated to have the potential to adopt biogas technology (Eshete et al., 2006). Hence, if the technology is able to be adopted and utilized by the lower estimated number of potential households (330,952), it would be possible to save a total of about 496,428 t of fuelwood equivalents per annum. This in turn would save a total of about 1962 ha to 3424 ha of tropical forest per year.

b) Replacing wood-fuel and other energy sources with biogas: The use of biogas energy has partly replaced the consumptions of wood-fuel and other household energy sources. Of the yearly total 6.5 TJ of energy consumed by the sample biogas user households, biogas energy constituted 1.2 TJ (18.5 %). Hence, the opportunity cost of consuming this much amount of biogas energy is the consumption of 78.1 t of fuelwood equivalents or the removals of 0.3 ha to 0.5 ha of tropical forests per annum for wood-fuel production.

Besides, reducing the depletion of woody biomass through the use of biogas technology also contributes to carbon sequestration. Reducing wood-fuel consumption by one tonne means getting roughly one-half tonne of carbon sequestered in the woody biomass.

4.5.3 Benefits of Biogas Technology in Improving and Maintaining the Soil Fertility

The use of biogas technology has both direct and indirect benefits to the improvement of the soil fertility. The utilization of bio-slurry as an organic fertilizer directly improves the soil fertility through both enriching its nutrients and ameliorating the physical properties. Depending on the digester sizes, a properly operating domestic biogas technology can on average generate 2.6 t to 3.5 t of solid bio-slurry per annum which gives a grand average of 3.1 t.

This shows that on average a domestic biogas digester provides an equal amount of nitrogen available in 235 kg of Urea per annum. It also provides approximately an equal amount of phosphorus (P_2O_5) available in 127 kg of DAP. Therefore, the amount of nitrogen fertilizer that can be obtained from a properly operating biogas digester exceeds the average amount of nitrogen obtained from 137 kg of DAP and 115.7 kg of Urea purchased in 2013/2014 production year by an average sample biogas user household. The phosphorus nutrient also accounts more than 90 % of the fertilizer purchased in the production year indicated. In a nutshell, the amount of bio-slurry that can be generated from a properly operating average domestic biogas digester can cover the full nitrogen and more than nine-tenth of the phosphorus fertilizer requirements of an average biogas household in the study sites. As already experienced in China (Ding et al., 2012), the yearly total amount of bio-slurry generated from a properly operating biogas digester reduces at least half of the annual purchase of chemical fertilizer by an average household. The main problem with the use of bio-slurry may be the issue of applying the required dosage of various nutrients.

Relative to the fresh manure, bio-slurry provides more readily available plant nutrients. Specifically, nitrogen nutrient in bio-slurry is indicated to have faster and immediate fertilizer effect than the one in the fresh manure (ESCAP, 2007; EREDPC and SNV, 2008; Bonten et al., 2014). Bio-slurry comprises both major and micro-nutrients that are valuable to the growth of plants (Barbosa, et al., 2014). It also embraces important substances like cellulose, protein, and lignin which improve the soil's physical properties. Furthermore, it creates favorable environment to the soil's microorganisms which are relevant to the transformation of soil nutrients into plant usable forms (ESCAP, 2007).

The substitution of traditional biomass fuels with biogas energy indirectly minimizes the depletion of woody biomass and the removals of dung and crop residue for fuels. As stated in Amigun et al. (2012), this enables the soil not to be exposed to erosion, flooding, and high evaporation. It also allows dung and crop residue to be devoted to organic fertilizer and/or animal feed. In the absence of nearly other energy alternatives, the scarcity of wood-fuel inevitably leads to an increasing reliance on inferior biomass fuels- dung and crop residue which would have been otherwise utilized as organic fertilizer (EREDPC and SNV, 2008). Thus, the complete or partial substitution of various biomass fuels with biogas energy indirectly lessens soil degradation through the reduced wood-fuel collection and utilization of dung and crop residue for fuel.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In agrarian countries like Ethiopia where more than fourth-fifth of the population resides in rural areas, the expansion of decentralized modern renewable energy systems like biogas technology can address the cyclical problems of energy poverty, land degradation, and agricultural productivity. However, adoption and dissemination of biogas technology has not been progressing as it was planned in Ethiopia. The factors that stunt the pace of its adoption and dissemination include the socio-economic, bio-physical, and institutional factors.

The rate of adoption of biogas technology has been found low among the rural households. The study identified a number of constraining factors that influence adoption of biogas technology in the study sites. Sex of the household head is recognized to be an important factor influencing adoption of biogas technology. Male-headed households are more likely to adopt biogas technology than the female-headed ones. Households having access to credit are more likely to adopt the technology than those without this opportunity. Educational level of the household head, heads of cattle, distance to the main fuelwood source, income level, and number of planted trees are identified to have significant ($p<0.01$) positive influence in the decisions of households on adoption of biogas technology. Furthermore, geographical location (*woreda*) of the households is found to have a significant ($p<0.01$) influence on adoption of biogas technology. Households in *Mecha Woreda* are likely to have more favorable biogas technology adoption characteristics than those households in *Ofla* W*oreda*.

The interaction effects of a few pairs of explanatory variables, namely, age of the household head by educational level, age of the household head by number of planted trees, household size by heads of cattle, and farmland size by number of planted trees are also found significant ($p<0.1$) factors. Age of the household head by educational level, and household size by cattle size had positive influence on adoption of the biogas technology whereas age of the household head by number of planted trees, and farmland size by number of planted trees have negative influence on adoption of the technology.

The spatial-based analysis of the factors indicates that male-headed households, both in *Ofla* and *Mecha woredas*, are likely to have greater probability of adopting biogas technology than the female-headed ones. Educational level, annual income, access to credit, and number of planted trees have also significant ($p\leq0.1$) positive influence on adoption of biogas technology in both *woredas*. Heads of cattle, farmland size, and distance to the main fuelwood source are significant ($p<0.1$) only in *Ofla* W*oreda*.

Given biogas technology has high investment cost and demands some technical skills of how to operate and make minor maintenances, the farmers seem to be quite conscious of watching out whether the biogas user neghbours, friends or relatives are benefiting well from the technology. More than two-third of the non-users mentioned the problems faced by the biogas users as a reason for not adopting the technology. *Injera* baking consumes as high as about half of the total domestic energy consumption in Ethiopia; thus, the absence of *injera* stove with the currently working biogas model is one of the barriers retarding adoption of biogas technology.

The institutional structure for NBPE is found to be less suitable for the smooth implementation of the programme. It extends only from federal to regional administrative levels. Programme implementation level is left to the pre-existing *woreda* level government structure. The *woreda* mines and energy office which is acting and serving as an extension of the biogas institutional structure was not suitably rearranged. There is no a direct 'chain of command' between the RBPCU and *woreda* mines and energy offices. There is (are) also only one or two employee(s) in the *woreda* mines and energy office structure.

The biogas programme steering committee established at different administrative levels is found to be inactive. The members lack commitment and even some important stakeholders, like the agricultural sector, are not involved at federal and regional levels. Hence, there is lack of coordination between related ministries. The biogas programme has a serious human resource shortage. The technical staff members particularly a single biogas engineer, three biogas technicians, and a single bio-slurry utilization expert (agronomist) in a region are few to give the required technical services. The programme does not also encourage private sector, NGOs and other civil society stakeholders adequately.

The provision of subsidies and credit arrangements, the latter as seen in Tigray Region, are found to have their own positive contributions towards speeding up the dissemination of biogas technology. Indeed, the frequently rising prices of biogas construction materials due to inflation are posing backlash effects on biogas dissemination and reduced real value of fixed and constant subsidy rate.

Biogas user training is neither given uniformly to all biogas user households nor across all biogas programme implementing regions. In Amhara Region, user training is being given only to the head of biogas user household, dominantly men. The provision of training on utilization of bio-slurry also lacks the necessary attention, and the involvement of the agricultural sector in this regard is found to be limited. Most of the biogas user households (more than 95 %) have either literate household heads or have at least one literate household member. But biogas user guidelines are not provided uniformly.

As evidenced by problems like the cracking of domes, bio-slurry outflow before fermenting, failure to work right from the beginning, the inability to identify the problems, and inability to solve the problem after ordering the laborious duty of emptying the digesters, some biogas masons lack basic biogas construction skills.

The biogas users are also not obtaining maintenance service regularly and immediately on demand. The enforcement mechanism is too weak for masons to give regular maintenance service. Therefore, for various reasons, of the total surveyed biogas digesters, 50 (27.9 %) were not operating at all, and 25 (14 %) had either non-operating stoves or biogas lamps. Biogas spare parts, particularly biogas lamp and its accessories, are not available regularly and at a reasonable distance from the biogas users. However, due to the frequent breakage of the biogas lamp glasses and burning of the mantles, these spare parts are demanded every time. The regular unavailability of these spare parts has a daunting effect on the further dissemination of biogas technology.

User survey has not yet been conducted. Thus, the numbers of operating and non-operating biogas plants have not yet been known at national level. Research and development in the NBPE is found to be fragmented and lacks continuity. Despite the various attempts, there are no any concrete research and development results that have reached to the public consumption level during the first biogas programme period. Given all these constraining factors and the absence of biogas masons developed to biogas construction enterprise level, realizing the emergence of market-driven biogas sector seems to take a long time and need an endless effort and commitment to resolve those constraints.

The biogas technology has neither been properly incorporated into energy policy, proclamation, and nationwide development plan like GTP-I in Ethiopia nor has obtained the necessary attention it deserves from its stakeholders. Biogas energy is missing in the country's renewable energy lists. The energy policy document neither exhaustively lists energy resources to include biogas nor has it been updated for two solid decades. It also lacks clearly stated policy instruments that promote involvement of the private investors towards the development of renewable energy technologies including biogas. Thus, biogas technology (domestic, industrial and institutional) is still forgotten and deserves attention in the energy portfolio of the country. The country does not have also household energy master plan.

Traditional biomass fuels are still the dominant sources of households' energy in rural Ethiopia. In the study areas, traditional biomass fuels constituted more than nine-tenth of the total households' energy consumptions. Interestingly, however, among the existing meager modern energy sources utilized in the study areas, the consumption of biogas energy has become the highest in the households' total energy mix. Its consumption has exceeded the combined consumptions of kerosene and electricity.

The utilization of domestic biogas technology, though not as effective as intended, has its own significant contributions towards addressing the socio-economic and environmental challenges in rural Ethiopia. The use of biogas energy significantly reduces per capita energy consumption. The biogas user households have significantly ($p<0.01$) lower per capita energy consumption than the non-user households. The former had a weekly per capita energy consumption of 153

MJ whereas the latter had 228 MJ. Specifically, the use of biogas energy significantly ($p<0.05$) reduce the consumptions of fuelwood, dung fuel, and kerosene. Had there been *injera* stove with the biogas technology, the difference in per capita energy consumption would have been even wider. Therefore, the biogas user and non-user households substantially differ in the type of fuels being utilized for cooking *wot*, boiling water, and lighting.

Based on the respondents' own report, the use of biogas technology also assists in reducing energy-related health problems. This is indicated to be possible through the reduced use of traditional biomass fuels and the existence of an already inbuilt pipe line with the currently working biogas digester model for possible toilet connection. It encourages the biogas user households to have digester-connected and better quality- concrete seat toilets which minimize the practice of random defecations and possible transmission of contagious diseases.

The utilization of biogas technology reduces the overall household workloads on average by 13.2 hours per week. The technology significantly ($p<0.05$) decreases the time needed for fuelwood collection and its preparation for use, cooking food, and cleaning utensils and kitchen. Besides, the use of the technology significantly ($p<0.05$) increases the involvement of men in the household chores. Men's average time spent on cooking food, mixing dung and water, and feeding the biogas digester significantly ($p<0.01$) increases with the use of biogas technology.

Biogas technology offers various benefits to the growth of the agricultural sector. It provides better quality bio-slurry fertilizer and reduces expenses of chemical fertilizer; it improves people's health and in turn their productive capacities; it reduces household workload where part of the time is devoted to the agricultural activities; it improves the livestock productivity through bio-slurry-grown fodder; the need to feed the biogas digesters daily entails daily cleaning of the livestock barn and improvement of the livestock health.

Nevertheless, bio-slurry has not been utilized as effectively as expected by all the biogas users. About 11 (8.5 %) of the biogas users do not use it at all as fertilizer. Having only one or no bio-slurry pit and storing bio-slurry in an open field or a pit without any cover are also critical problems that reduce qualities of bio-slurry. Consequently, even if about four-fifth of the biogas users acknowledge its superior fertilizer qualities; only 43 (33.3 %) actually reduce the amount of chemical fertilizer being purchased.

Biogas technology is realized to have different environmental benefits. One of its promising benefits is GHG emission reduction. Through the substitution of traditional biomass fuels and kerosene alone, the technology on average reduces about 1.9 t of CO_2e annually.

The proper utilization of bio-slurry can also greatly reduce emission of GHG like CO_2. The production of chemical fertilizers particularly Urea is an energy-intensive process. As indicated in IFA (2009), the global average rates of GHG emissions from the production of Urea and DAP are proved to be 1.0 kg and 0.6 kg of CO_2 per kg, respectively. Consequently, from the mere reduction of 1.6 t of DAP and Urea each, on average, 2.6 t of CO_2 was able to be reduced in 2013/2014 crop production year.

The utilization of biogas technology also assists in reducing depletion of woody biomass through both improving efficiency of energy use and replacing wood-fuel with biogas energy. Specifically, the former enables the user households to save about 1.5 t of fuelwood equivalents and the latter 0.6 t of fuelwood equivalents per household per year. Saving fuelwood has clearly a spillover effect on the availability of wood to non-users of biogas technology. In other aspect, reduced woody biomass removals as fuels mean the technology has contributed to carbon sequestration.

Moreover, the use of biogas technology assists in improving the soil fertility through both supplying nutrient rich bio-slurry fertilizer and reducing the removal of woody biomass, dung, and crop residue for fuel. Relative to the conventional manure, bio-slurry offers better quality fertilizer in terms of at least in giving immediately available nitrogen nutrient. It also embraces various micro-nutrients and ingredients improving the soil's physical properties which one can't find in chemical fertilizer. Besides, bio-slurry has a residual effect that can last for at least three years which is not also evident in the chemical fertilizer. However, despite such better fertilizer qualities over that of conventional manure and chemical fertilizer, the use of bio-slurry has not yet been given due attention in the study sites.

5.2 Recommendations

1. For further promotion of the biogas technology, attention should be given towards empowering females and female-headed households, improving educational levels of the household heads, and households' access to credit and income levels.
2. Households should also be encouraged to plant more trees. Planting more trees, beyond promoting adoption of biogas technology through improving the households' income, can assist in the global efforts of mitigating GHG emissions.
3. The institutional structure of the national biogas programme should be increased to the programme implementation level, *woreda* administration, with clear 'chain of command' and accountability.

4. The shortage of biogas engineers, biogas technicians, and agronomists should be resolved. Biogas masons having basic skill gaps should be identified and corrected as early as possible through establishing communication network with biogas users and closer follow-up and supervision.
5. To reduce the negative effect of inflation on fixed subsidy rate over programme period, subsidy size should be adjusted based on inflation rate scenario ranges from a given base year.
6. Biogas being a new technology to farmers, provision of timely user training to each biogas user household involving women and children should not be compromised.
7. A detail user guideline comprising step-by-step techniques of operating and maintaining the biogas plant with pictorial depictions and principles of do's and don'ts can augment user training and thus should be presented at least with reasonable price.
8. Biogas spare parts like biogas lamp and its accessories which are less durable and frequently demanded by the users should be purchased in bulk with revolving fund and be available regularly for sale at centers (rural *kebele* offices) that are reasonably near to the biogas users.
9. Research and development should focus on cost reduction aspect of biogas technology, augmenting the technology's service through developing biogas stove for *injera* baking, and improving durability of biogas lamp and its accessories. Baking *injera* is estimated to consume as high as half of the total domestic energy consumption in Ethiopia. Hence, developing the currently existing pilot level *injera* stoves to the public consumption level would be a great breakthrough both in terms of substituting other household energy sources with biogas and promoting the dissemination of the technology. Therefore, the

NBPCO and the Ministry of Water, Irrigation, and Electricity should give the necessary attention for its realization.

10. To realize the emergence of market or demand-driven biogas sector, i) the existing government roles of promotion, construction, and after sales services in the biogas technology dissemination should be shifted to the private sector; ii) the development of private sector biogas companies should be encouraged through creating conducive working environment and providing performance-based and reasonably attractive incentives. Thus, the roles of the government should be limited to regulation only. It can be guarantor of quality and regulator of transaction between biogas user and provider including after sales service. It should also establish a strict monitoring and evaluation system to monitor the progress, evaluate the impact, and use the result for designing and updating policy.
11. The energy policy of the country should be updated regularly to accommodate dynamic realities and exhaustively identify and incorporate missing energy resources. Policy makers should incorporate biogas technology in energy policies and develop policy instruments that create conducive environment for the involvement of the private investors and the creation of a commercial biogas-sector.
12. In the preparation of nationwide development plans, planners should incorporate biogas technology to the renewable energy list of the plans, so that stakeholders can give the necessary attention to its development and dissemination. This can also create harmony with the national vision of building middle income and climate-resilient green economy.
13. The use of biogas technology is found to have various significant positive impacts on the rural households. However, as high as 50 (27.9 %) and 25 (14 %) of the surveyed biogas

households have non-operating and partially functioning biogas installations, respectively. Therefore, the NBPCO should focus not only on the dissemination of the technology but also ensure the continuous and proper functioning of the already installed biogas plants.

14. The NBPCO should also give due attention for how words of mouth from the satisfied or dissatisfied biogas users can enhance or retard adoption of biogas technology. The office should ensure the proper functioning of the already installed biogas plants through monitoring and evaluation services, establishing biogas technology maintenance service centers at reasonable distance, and assigning a standby biogas technology technician(s) for the centers so that biogas households can get immediate maintenance and aftersales services. To learn the number of operating and non-operating biogas installations, ensure whether the biogas adopters have gained the intended benefits of the biogas technology, identify the practical problems of the users, and formulate a successful plan to the future, conducting a national level user survey at a regular time should not be an optional in a biogas programme period.
15. A few biogas user households seem to prefer either not to connect toilets with the biogas digesters or not to use bio-slurry if connected. Therefore, to resolve this problem, raising people's awareness level could be a way forward. To this end, the health extension workers should coordinately work with the Biogas Programme Coordination Office.
16. The use of biogas technology assists women in reducing workloads through both minimizing the time needed for various household activities as well as increasing men's involvement in the household activities. Therefore, promoting the beneficial roles of biogas technology should not be left to the Biogas Programme Coordination Office.

Other stakeholder like the Ministry of Women, Youth, and Children's Affairs should jointly work on its promotion.

17. Not all the biogas users utilize bio-slurry as organic fertilizer. The majority of its users do not strictly follow the necessary procedures to maintain the fertilizer qualities of bio-slurry while storing. Hence, to ensure proper storage and utilization of the bio-slurry, all the biogas users should get the necessary training and practical demonstrations. The NBPCO should closely work with the Ministry of Agriculture and Natural Resources Development to ensure the proper management and utilization of bio-slurry so that the soil fertility can be enhanced, expenses on chemical fertilizer can be reduced, and emission of GHG from the production of the same can be curtailed.
18. Given the GHG emission reduction potentials of the biogas technology, exploiting the existing carbon market can assist its further expansion.
19. Finally, the research gaps that the author would like to suggest further studies include: developing national specific greenhouse gas emission factors for various potential sources; measuring the skills of masons and effectiveness of the trainings given; and showing the relative advantages of bio-slurry fertilizer over that of chemical fertilizer, the conventional manure, and compost supported with practical demonstration over different agro-ecologies and soil types; transaction costs of biogas technology in rural Ethiopia.

Endnotes

1. Though there are variations among authors as to the exact time when biogas was introduced into Ethiopia, it seems reasonable that it was Bekele who wrote that it was he himself who constructed the first biogas installation in 1962 at Ambo School of Agriculture, the later Ambo College of Agriculture (Bekele, 1978).

2. *Woreda* is the second lowest administrative unit next to *kebele* in Ethiopia.

3. Average market prices of different grains per quintal in United State Dollar ($): *Teff* (*Eragrostis tef*) = 65.30, Barley = 43.60; Wheat = 46.10, Maize = 38.40, Sorghum = 51.25, *Dagusa* (*Eleusine coracana*) = 41.00, Chick pea = 46.10, Peas = 51.25, Beans = 43.60, Vetch = 38.40, Niger seed=60.20, Lentil= 71.75, and Rape seed = 38.40. United States Dollar ($) is based on January 2014 exchange rate with Ethiopian currency- Birr (1 Birr= 0.05125 $).

4. DAP and Urea are nearly the only two types of chemical fertilizers utilized in Ethiopia (Negussie, 1995; Spielman et al., 2011).

5. *Injera* is Ethiopia's popular thin-flat pan-cake prepared from leavened flour mainly from *teff* (*Eragrostis tef*).

6. Average market prices of a bundle of fuelwood, a sack of charcoal, a basket of dung fuel, and a bundle of crop residues were 1.95 $, 5.33 $, 0.67 $, and 0.77 $, respectively.

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Appendices

Appendix A: Semi-Structured Interview Questionnaire Prepared for Biogas Adopter Sample Households

Woreda ______________________	Interviewer's Name _________________
Kebele/Tabiya _________________	Supervisor's Name ________________
Kushet _________________________	Date of interview__________________
Code of sample household ________	Interview starting time ___________

Dear Respondents,

The main purpose of this interview questionnaire is to acquire information relevant for a research entitled "Biogas Technology Adoption and its Contributions to Rural Livelihood and Environment". The research outcome is expected to be helpful for the improvement of biogas dissemination programme 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. The information is meant only for academic purpose. The responses you give will not have a negative impact on anybody. I honestly assure you that your personal information will be kept confidentially. Hence, just feel free to provide the correct answer.

Thank you for your responsible cooperation in advance!!!

N.B:
- For closed questions, you may give one or more answers as needed.
- For some tabular questions, please put tick mark (√) where needed.
- For questions that request ranking, please write the ranks1, 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.

Part I. Demographic Characteristics of the Sample Households

1. Please tell age, sex and educational status (by writing either illiterate=a, read & write=b or grade 1, 2, 3, …) of the family members in order of their ages.

S. No.	Age	Sex	Educational status	S. No.	Age	Sex	Educational status
1. Household head's				7			
2				8			
3				9			
4				10			
5				11			
6				12			

2. Household head's marital status: a. Married ☐ b. Single ☐
   c. Separated/Divorced ☐ d. Widow/widower ☐

Part II. Sample Households' Assets and Income Sources

3. Size of total farmland owned in hectare ___________ or in'timad'/'qada' _________
   Size of rented /share cropping farmland/ in hectare ________ or in'timad'/'qada' _________
4. Size of backyard in hectare ___________ or in 'timad'/'qada' _____________
5. How do you rate the availability of grazing lands vis-à-vis the size of the livestock in your locality? a. Enough ☐ b. Medium ☐ c. Not enough ☐
6. Type and number of livestock owned and yearly income from their sale (Birr)

Animal	Cattle											Apiary
type	Cow	Ox	Heifer	Bull	Calf	Goat	Sheep	Donkey	Mule	Horse	Chicken	(hives)
# (native)												
# (hybrid)												
Yearly income from sale												

7. If you sold ox/oxen, why did you sell? ____
8. Average monthly income (birr) from sale of livestock products:

   8.1. milk ____________, 8.2. butter ____________ ,

   8.3. egg ______________, 8.4 honey (per annum) ____________

9. Income from production of cereals, oil seeds and pulses in 2012/13 production year

Crop type	Cereals							Oil seeds			Pulses					Others, specify
	'Teff'	Wheat	Barley	Millet	Oat	Maize	Sorghum	Nigger seed	Flax	Rape seed	Peas	Beans	Chick peas	Lentils	Vetch	
Total yield (Qt)																

10. Income from sale of other crop types and planted trees in 2012/13 production year, if any

Crop type	Vegetables (garlic, onion, cabbage, potato, etc)	Spices (basil, rue, ginger, fenugreek, etc.)	'gesho', chat, coffee, fruits, etc)	Planted trees	Others, specify
Total sale (Br)					

11. Household income from off farm/non-farm activities and other sources per month/year, if any

Source of income	Income (Birr)		Source of income	Income (Birr)	
	Monthly	Yearly		Monthly	Yearly
Trade			Pension		
Carpentry			Remittance		
Daily labour			Salary		
Selling local beer			Others(specify)		

Part III. Access to Water Resource

12. Which is/are your main water source(s)?

a. Private well water ☐ b. Private hand pump water ☐. Private tap water ☐

d. Community well water ☐ e. Community hand pump water ☐ f. Spring water ☐

g. River water ☐ h. Pond water ☐ i. Others, specify ______________

13. On average, how many minutes walk does your main water source take from home? ______

14. Is (are) your water source(s) sufficient and reliable? a. Yes ☐ b. No ☐

Part IV. Pre-construction Information on Biogas and Decision Making Process for Adoption

15. When did you hear and know about biogas technology? Year ___________ Month____________

16. What was your first and main source of information about biogas technology?

    a. Orientation ☐ b. Training ☐ c. Neighbors & Friends ☐

    d. Radio ☐ e. Television ☐ f. Others (specify) ______________

17. Prior to adoption of biogas, do you think you obtained the appropriate information about the technology? a. Yes ☐ b. No ☐

18. If no, for Q. 17, why? ____

19. Which electronic media do you have? a. Radio ☐ b. Television ☐ c. None ☐

20. Among household members, who motivated the rest family members for the adoption of biogas technology? a. Wife ☐ b. Husband ☐ c. Daughters ☐

    d. Sons ☐ e. Others, specify ____________________

21. Who mostly makes final decisions in the household?

    a. Wife ☐ b. Husband ☐ c. Both a & b ☐ d. Others, specify _______

22. What led you to investing in Biogas technology?

    a. Fast and more convenient cooking stove ☐ b. Reduce energy expense ☐

    c. Saves time and reduces workload ☐ d. Better quality bio-slurry ☐

    e. Reduce health risks and associated costs ☐ f. Government subsidy for the plant ☐

    g. Brighter biogas light ☐ h. Existence of credit arrangements ☐

    i. Others, specify ___________________

Part V. Construction processes

23. When have you started using biogas? Month ___________ year______________

24. After the beginning of construction of biogas, do you say the construction process was delayed unnecessarily? a. Yes ☐ b. No ☐

  24.1 If yes, for how months was it delayed? ________________________________

  24.2 What were the reasons for delay? _____________________________________

25. Is the site where your biogas plant built well chosen? a. Yes ☐ b. No ☐

26. If no, for Q. 25, why? ____

27. Was the mason skillful enough? a. Yes ☐ b. No ☐

28. If no, for Q. 27, what was his/her weakness? _______________________________

29. What is the digester size (m^3) of your biogas installation? _______________

30. What was/were the main reason/s for choosing this plant size?

a. Number of cattle	☐	b. Suggested by masons/project staff	☐
c. Farm size	☐	d. Capital available	☐
e. Family size	☐	f. suggested by friends and neighbors	☐
g. Number of rooms	☐	h. Others, specify _______________	

31. Is the choice of the digester size of your biogas installation appropriate?

  a. Yes ☐ b. No ☐

32. If no, for Q. 31, why? ____

33. How many biogas stoves and lamps do you have? ______stoves and _________lamps

Part VI. Financing Biogas Construction, Subsidy and Access to Credit

34. How much Birr did you spent for the construction of biogas? __________________

35. What was/were your source(s) of financing biogas construction?

a. Own cash saving ☐ b. Microfinance ☐ c. Bank ☐

c. Individuals (local lenders, friends, relatives, etc) ☐ d. others, specify __________

36. If you borrow either in cash and/or in kind for your biogas construction:

36.1 What is the total money (Birr) you borrow either in cash or kind? _______________

36.2 What is the interest rate per year (Birr)? ___________________________________

36.3 How much debt do you have now? ____________________________________

36.4 What is the payback period? ____

37. Do you think installation of biogas is financially feasible? a. Yes ☐ b. No ☐

38. For your biogas construction, please list your contributions and government supports

38.1 Your contributions ____

38.2 Government supports ____

39. How was the process of getting government subsidy?

a. Difficult ☐ b. Fairly difficult ☐ c. Easy ☐

40. Is the current government subsidy size given to biogas installation reasonably sufficient?

a. Yes ☐ b. No ☐

41. Is there a transparent way to check whether you properly get government subsidy for biogas installations? a. Yes ☐ b. No ☐

42. If yes, for Q. 41, how? ____

43. Do you have access to credit if the need arises at any time? a. Yes ☐ b. No ☐

43.1 If yes, for Q. 43, from where can you borrow?

a. Microfinance ☐ b. Bank ☐

c. Informal channels (local lenders, friends, relatives, etc) ☐ d. others, specify ___

43.2 What is the maximum amount of money that can be borrowed at a time? __________

43.3 If you know, what is the interest rate per year (Birr)? ________________________

Part VII. Inputs of Biogas Digester

44. How many kilograms of cattle dung do you add daily to your biogas digester? __________

45. How do you measure the daily amount of cattle dung you feed to your biogas digester?

a. Measure by scale ☐ b. Measure by bucket/container ☐

c. rough estimate by shovel ☐ d. Others, specify _______________________

46. Is your cattle dung sufficient to feed your biogas digester? Yes ☐ b. No ☐

46.1 If yes, how much percent of cattle dung produced daily entered into the digester? ____

46.2 If you don't add all dung into the digester, what do you do with the remaining dung?

a. for fuel ☐ b. for fertilizer ☐ c. Others, specify _______________

46.3 If no, for Q. 46, what do you do to have sufficient feedstock for your biogas digester?

a. Collecting dung from the field ☐ b. Stall feeding of the cattle ☐

c. Others, specify _______________________________

47. Does the daily amount of cattle dung added to biogas digester vary? a. Yes ☐ b. No ☐

48. If Yes, for Q. 47, state why? ____

49. How many liters of water do need to feed your biogas digester daily? ___________________

50. Do you feed you biogas digester regularly every day? a. Yes ☐ b. No ☐

51. If no, for Q. 50, why? ____

Part VIII. Training/Orientation/Expert Instruction on Biogas

52. With regard to your biogas which service have you got?

b. Training ☐ b. Orientation/instruction ☐ c. None ☐

53. If you take training:

53.1 When have you taken it? a. Before biogas adoption ☐ b. After biogas adoption ☐

53.2 For how long was the training given? _________hours or __________days

53.3 How many members of your household have taken the training? ______________

53.4 Was the training given on the spot of biogas installation? a. Yes ☐ b. No ☐

53.5 How do you evaluate the adequacy of the training in enabling you to properly operate the technology? a. Sufficient ☐ b. Fairly sufficient ☐ c. Not sufficient ☐

53.6 How do you evaluate the adequacy of the training in enabling you to make minor maintenance on the technology?

a. Sufficient ☐ b. Fairly sufficient ☐ c. Not sufficient ☐

54. Have you been given a manual on biogas? Yes ☐ b. No ☐

55. How do you rate the usefulness of the manual? High ☐ b. Moderate ☐ c. Low ☐

Part IX. Operational Status of biogas installations and Problems Faced

56. Does your biogas plant operate? a. Yes ☐ b. No ☐

(If yes, continue to Q. #57 and if no, go to Q. #62)

57. If yes, please put tick mark (√) on those functioning biogas stoves and lamps, and indicate for how many hours you use each stove and lamp per day.

	1st stove	2nd stove (if any)	1st lamp	2nd lamp (if any)	3rd lamp (if any)
Functioning					
Hours					

58. Is the gas enough for your daily cooking and lighting requirements?

a. Yes ☐ b. No ☐

58.1 If no, what percentage of your demand does it fulfill? _____________

58.2 For which purpose(s) do you give priority?

a. Cooking ☐ b. Lighting ☐ c. Water boiling ☐

59. If any, please state the problems for a non functioning stove or lamp(s).

59.1 stove ____

59.2 lamp(s) ____

60. Do you use other fuels while gas is available? a. Yes ☐ b. No ☐

61. If yes, for Q. 60, what are your reasons? (Put in descending order of importance)

a. Not yet possible to bake *injera* and bread with biogas stove ………… ☐

b. To make use of available wood and other fuels ………………………… ☐

c. Save gas for quick cooking in busy time ………………………………… ☐

d. It is more convenient with traditional stove …………………………… ☐

e. Others, specify __________________________________

62. If your biogas plant is not operating at all,

62.1 for how many months did it stop functioning? ____________________

62.2 what are the problems? ____

62.3 Please state the efforts you make to solve the problem ______________________

63. Have you ever spent money to maintain your biogas installation? a. Yes ☐ b. No ☐

63.1 If yes, how much money did you spent? _____________________________

63.2 For what purposes? ____

63.3 How many times did you face the problem(s)? _________________________

64. If you need spare parts for your biogas installation from where do you get (buy)?

a. From biogas coordination office ☐ b. Shop ☐ c. Have no information ☐

65. If your answer is "b" for Q. 64, how many minutes walk does the nearest shop take from home? ________________ OR what is its distance in km? ___________________

66. Do you strictly follow the instructions given in operating your biogas plant?

a. Yes ☐ b. No ☐

67. If no, for Q. No. 66, why? ____

68. Do you think operating of biogas technology is difficult? a. Yes ☐ b. No ☐

69. If yes, for Q. 68, what are the most difficult things in plant operation? ______________

____

Part X. Impacts of Biogas on Health and Sanitation

70. Have the household members ever faced any health problems assocaited with use of fuel energy? a. Yes ☐ b. No ☐

71. If yes, for Q. 70, which health problem(s) has (have) faced your household member(s).

a. Eye diseases due to smokes ☐ b. Coughing ☐

c. Difficulty of breathing ☐ d. Burning accidents ☐

e. Injury/violence during collection ☐ f. Back pain due to loading ☐

g. Headache due head-loading ☐ h. Others, specify ___________________

72. How do you evaluate the condition of energy related health problems to your household members after installation of biogas? a. Increase ☐ b. Decrease ☐ c. No change ☐

73. If your answer is either "a" or "b", for Q. 64, please specify the diseases that increase or decrease.____

74. If there is any, how many times do your household members visited health organizations with in one year? ______________

75. Due to health problems, on avarage, how much Birr does your household spend with in one year time (if any)? ______________

76. Who does suffer most and least from energy related health problems in the household? (Pleases, tell in descending order of importance).

a. Wife ☐ b. Husband ☐ c. Daughters ☐ d. Sons ☐ e. Others, specify _____

77. Do you have toilet? a. Yes ☐ b. No ☐

77.1 Please tell the construction materials for each part of your toilet.

a. floor ___________________ b. wall ___________________ c. roof _______________

77.2 Is your toilet connected to biogas system? a. Yes ☐ b. No ☐

77.3 If no, for Q. 77.2, why? ____

Part XI. Impacts of Biogas on Gender and Social Conditions

78. Do you think use of biogas saves time? a. Yes ☐ b. No ☐

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

a. Children have been enrolled in the school ☐

b. Reduce workload and stress for women and children ☐

c. Enable women to have more time for agricultural work ☐

d. Enable women to engage in income generating activities ☐

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

f. Others, specify ____

b. If you utilize the saved time to engage yourself in income generating job, please indicate the average income earned per month___________ and the job type __________

79. If any, please mention a new job that you have started doing with brighter biogas light during evening. ____

80. Following adoption of biogas technology, the social status that the society provides you has _____________. a. increased ☐ b. decreased ☐ c. shown no change ☐

81. If your answer is either 'a' or 'b', for Q. No. 80, why? ______________________________

82. Prior to installation of biogas, was there any student in the household who used to rent dormitory in the town for purpose of studying with electric light? a. Yes ☐ b. No ☐

83. If yes, for Q. 82, please tell the average amount of money (Birr) saved per month. __________

84. Division of household tasks and time allocations by gender and age (Please encircle sex of hired labor, if any)

Activities	average hours daily				
	Wife	Husband	Daughters	Sons	Hired labor (Sex:F/M)
Cooking excluding *injera*					
Cleaning utensils					
Cleaning kitchen					
Fetching of water					
Collecting of dung from home and making dung cakes					
Mixing of dung & water, & feeding					
Preparation of firewood					
Livestock care / management					
Lighting biogas/kerosene lamps					
	average hours per week(If it is per month please put *)				
Baking *injera*					
Collecting fodder					
Collecting of firewood					
Collecting of crop residues					
Collecting of dung from the field					
Searching charcoal wood & making charcoal					
Maintenance of digester and repairs					
Purchasing fuel(wood, dung, crop residues, kerosene, etc)					

Part XII. Impacts of Biogas Technology on Agriculture

85. After installation of biogas, size of your cattle ___________________

    a. Increase ☐ b. Decrease ☐ c. Show no change ☐

    a. If increase or decrease, by how many? __________________, and

    b. Why? ____

86. Which livestock feeding system do you use?

    a. Open grazing ☐ b. Stall-fed ☐ c. Both ☐

    86.1 If your answer is either “b” or “c”, when have you started stall feeding?

    a. before installation of biogas ☐ b. after installation of biogas ☐

    86.2 If your answer is “b”, for Q.86.1, why? ___________________________________

    86.3 If you use both livestock feeding system, please tell the stall-fed livestock type and number. ____

87 Do you grow fodder crops? a. Yes ☐ b. No ☐

    87.1 If yes, what type of fodder? ____

    87.2 When have started it? a. before biogas construction ☐ b. after biogas ☐ construction

    87.3 If you say ‘b’, for Q.87.2, why? ______________________________________

88 Does installation of biogas have any noticeable effects on animal health?

    a. Yes ☐ b. No ☐

89 If yes, for Q. No 88, please state the effects ____________________________________

90 Do you use bio-slurry for fertilizer? a. Yes ☐ b. No ☐

(If yes, continue to Q. #91 and if no, go to Q. #103)

91. In what state do you apply bio-slurry?

a. Wet bio-slurry pour on plant roots ☐ b. Wet bio-slurry flows over to farm yard ☐

c. Semi-dried ☐ d. Dried ☐

92. Do you have bio-slurry pit (s)? a. Yes ☐ b. No ☐

92.1 If yes, how many? ____________

92.2 What are their sizes ____

93. If you store bio-slurry, in what way do you store it?

a. Composted (with organic matter) ☐ b. Stored dry (without organic matter) ☐

c. Others, specify____________________

94. If you store bio-slurry, do you cover it? a. Yes ☐ b. No ☐

95. If yes, for Q. 94, by what? ____

96. If you apply bio-slurry on farm plot(s) outside your home compound, how many minutes walk do you transport for use from your home? ___________

97. How do you transport it? a. manually ☐ b. using pack animals ☐ c. using cart ☐

98. Do you think fertilizer quality of bio-slurry is better than the traditional manure?

a. Yes ☐ b. No ☐

98.1 If yes, what better qualities does it have? (You may give multiple answers)

a. Provides more yield ☐ b. Has less weeds ☐ c. Prevent pests ☐

d. More fragile and easier to apply ☐ e. Has less smell ☐ f. Other, specify ___

98.2 If no, state your reason ____

99. For which crops do you apply bio-slurry?

a. Cereals ☐ b. Oil crops ☐ c. Pulses ☐

d. fodder crops ☐ e. Garden crops ☐ f. Others, specify _______________

100. Does the use of chemical fertilizer decrease after biogas installation?

a. Yes ☐ b. No ☐

101. If yes, for Q. No. 100, how many quintals of commercial fertilizer do you reduce? DAP ________ quintal(s), Urea ________ quintal (s)

102. How much money have you saved from the reduction of chemical fertilizer? ________

103. If you don't use bio-slurry for fertilizer, please, state why. ________________________

____

104. If you don't use bio-slurry for fertilizer wholly or partly, what do you do with it?

____

105. If you use commercial fertilizer, how many quintals did you use in 2004/2005 E.C cropping season? DAP ________ quintal(s), Urea ________ quintal (s)

106. In 2013/2014 production year, how much money did you spend on purchasing of commercial fertilizer? _______

Part XIII. User's Satisfaction Level and Perception

107. How many years do you think the durability of biogas technology? _________ How many years were you learnt it can serve? ______________

108. Do you think that use of biogas technology is compatible with the existing culture?

a. Yes ☐ b. No ☐

109. If no, for Q. No. 108, specify your reason. _____________________________________

110. How do you rate your satisfaction level with the overall usefulness of the technology?

a. High ☐ b. Moderate ☐ c. Low ☐ d. never ☐

111. If your answer is either 'c' or 'd', for Q. No. 109, please state your reason

____

112. How do you rate level of your satisfaction with biogas stove functioning?

a. High ☐ b. Moderate ☐ c. Low ☐ d. never ☐

113. How do you rate level of your satisfaction with biogas lamp functioning?

a. High ☐ b. Moderate ☐ c. Low ☐ d. never ☐

114. Have you ever motivated/advised other households to adopt the technology?

a. Yes ☐ b. No ☐

115. If no, for Q. 113, why? ____

116. Have you ever regret in the construction of biogas? a. Yes ☐ b. No ☐

117. If yes, for Q. 116, why? ____

118. Please state your suggestion for possible improvements on the future

____

Part XIV. After-Sales service

119. Have you been given guarantee certificate for your biogas that enables you to request free maintenance service for certain years provided that the problems are construction related ones? a. Yes ☐ b. No ☐

a. If no, were you told orally? a. Yes ☐ b. No ☐

b. If you are given guarantee, for how many years? ______________

c. Do you think the given guarantee is enough? a. Yes ☐ b. No ☐

120. Was there any biogas expert that visits your biogas after the completion of its construction? a. Yes ☐ b. No ☐

120.1 If yes, how many times? ________________

120.2 What technical assistance did you get during the visit? (if any) ________________

____

121. If you need technical assistance for your biogas, how do you get experts?

a. Through mobile ☐ b. Through office telephone ☐

c. Going in person to Coordination Office ☐ f. Others, specify ________________

Part XV. Woodfuel Sources and Consumption Amount

122. After installation of biogas does your household use fuelwood? a. Yes ☐ b. No ☐

(If yes, continue to Q. #123 and if no, go to Q. #127)

123. On average human load, how many bundles of fuelwood do you consume per week? _____

124. From where does the family get fuelwood? (Tick all that apply.)

a. Collecting from communal scrublands/bush lands ☐

b. Own planted trees and shrubs ☐

c. Naturally grown vegetation from own farmlands ☐

d. Purchasing ☐

f. Others, specify_______________________

125. How many minutes walk does your main source of fuelwood take from home? ________

126. If you purchase fuelwood, what is your monthly average expense (Birr)? ______________

127. Does the household own planted trees and/or shrubs? a. Yes ☐ b. No ☐

128. If yes, for Q. 126, please tell the number of planted trees and/or shrubs by type

Type of Trees	Eucalyptus species	Cupressus species	Casuarinia eqisetifolia	Sesbania sesban	Olea_europaea	'Gravillia'	Vernonia amygdalia	Calocedrus decurrens	Cordia africana	Grevillea robusta	Croton macrostachyus	Millettia ferruginea	Albizia gummiferas	Others, specify
Number														

129. Does the number of your planted trees and/or shrubs is sufficient to meet your wood demand? a. Yes ☐ b. No. ☐

130. If you use wood for fuel from your own planted trees and/or shrubs, how much percent do you think it constitutes your total woodfuel consumption? ______________________

131. How do you rate the current availability of wood for fuel in your locality?

a. Enough ☐ b. Moderate ☐ c. Not enough ☐

132. Does the household use charcoal for fue? a. Yes ☐ b. No ☐

(If yes, continue to Q. #133 and if no, go to Q. #136)

133. How many sucks or baskets of charcoal do you consume per month? _____________sucks or __________________baskets.

134. From where does the household get charcoal?

a. Purchasing ☐ b. Preparing by yourself ☐ c. Others, specify _______________

135. If you purchase charcoal, what is your monthly average expense in birr? _________________

Part XVI. Dung Fuel and Crop Residue Sources and Consumption Amount

136. After installation of biogas, does your household use dung fuel? a. Yes ☐ No ☐

(If yes, continue to Q. #137 and if no, go to Q. #141)

137. On average, how many baskets of dung fuel do you consume per week? ____________

138. What is (are) the source(s) of your dung fuel?

a. Own cattle ☐ b. Purchasing ☐

c. Collecting from grazing lands ☐ d. Others, specify ____________________

139. If you purchase dung fuel, how much money do your spend per month?________

140. Do you use dung fuel other than cattle? a. Yes ☐ b. No ☐

140.1 If yes, please, specify the type of animals? ______________________________

140.2 If no, why? ____

141 If you don't use dung fuel at all, please specify your reason. ______________________

____

142 Do you use crop residues for fuel? a. Yes ☐ b. No ☐

(If yes, continue to Q. #143 and if no, go to Q. #147)

143 On average, how many bundles of crop residues do you consume per week? __________

144 Which type of residues do you use for fuel? (Tick all that apply)

a. Maize stalks & cobs ☐ b. Stalks of sorghum ☐

c. Stalks of rape seed ☐ d. Others, specify _____________________

145 Starting from the month in which you began using crop residues for fuel, for what range of months do you expect your collected crop residues will be used? _____________________

146 If you purchase crop residue for fuel, what is your average monthly expenditure? _________

147 If you don't use crop residue for fuel all in all, please specify your reason.

____

Part XVII. Stove Types and Energy End Uses

148 Excluding biogas stoves, which type of stove(s) do you use currently?

a. Modern ('Mirt') stove ☐ b. Closed mud-made stove ☐

c. Traditional (iron) charcoal stove ☐ d. Lackech charcoal stove ☐

e. Traditional clay-made charcoal stove ☐ f. Three-stone stove ☐

g. Electric stove ☐ h. Kerosene stove ☐

i. LPG stove ☐ j. Others, specify ______________

149 Please, specify the type of stove(s) you abundon following adoption of biogas technology.

____

150 Please, tell the end uses of the following fuel types.

Fuel type	Baking *injera*/bread	Cooking (except *injera*/bread)	Boiling water	Lighting	Others, specify
Fuelwood					
Charcoal					
Animal dung					
Crop residues					
Biogas					
Kerosene					
Dry cells					
Wax/Candle					
Others, specify					

151 If you use wax/candle, dry cells, and kerosine, please, specify your average monthly consumption and expenses.

S. No	Fuel type	unit	Average monthly comsumption	Average monthly expenses (birr)
1	Wax/candle	Piece		
2	Dry cells	# of pairs		
3	Kerosine	liter		
4	Others, specify			

Part XVIII. Access to Other Alternative Energy Sources

152 Do you have electricity connection? a. Yes ☐ b. No ☐

152.1If yes, on average, how much money do you pay per month? __________

152.2 For which purposes does your household use it? (Tick all that apply)

a. Baking *injera* /bread ☐ b. Cooking ☐ c. Lighting ☐

d. Boiling water ☐ e. Radio/Television /Mobile ☐ f. Ironing ☐

g. Refrigerator ☐ h. Others, specify ______________________

152.3 If no, how many minutes walk does the nearest electrified village or town take from your home? ____________ or how far is it in kilo meters? ____________________

153 How many minutes walk does the nearest market take from your home? ________ Or how far is it in kilo meters? _____________________

154 Do you use photovoltaic/solar energy/ for domestic purpose? a. Yes ☐ b. No ☐

154.1 If yes, for what purpose do you use it? (Tick all that apply)

a. Lighting ☐ b. water boiling ☐

c. Mobile charging ☐ f. Others (specify) __________________

154.2 How do you rate your level of satisfaction with the technology?

a. High ☐ b. Moderate ☐ c. Low ☐ d. never ☐

154.3 What is its total cost of investment? _________________________

Thank you!

Interview ended at time_______________

Appendix B: Semi-Structured Interview Questionnaire Prepared for Non-Adopters of Biogas Sample Households

Woreda ____________________ Interviewer's Name _____________________

Kebele/Tabiya ________________ Supervisor's Name _____________________

Kushet _______________________ Date of interview_________________

Code of sample household _______ Interview starting time __________

Dear Respondents,

The main purpose of this interview questionnaire is to acquire information relevant for a research entitled "Biogas Technology Adoption and its Contributions to Rural Livelihood and Environment". The research outcome is expected to be helpful for the improvement of biogas dissemination programme 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. The information is meant only for academic purpose. The responses you give will not have a negative impact on anybody. I honestly assure you that your personal information will be kept confidentially. Hence, just feel free to provide the correct answer.

Thank you for your responsible cooperation in advance.

N.B: ➢ For closed questions, you may give one or more answers as needed.

➢ For some tabular questions, please put tick mark (√) where needed.

➢ For questions that request ordering, please write 1, 2, 3, … in the boxes by giving value 1for the most important, 2 for the next most important, etc.

A. Demographic Characteristics of the Sample Household

1. Please tell age, sex and educational status (by writing either illiterate=a, read & write=b or grade 1, 2, 3, …) of the family members in order of their ages.

S. No.	Age	Sex	Educational status	S. No.	Age	Sex	Educational status
1. Household head's				7			
2				8			
3				9			
4				10			
5				11			
6				12			

2. Household head's marital status: a. Married ☐ b. Single ☐

   c. Separated/Divorced ☐ d. Widow/widower ☐

B. Sample Households' Assets and Income Sources

3. Size of total farmland owned in hectare ___________ or in'timad'/'qada' _________

   Size of rented /share cropping farmland/ in hectare ________ or in'timad'/'qada' _________

4. Size of backyard in hectare ___________ or in 'timad'/'qada' _____________

5. How do you rate the availability of grazing lands vis-à-vis the size of the livestock in your locality? a. Enough ☐ b. Medium ☐ c. Not enough ☐

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

Animal type	Cattle					Goat	Sheep	Donkey	Mule	Horse	Chicken	Apiary (hives)
	Cow	Ox	Heifer	Bull	Calf							
# (native)												
# (hybrid)												
Yearly income from sale												

7. If you sold ox/oxen, why did you do? ____

8. Average monthly income (birr) from sale of livestock products:

   8.1) milk ____________, 8.2) butter _________ ,

   8.3) egg ____________, 8.4) honey (per annum) ____________

9. Income from production of cereals, oil seeds and pulses for 2004/2005 E.C. production year

Crop type	Cereals							Oil seeds			Pulses					Others, specify
	'Teff'	Wheat	Barley	Millet	Oat	Maize	Sorghum	Nigger seed	Flax	Rape seed	Peas	Beans	Chick peas	Lentils	Vetch	
Total yield (Qt)																

10. Income from other crop types and planted trees in 2004/2005 E.C production year, if any

Crop type	Vegetables (garlic, onion, cabbage, potato, etc)	Spices (basil, rue, ginger, fenugreek, etc.)	'gesho', chat, coffee, fruits, etc)	Planted trees	Others, specify
Total sale (Br)					

11. Household income from off farm/non-farm activities and others per month/year, if any

Source of income	Income (Birr)		Source of income	Income (Birr)	
	Monthly	Yearly		Monthly	Yearly
Trade			Pension		
Carpentry			Remittance		
Daily labour			Salary		
Selling local beer			Others(specify)		

12. Which livestock feeding system do you use?

a. Open grazing ☐ b. Stall fed ☐ c. Both ☐

13. If your answer is "both", for Q. 12, please tell stall feeding livestock type and number.

____

C. Access to Water Resources

14. Which is your main source?

a. Private well water ☐ b. Private hand pump water ☐

c. Private tap water ☐ d. Community well water ☐

e. Community hand pump water ☐ f. Spring water ☐

g. River water ☐ h. Pond water ☐

i. Others, specify ____

15. On average, how many minutes walk does your main water source take from home? ______

16. Is (are) your water source(s) sufficient and reliable? a. Yes ☐ b. No ☐

D. Wood-fuel Sources and Consumption Amount

17. On average human load, how many bundles of fuelwood do you consume per week? _____

18. From where does the family get fuelwood? (Please, tell in descending order of importance.)

c. Collecting from communal scrublands/bush lands ☐

d. Own planted trees and shrubs ☐

e. Naturally grown vegetation from own farmlands ☐

f. Purchasing ☐

g. Others, specify______________________

20. If you purchase fuelwood, what is your monthly average expense in birr? _____________

21. Does the household own planted trees and/or shrubs? a. Yes ☐ b. No ☐

22. If yes, for Q. No. 21, please tell the number of planted trees and/or shrubs by type

Type of Trees	Eucalyptus species	Cupressus species	Casuarinia equisetifolia	Sesbania sesban	Olea europaea	'Gravillia'	Vernonia amygdalia	Calocedrus decurrens	Cordia africana	Grevillea robusta	Croton macrostachyus	Millettia ferruginea	Albizia gummifera	Others, specify
Number														

23. Do you think that the number of trees and/or shrubs you have planted is sufficient to meet your wood demand? a. Yes ☐ b. No. ☐

24. If you use wood for fuel from your own planted trees and/or shrubs, how much percent do you think it constitutes your total wood-fuel consumption? ____________________

25. How do you rate the current availability of wood for fuel in your locality?

a. Enough ☐ b. Moderate ☐ c. Not enough ☐

26. Does the household use charcoal for home consumption? a. Yes ☐ b. No ☐

(If yes, continue to Q. #27 and if no, go to Q. #30)

27. If yes, how many sucks or baskets of charcoal do you consume per month? ______sucks or _______baskets.

28. From where does the household get charcoal?

a. Purchasing ☐ b. Preparing by yourself ☐ c. Others, specify ________________

29. If you purchase charcoal, what is your monthly average expense (birr)? ________________

E. Dung Fuel and Crop Residue Sources and Consumption Amount

30. Do you use cattle dung for fuel? a. Yes ☐ b. No ☐

(If yes, continue to Q. #31 and if no, go to Q. #35)

31. On average, how many baskets of dung fuel do you consume per week? _____________

32. What is (are) the source(s) of your dung fuel?

a. Own cattle ☐ b. Purchasing ☐

c. Collecting from grazing lands ☐ d. Others, specify___________________________

33. If you purchase dung fuel, how much money do you spend per month?___________

34. Do you use dung fuel other than cattle's? a. Yes ☐ b. No ☐

34.1 If yes, please, specify the type of animals? _______________________________

34.2 If no, why? ____

35. If you don't use dung for fuel, please specify your reason. ___________________________

____

36. Do you use crop residues for fuel? a. Yes ☐ b. No ☐

(If yes, continue to Q. #37 and if no, go to Q. #41)

37. On average, how many bundles of crop residues do you consume per week? ______________

38. Which type of crop residues do you use for fuel? (Tick all that apply)

    a. Maize stalks & cobs ☐ b. Stalks of sorghum ☐

    c. Stalks of rape seed ☐ d. Others, specify ____________________

39. Starting from the month in which you began using crop residues for fuel, for what range of months do you expect your collected crop residues will be used? _____________________

40. If you purchase crop residue for fuel, what is your average monthly expenditure? _________

41. If you don't use crop residue for fuel all in all, please specify your reason. _______________

    ____

F. Access to Alternative Energy Sources

42. Do you have electricity connection? a. Yes ☐ b. No ☐

    42.1 If yes, on average, how much money do you pay per month? ___________

    42.2 For which purposes does your household use it? (Tick all that apply)

    a. Baking *injera*/bread ☐ b. Cooking ☐ c. Boiling water ☐

    d. Lighting ☐ e. Radio/Television /Mobile ☐ f. Ironing ☐

    g. Refrigerator ☐ h. Others, specify _______________________

    42.3 If no, how many minutes walk does the nearest electrified village or town take from your home? ____________ or how far is it in kilo meters? _____________________

43 How many minutes walk does the nearest market take from your home? ________ Or how far is it in kilo meters? _____________________

44 Do you use photovoltaic/solar energy/ for domestic purpose? a. Yes ☐ b. No ☐

44.1 If yes, for what purpose do you use it? (Tick all that apply)

b. Lighting ☐ b. water boiling ☐

c. Mobile charging ☐ f. Others (specify) ________________

44.2 How do you rate your level of satisfaction with the technology?

a. High ☐ b. Moderate ☐ c. Low ☐ d. never ☐

44.3 What is its total cost of investment? ______________________

G. **Stove Types and Energy End Uses**

45 Which type of stove(s) do you use?

a. Modern ('Mirt') stove ☐ b. Closed mud-made stove ☐

c. Traditional (iron) charcoal stove ☐ d. Lackech charcoal stove ☐

e. Traditional clay-made charcoal stove ☐ f. Three-stone stove ☐

g. Electric 'stove ☐ h. Kerosene stove ☐

i. LPG stove ☐ j. Others, specify _____________

46. Please, tell the end uses of the following fuel types.

Fuel type	Baking *injera*/bread	Cooking (except *injera* & bread)	Boiling water	Lighting	Others, specify
Fuelwood					
Charcoal					
Animal dung					
Crop residues					
Kerosene					
Dry cells					
Wax/Candle					
Others, specify					

47. If you use wax/candle, dry cells, and kerosine, please, specify your average monthly consumption and expense.

S. No	Fuel type	unit	Average monthly comsumption	Average monthly expenses (birr)
1	Wax/candle	Piece		
2	Dry cells	# of pairs		
3	Kerosine	liter		

H. Energy Related Health Problems and Expenses

48. Have the household members ever faced any health problems assocaited with use of energy?

a. Yes ☐ b. No ☐

49. If yes, for Q. No. 48, which health problem(s) has (have) faced your household member(s)?

a. Eye diseases due to smokes ☐ b. Coughing ☐

c. Difficulty of breathing ☐ d. Burning accidents ☐

e. Injury/violence during collection ☐ f. Back pain due to loading ☐

g. Headache due head-loading ☐ h. Others, specify ______________________

50. How do you evaluate the condition of energy related health problems to your household over time? a. Increase ☐ b. Decrease ☐ c. No change ☐

51. If your answer is either "a" or "b", for Q. No 50, please specify the diseases that increase or decrease.____

52. If any, how many times do your household members visited health organizations with in one year? ______________

53. Due to health problems, on avarage, how much Birr does your household spend with in one year time (if any)? ______________

54. Who does suffer most and least from energy related health problems in the household?

(Pleases, tell in descending order of importance).

a. Wife ☐ b. Husband ☐ c. Daughters ☐

d. Sons ☐ e. Others, specify ___________________________

55. Do you have toilet? a. Yes ☐ b. No ☐

56. Please tell the construction materials for each part of your toilet.

a. floor __________________ b. wall __________________ c. roof ______________

I. Household Tasks by Gender and Age

57. Division of household tasks and time allocations by gender and age (Please encircle sex of hired labor, if any)

Activities	average hours daily				
	Wife	Husband	Daughters	Sons	Hired labor (Sex:F/M)
Cooking excluding *injera*					
Cleaning utensils					
Cleaning kitchen					
Fetching of water					
Collecting of dung from home and making dung cakes					
Mixing of dung & water, & feeding					
Preparation of firewood					
Livestock care / management					
Lighting biogas/kerosene lamps					
	average hours per week(If it is per month please put *)				
Baking *injera*					
Collecting fodder					
Collecting of firewood					
Collecting of crop residues					
Collecting of dung from the field					
Searching charcoal wood & making charcoal					
Maintenance of digester and repairs					
Purchasing fuel(wood, dung, crop residues, kerosene, etc)					

58. Who mostly makes final decisions in the household?

a. Wife ☐ b. Husband ☐ c. Both ☐ d. Others, specify _______

J. Awareness Level, Sources of Information and Perception about Biogas

59. Which electronic media do you have?

a. Radio ☐ b. Television ☐ c. Mobile ☐ d. None ☐

60. Are you aware of what biogas technology is? a. Yes ☐ b. No ☐

(If yes, continue to Q. #61 and if no, go to Q. #75)

61. Could you please tell three of the most important benefits of biogas technology?

a. ____________________ b. __________________ c. ______________________

62. When did you hear and know about biogas technology? Year __________ month __________

63. What was your first and main source of information about biogas technology?

a. Orientation ☐ b. Training ☐ c. Neighbors & Friends ☐

d. Radio ☐ e. Television ☐ f. Others (specify)________________

64. Which service(s) of the experts have you got on biogas technology?

a. Training ☐ b. Orientation ☐ c. None ☐

65. Have you got any a guide/manual/leaflet on biogas? a. Yes ☐ b. No ☐

66. Do you know whether one will be given guarantee certificate for biogas installation that enables him/her to request free maintenance service for certain years provided that the problems are construction related ones? a. Yes ☐ b. No ☐

66.1 If yes, how many years is it? ______________

66.2 Do you think it is reasonably enough? a. Yes ☐ b. No ☐

67 Do you know whether the government provides subsidy for biogas installations?

a. Yes ☐ b. No ☐

68 If yes, for Q.67, do you think the size of subsidy is reasonably enough?

a. Yes ☐ b. No ☐ c. I don’t know the size of subsidy ☐

69 How many years do you think the durability of biogas technology? _________ How many years were you learnt (if any) it can serve? ______________

70 Do you think installation of biogas is financially feasible? a. Yes ☐ b. No ☐

71 Do you think operating of biogas technology is difficult? a. Yes ☐ b. No ☐

72 What do you think the effect of adopting biogas technology on the social status of its users?

a. increase ☐ b. decreases ☐ c. no effect ☐

73 If your answer is 'a' or 'b', please state your reasons. __________________________

____

74 If you are aware of biogas technology, why you haven't adopted the technology yet?

____

K. Access to Credit

75. Do you have access to credit if the need arises at any time? a. Yes ☐ b. No ☐

75.1 If yes, from where can you borrow?

a. Microfinance ☐ b. Bank ☐

c. Informal channels (local lenders, friends, relatives, etc.) ☐

d. Others, specify __________________________________

75.2 What is the maximum amount of money that can be borrowed at a time? ___________

75.3 If you know, what is the interest rate per year (Birr)? _________________________

Thank you!

Interview ended at time______________

Appendix C: Checklist of Key Informant Interview with Biogas Experts and Administrative Bodies at the NBPCO or its Branches

1. Why the NBPE has been established after more than four decades since the introduction of biogas technology into the country? (*For national level key informants only)
2. How the biogas sector has been institutionally organized or structured from national to *woreda* or *kebele/tabiya* administrative levels (if any?) (Members of biogas programme steering committee and roles)
3. How do you see the appropriateness of the existing institutional organization in terms of accelerating dissemination of biogas technology? (e.g. Is the *woreda* biogas programme coordinating units directly accountable to your office? If not, what type of relation do you have with *woreda* offices? (For national and regional level key informants only)
4. What are the basic responsibilities of biogas programme coordinating office/units at various administrative levels?
5. Staff size, qualification, field of specialization and responsibility at the NBPCO, RBPCUs and *Woreda* Level

S. No.	Staff size (#)	Qualification	field of specialization	Responsibility	Remark
1					
2					
3					
4					
5					

6. Are there human resource gaps? What field?

7. Number of biogas installations constructed so far at national level, at the region by *woreda or in woreda by kebele/Tabiya*, year of construction, size and model type in the first NBPE phase
8. How many biogas digesters have been connected to toilets so far?
9. How do you reach potential biogas adopters (if there are specific procedures)? What are the criteria of selecting biogas users?
10. Do you make any agreement with biogas adopters and masons? (On what issues)?
11. How many of the biogas plant installed in the first phase of NBPE are still operating? If there are failures, why?
12. Promotion/Advertizing Work:
    a. What promotion/advertizing media does the NBPCO/RBPCU/*woreda* office utilize to accelerate adoption and dissemination of biogas technology?
    b. How often do you advertize the benefits of the technology?
    c. How do you evaluate the adequacy of the existing promotion and marketing work?
    d. What techniques do you use to promote utilization of bio-slurry for fertilizer purpose?
13. Does the NBPCO/RBPCU/*woreda* office provide trainings?
    a. If yes, how often?
    b. What are the types of training?
    c. Who are the target trainees?
    d. How many individuals have been trained so far by training type (if there exists more than one training type)?

14. Have you ever organized workshop(s)?
    a. If yes, on what issues and why?
    b. Who were the participants?
    c. How often do you organize workshops?
15. How do you control the quality of the installation? What measures do you take in case of failure to meet quality requirements?
16. Amount of incentives given to *woreda* biogas programme coordinators and energy experts per unit installation? (For national and regional level key informants only). Amount of payment to masons per unit installation? Is it progressive?
17. Are there monitoring and evaluation services on regular basis? If yes, have there been any corrective measures ever taken on the basis of monitoring and evaluation results? (For national and regional level key informants only)
18. Institutional support:
    a. How is the cost sharing? Does it vary with size and location? What are the sources of fund (including fund for cement and its repayment mechanism)?
    b. Are there consultancy and technical assistance services to biogas users?
    c. How do you describe availability and supply of spare parts at reasonable distance?
    d. Are there manuals/guiding materials to the biogas users, masons, and officers at different administrative levels?
19. Are there private investors (companies) involving in biogas dissemination? (For national and regional level key informants only) If yes,
    a. Number and name of private companies involved

b. Areas of involvement of private companies

    i. importing spare parts
    ii. manufacturing biogas component/spare parts
    iii. involving in construction

c. Are there incentives and promotion works towards attracting private investors in the biogas sector?

20. Involvement of nongovernmental organizations (For national and regional level key informants only)
    a. Number and name of NGOs involved
    b. Areas of involvement
        i. Providing fund
        ii. Providing training and technical assistance
        iii. Organizing workshop
    c. Promotion work to get assistance of NGOs
21. Other stakeholders involvement and support for the implementation of BP, if any e.g coordination and agreements between NBPCO//RBPCUs with MoH and MoRDA (For national and regional level key informants only)
22. Research and development aspects of biogas technology (For national and regional level key informants only)
    a. What have been done towards improving efficiency and cost effectiveness of biogas models and stoves (including ‘enejra’ stove)?

b. What components and spare parts of biogas plants have started to be produced domestically? How are their qualities and costs in comparison to imported ones? Which components and spare parts are still being imported? Why?

c. How do you evaluate the overall import substitution efforts for various biogas plant component/spare parts?

23. Why does the pace of construction of biogas plants not progressed as planned?
24. How do you evaluate the sustainability of biogas program and technology dissemination? Can we really create a commercially viable biogas development as planned? (For national and regional level key informants only)
25. Are there attempts of getting carbon credits for the expansion of GHG emission reducing biogas plants? (For national and regional level key informants only)
26. What is the future plan about biogas dissemination? (For national and regional level key informants only)

Appendix D: Interview Checklist with Heads of Regional Energy and Mines Agency

1. How the biogas sector has been institutionally organized from regional to the lowest administrative level?
2. How do you see the appropriateness of the existing institutional organization in terms of accelerating dissemination of biogas technology?
3. How do you evaluate the roles and functionality of regional biogas program steering committee?
4. Are there monitoring and evaluation activities on biogas installations on regular basis? If yes, how do you see the evaluations results?

5. Are there efforts to involve and attract NGOs and private companies to be involved in the development and dissemination of biogas technology?
6. How do you evaluate roles of NGOs and private companies in the development and dissemination of biogas technology (if any)?
7. Are there research and development activities on biogas technology?
8. Why does the pace of construction of biogas plants not progress as planned?
9. What is the future plan on biogas development and dissemination?
10. How do you evaluate the sustainability of biogas program and technology dissemination? Can we really create a commercially viable biogas development as planned?

Appendix E: Checklist of Key Informant Interview with Heads of NGOs or Experts in NGOs Who in One Way or Another Have Some Involvement in the Dissemination of Biogas Technology

1. What initiated you to be involved in the development and dissemination of biogas technology in Ethiopia?
2. Your contributions to development and dissemination of biogas technology
   a. Involving in construction? If yes,
      i. Number of plants constructed so far?
      ii. Cost of construction per size of an installation?
      iii. Size of labour power employed: a) permanent b) Causal/Seasonal
      iv. Length of time on the job?
   b. Organizing workshop? If yes, on what issue(s)? Why? When? Where? To whom?
   c. Providing training and technical assistance? If yes, on what issue(s)? Why? When? Where? To whom?

d. Providing fund? If yes,

   i. To whom?

   ii. Amount per unit of time?

   iii. Amount per size of an installation?

   iv. Why?

e. Preparing manuals/guidelines? If yes, what type? How many? To whom?

f. Other involvements (if any)?

Appendix F. Interview Checklist for Masons

1. How do you enter to the construction of biogas plants?
2. Have you taken training?
   - How many days training have you taken?
   - Have you taken any refresher courses? How many times?
3. How many biogas plants have you installed so far?
   - Do you have the information about how many of the biogas plants you installed have still been operating?
4. Do you make any agreement with the mines and energy coordinating office? If yes, on what issue?
5. Do you make any agreement with biogas users? If yes, on what issue?
6. Do you have any obligation to make maintenance provided that biogas plants have some construction related problems? For how many years?
7. Do you give maintenance services to any biogas users up on request?
8. Do you make any promotion work to convince farmers for the adoption of biogas? Does it have payment?

9. How many causal labors do you employ per installation?
10. If there is no problem of material supply, in how many days do you complete installation of one biogas plant?
11. Is the plumbing work (assembling pipes and fixing appliances) done by you? If not, who does the plumbing work?

Appendix G: Checklist of Key Informant Interview with Biogas Spare part Manufacturers

1. What initiated you to be involved in the development and dissemination of biogas technology?
2. Contributions to development and dissemination of biogas technology
   a. Producing biogas plant components/spare parts? if yes,
      i. What component/spare part types do you produce?
      ii. How do you evaluate their qualities and costs relative to imported ones?
      iii. How do you check the relative qualities?
      iv. Any feedback about qualities from customers?
      v. Number of employees: Permanent? ______ Casual/seasonal? _______
      vi. Length of time on the job?
   b. Distributing/retailing/ biogas plant components/spare parts? If yes,
      i. What components/spare parts do you distribute/retail?
      ii. Prices of each component/spare part?
      iii. Who are the customers?
      iv. Size of labour power involved in distributing/retailing components/spare parts: Permanent? __________ Casual/seasonal? _____________
      v. Length of time on the job?

c. Other involvements (if any)?

Appendix H: Checklist of Key Informant Interview with Biogas *Injera* Stove Researcher

1. What initiated you to be involved in researching and developing biogas *injera* stove?
2. What is the current stage of your biogas *injera* stove?
    a. What is its gas consumption efficiency right at this time? (Your pilot level biogas *injera* stove beneficiary informed the the need to save biogas for three days to cook 23 *injera* with the stove)
    b. Have you got patent right on the stove you developed?
    c. Do you get any financial assistance from an organization for its further improvement?
3. What is the estimated average cost per unit biogas *injera* stove?
4. Do you have any specific time table to develop it to public consumption level?
5. Related to biogas technology, do you have any other research area of involvement? If yes on what area?

Appendix I: Checklist of Key Informant Interview with Biogas Programme Steering Committee Members at *Woreda* Level

1. Who are the members of biogas programme steering committee? (For the chair persons)
2. What are the roles of the biogas programme steering committee members? (Division of tasks in the committee if any?)
3. Does the biogas programme steering committee meet regularly?
4. Do you make monitoring and evaluation on biogas installations? If yes, what results do you get?

5. Some biogas installtions have been destroyed due to illegal possession of land. This may have negative impact on dissemination of biogas what do you think? (For *Ofla Woreda* only)
6. The *woreda* mines and energy office has only one individual? Can he really be effective to coordinate all mines and energy issues of the *woreda*? (For *Ofla Woreda* only)
7. Famers in the *woreda* are expected to purchase the minimum predetermine amount of chemical fertilizer that was fixed based on the plot size they have. This may have negative impact on effective utilization of bio-slurry and manure as a whole for fertilizer. What do you say about it? (For *Ofla Woreda* only)

Appendix J. Checklist of Key Informant Interview with Rural Energy Resources Development Experts at *Woreda* Administrative Level

1. How do you evaluate the current woodfuel availability (scarcity) in the *woreda*?
2. How do you evaluate the overall tree planting activities of the people in the area? What favorable and constraining factors are there to further promote tree planting activities?
3. What institutional measures are being taken to minimize the problem of domestic energy in the *woreda*?
    a. What alternative sources of energy are there to the rural community?
    b. Distribution of photovoltaic?
    c. Distribution of improved stoves
    d. On/off-grid hydroelectricity
4. Are there plans to further promote alternative sources energy?

K. Checklist of Key Informant Interview with Development Agents

1. How do you evaluate the current woodfuel availability (scarcity) of the area?
2. What institutional measures are being to minimize the problem of domestic energy in the area?
3. How do you evaluate the grazing habits of the people in the area?
4. How do you evaluate of people's habit of utilizing manure for fertilizer?
5. Are there extension services related to domestic energy?
6. How do you see the expansion of biogas installations in your locality?
7. What favorable and constraining factors are there to further promote biogas technology in the area?
8. Do you have any involvement in the biogas technology dissemination?
9. Are there extension services related to management and use of bio-slurry that specifically targeted the biogas user households?

L. Checklist for Focus Group Discussions

1. How do you evaluate the current scarcity of woodfuel in your locality?
2. What problems do you experience in association with wood-fuel scarcity?
3. What are the measures being taken against the problem of wood-fuel scarcity in your locality?
4. How do you evaluate the benefits of biogas technology dissemination to the community?
5. With increased dissemination of biogas technologies, among the community and household members, who do you think getting more benefits?

6. What are the barriers for further adoption and dissemination of biogas technology in your locality?
7. What opportunities are there for further dissemination of the biogas technology in your locality?
8. What weaknesses do you observe with the implementation of the biogas programme or biogas program implementing office?
9. What do you suggest for further promotion of biogas technology in your locality?
10. What do you suggest as lasting solutions for the problems of domestic energy in your locality?