



Contribution of Biogas Technology in Forest Conservation and Carbon Emission Reduction, Gimbi District, Western Ethiopia

Leta Wakjira¹, Motuma Tolera², Garome Shifaraw^{3,*}

¹Water and Energy Office, Gimbi District, Gimbi, Ethiopia

²School of Forestry, Hawasa University, Hawasa, Ethiopia

³Department of Plant Science, Mattu University, Bedele Campus, Bedele, Ethiopia

Email address:

shifarawgarome@gmail.com (Garome Shifaraw)

*Corresponding author

To cite this article:

Leta Wakjira, Motuma Tolera, Garome Shifaraw. (2024). Contribution of Biogas Technology in Forest Conservation and Carbon Emission Reduction, Gimbi District, Western Ethiopia. *Science Development*, 5(1), 1-18. <https://doi.org/10.11648/j.scidev.20240501.11>

Received: December 6, 2023; **Accepted:** December 27, 2023; **Published:** January 11, 2024

Abstract: Lean energy sources have a substantial role for sustainable development. It reduces the threat that climate change poses in human life. However, most rural communities in developing countries rely heavily on biomass for their domestic energy use. In the study site, forest land has been converted to other land uses for the last decades. This situation leads to scarcity of fuel wood. This study was aimed to examine the contribution of biogas technology in forest conservation and carbon emission reduction in Gimbi district, Western Ethiopia. Multi-stage sampling procedure was employed to select sample households. A total of 152 sample households (54 adopters and 98 non-adopters) were involved on household survey. Over more, 25 test subjects were also taken randomly from both adoption categories to conduct Kitchen performance test. Statistical Package for Social Scientist (SPSS 20.0) software was used to analyze the collected data. The result of this study revealed that *Eucalyptus camaldulensis* was the most commonly used tree species by adopter and non adopter households. Over more, the result shows relatively a higher pressure by non-adopters of the technology on tree species like *Cordia africana* and *Podocarpus falcatus* which were considered to be threatened in Ethiopia. The major fuel wood sources were plantation forest, natural forest, crop residues and dung cake which account 46.71%, 30.92%, 15.13% and 7.24% respectively. This study revealed that currently functioning biogas plants (145) have a potential of conserving about 0.79 hectare of forest annually. Furthermore, annual fuel wood saving of biogas technology was found to be 1423.06 kg with emission reduction potential of 1.53 t CO₂ e per biogas digester/year. Accordingly, from all functional biogas digesters found in the study site about 221.85 tons of carbon was saved annually. The result of this study also showed that relatively a higher amount (68.5% and 62.2%) of adopter and non-adopter households have positive attitude respectively. Hence, they are assumed to have a better awareness about the advantages of the technology. To make the role of biogas technology sustainable, experts working on the energy sector should work cooperatively with experts who are working in other sectors like agricultural and health experts.

Keywords: Climate Change, Domestic Energy, Fuel Wood, Renewable Energy

1. Introduction

1.1. Background and Justification

Energy plays an indispensable role in changing the life of human beings. The global energy demand is increasing rapidly as the result of population growth and economic development; and about 88% of this demand relies upon

fossil fuels [1]. According to Shakya [2], about eight million tons of greenhouse gases (GHGs) are emitted into the atmosphere annually of which developed countries are emitting 70% and the rest is shared by developing countries. An increase in concentration of CO₂ and other GHGs in the stratosphere leads to global warming, and ultimately, climate change. This has severe adverse effects on human health, ecological productivity, biodiversity, water reserves, and on

socio-economic groups whose adaptive capacity is low, especially the poor in developing countries [3]. Developing and using clean and renewable energy sources have become an important part of policies and strategies of many countries including Ethiopia. Strategies which enable to reduce fuel wood consumption have the potential of simultaneously mitigating climate change, conserving forests and improving human livelihoods. Transforming from today's use of biomass into cleaner technologies in the rural developing area would improve the standard of living, health and local environment and at the same time help to mitigate climate change. Furthermore, it would give an improved chance of sustainable economic development [4].

To realize sustainable development, Ethiopia has planned Climate Resilient Green Economy strategy [5]. Expansion of renewable energy sources for electricity generation is among the four pillars of CRGE strategy of Ethiopia. Clean and renewable energy which is environmentally friendly beside its economic value, like biogas energy, is necessary for sustainable forest conservation and climate change mitigation. The use of anaerobic digestion to create biogas from dairy manure and other organic wastes can reduce GHG emissions in two distinct ways. First, when used in combination with a manure management system that stores manure under anaerobic conditions, it can prevent the release of a greenhouse gas like CH_4 into the atmosphere. Second, the biogas generated by anaerobic digestion process can replace the use of fuels that generate GHGs [6]. According to Lansing *et al.* [7] biogas is a renewable energy technology that utilizes organic waste sources to produce a flammable methane gas suitable for cooking and lighting purposes. Biogas consists between 40% and 70% CH_4 with the remainder being CO_2 , H_2S and other trace gases [8]. The resulting CH_4 gas is an efficient source of energy for cooking, combustion engine and burned to produce electricity. Utilization of biomass energy for cooking and lighting is an important factor for the decline of forests currently and thereby an important factor to aggravate climate change. Deforestation and degradation of forests contribute a huge amount of greenhouse gas emissions in many developing countries, particularly in Sub-Saharan Africa [9]. At the same time, energy from fuel wood is essential to sustain livelihoods in this region [10]. Fuel wood collection for cooking is a main driver of forest degradation in these countries [11]. As a result, in most areas of Sub-Saharan Africa indoor air pollution caused by traditional cooking constitutes a major health risk [12]. So far, research activities related to biogas in Gimbi district are limited to investigating the contribution of biogas energy in reducing GHG emission since very few biogas plants have been available. Nevertheless, in recent times, biogas technology has been spreading profoundly and the number of rural households using this technology has been increasing. In relation to this, there is a need to study role of biogas technology in forest conservation and greenhouse gas emission reduction.

1.2. Statement of the Problem

Globally, 55% of the wood extracted from forests is for fuel and fuel wood is responsible for 5% of global deforestation [13]. Especially, the life of people in most developing countries is highly dependent on extraction of fuel wood from forests. Over 80% of Sub-Sahara Africa countries including Ethiopia rely mainly on solid biomass such as firewood, charcoal, agricultural by-products and animal waste to meet basic needs for cooking and lighting [14]. Unless the economy and awareness of least developed countries improved, most of the rural communities will continue to rely on forest biomass for cooking and lighting. Although developed world has replaced highly polluting fuel sources with cleaner sources, it is estimated that 50% of all households worldwide and 90% of all rural households continue to use biomass fuel as their main domestic energy source [15]. Ethiopia is a top ranking country in Africa and among the first ten countries in the world by its livestock resource. However, its energy consumption relies extremely on biomass that accounts about 94% of the total energy consumption for cooking and lighting [16]. Like other areas of Ethiopia, in Gimbi district most rural communities rely on biomass for their domestic energy use. This situation largely contributed to deforestation and forest degradation. In addition, large area of forest land has been converted to other land uses. However, detailed empirical researches, documentation and publication of major findings on role of biogas energy in forest conservation and carbon emission reduction in Gimbi district are lacking yet. Therefore, this research has been initiated to assess empirically the role of using biogas technology in forest conservation and carbon emission reduction. The following are the main questions needed to be addressed by this study: What are the most commonly used tree species for domestic energy consumption? What amount of fuel wood is saved by using biogas technology? How much hectare of forest can be conserved annually by using biogas technology? What amount of carbon emission is reduced by using biogas technology? What is peoples' attitude towards biogas technology? What factors are significantly affecting adoption of biogas technology? Therefore, the overall objective of this study was to investigate the role of biogas technology in forest conservation and carbon emission reduction in Gimbi district, Western Ethiopia.

1.3. Significance of the Study

The empirical findings from this study will enhance the efforts that have been made by governments, non-government institutions, private enterprises and interested public on promoting utilization of biogas as an environmentally and ecologically friendly technology for improving forest conservation and carbon emission reduction. Particularly, it is expected to provide information related to amount of fuel wood saved by using biogas technology. This would show the potential of biogas technology in reducing the pressure on forest resources that

would further indicate the rate of deforestation. The findings will also show the most important tree species which have been used for firewood and are at risk for proper management. Apart from these, rural households' attitude towards biogas technology adoption will be assessed. Additionally, the findings could also be used as an input in decision-making process by the policy makers, planners, and NGOs which are working on expansion of renewable energy resources like Ministry of Water, Mineral and Energy and National Energy Program of Ethiopia. Finally, the findings from this study will, therefore, contribute towards sustainable adoption of biogas technology for forest conservation and reducing carbon emission especially in Gimbi district.

1.4. Scope and Limitations of the Study

The study was limited to assess the contribution of biogas technology on forest conservation and carbon emission reduction in Gimbi district, western Ethiopia. The study was also limited on the sample 152 household which is the representative of whole population of the district. The potential of biogas technology to reduce Methane emission was not included in this study due to limitation of finance and time.

1.5. Conceptual Framework

The conceptual framework on Figure 1 shows a general diagrammatic representation of impacts of using traditional tree biomass and biogas technology.

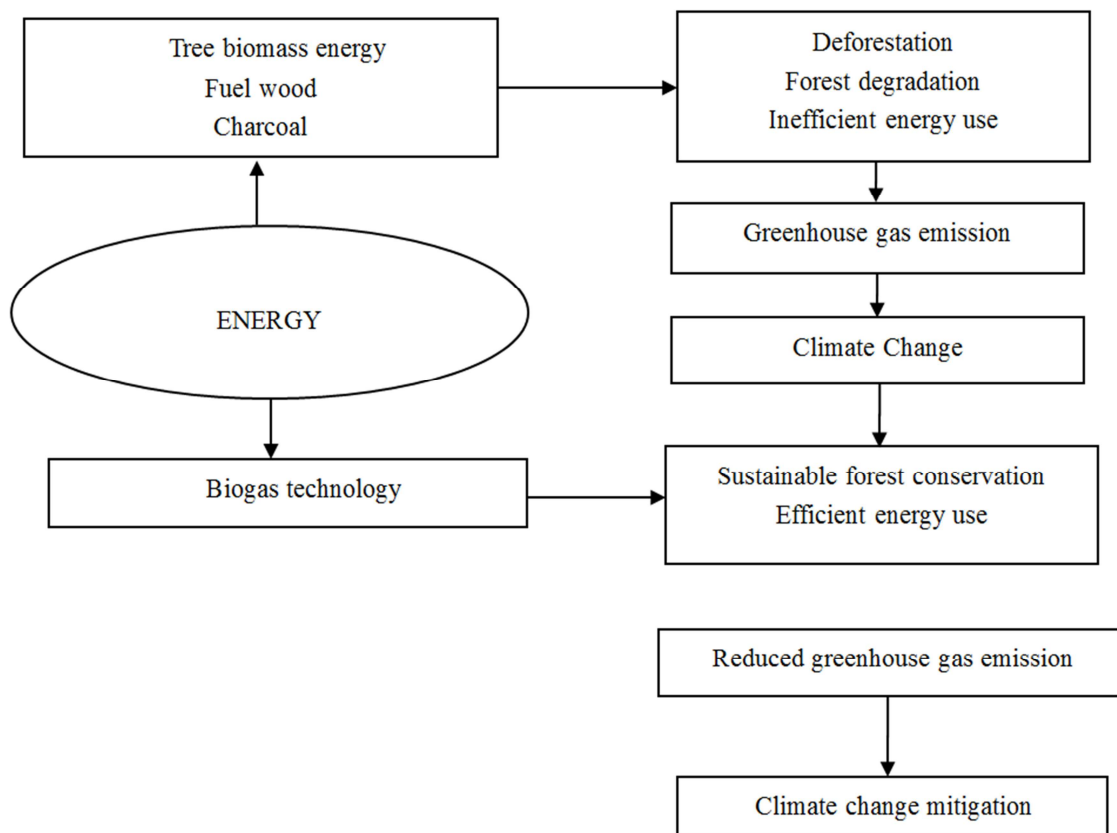


Figure 1. Conceptual framework showing the impacts of using traditional tree biomass energy and biogas technology.

2. Materials and Methods

2.1. Site Description

Gimbi district is found in the West Welega Zone of the Oromia region, Ethiopia. It has a latitude and longitude of 9°10'N 35°50'E with an elevation between 1845 and 1930 meters above sea level. Gimbi is one of the 180 woredas in the Oromia Region of Ethiopia and is bordered on the south by Haru, on the southwest by Yubdo, on the west by Lalo Asabi, on the north by the Benishangul-Gumuz region, on the East by the East Welega Zone, and on the southeast by an

exclave of the Benishangul-Gumuz region. Based on figures from the central statistical agency in 2007, Gimbi district has an estimated total population of 36,612, of whom 18,623 are men and 17,989 are women.

Climate, Soil, Water, Forest and Wildlife

Gimbi district is classified into kola and woina dega agro climatic zone with mean annual temperature of about 14.7°C and mean annual rain fall of 1294mm. Fertile soil, water, forest and wildlife are some of the natural resources Gimbi is bestowed with. Loamy sand textured soils, which contain most important nutrients, cover the area (cited in Gimbi woredas agricultural offices, 2009).

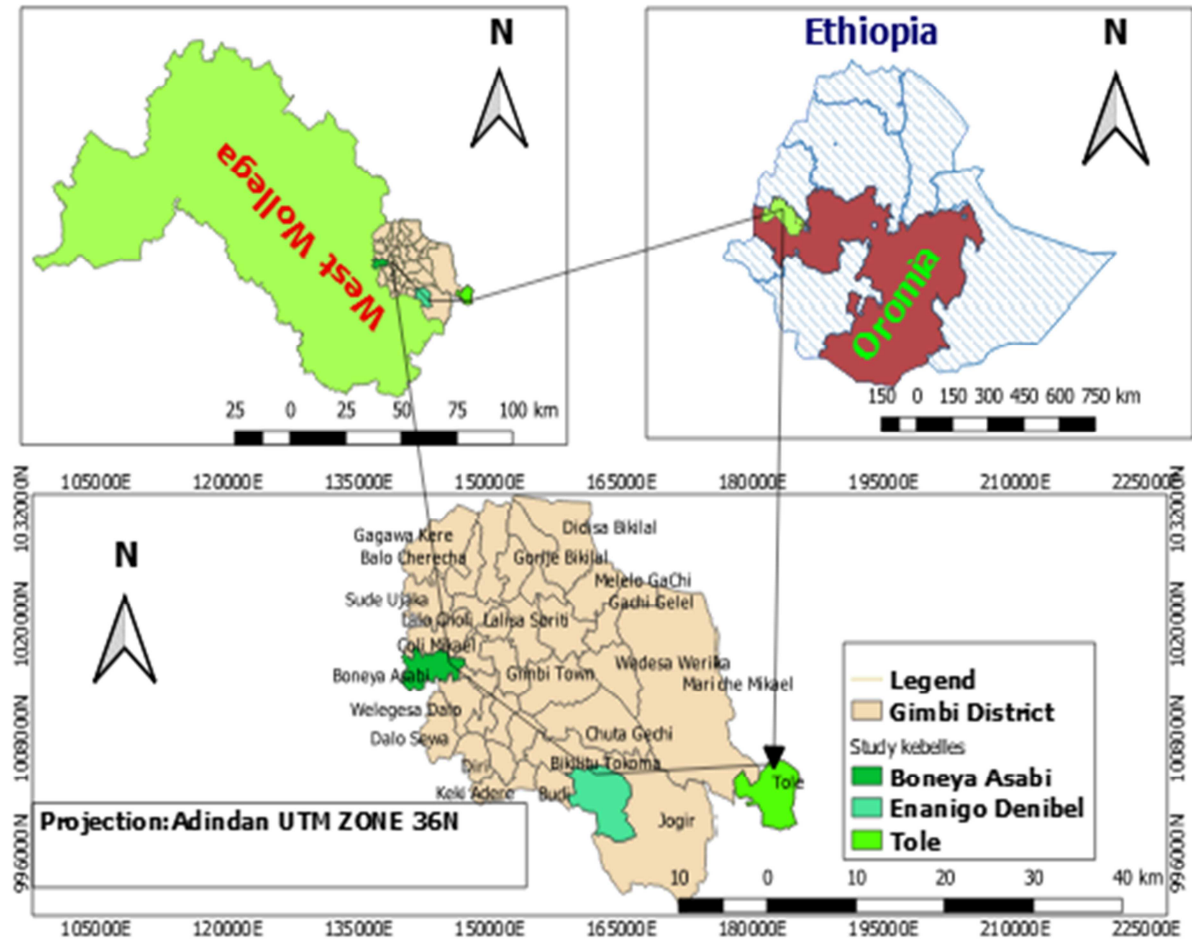


Figure 2. Location map of study area.

2.2. Methods

2.2.1. Sampling Techniques and Sample Size

For this study multi-stage sampling procedure was employed to select adopter and non-adopter sample households. At first stage, out of 32 kebeles found in Gimbi district three kebeles were selected purposively due to presence of relatively higher intervention of biogas technology and their proximity to the forest. At the second stage, a list of biogas technology adopter and non-adopter household heads in the selected kebeles was obtained from the district and Kebeles administration offices. The total number of biogas technology adopter in the district is 166 households. There is 4960 total number of households in selected three kebeles. From these 119 households were adopter and 4841 were non-adopter. From this, the total

sample size was determined for adopter and non-adopters of the technology separately. The number of sample households for both adopter and non-adopter of the target population at 95% confidence level and 0.1 (10%) level of precision were determined by using a simplified formula provided by Yamane [17] and reviewed by Israel, [18]

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

Where n is the sample size, N is the population size, and e is the level of precision at 95% significance level.

In the third stage, probability proportional to size (PPS) sampling technique was used to determine the number of sample households selected from each kebeles. Finally, simple random sampling technique was used to select sample respondents from the three kebeles.

Table 1. Distribution of sample sizes in each selected kebeles.

Kebeles	Total number of households		Sample size taken	
	Adopters	Non-adopters	Adopters	Non-adopters
Boneya Asabi	42	1259	19	25
Tole	56	2174	25	44
Inango Dambali	21	1408	10	29
Total	119	4841	54	98

Source: own computation, 2020

2.2.2. Data Sources and Types

For the purpose of this study data from both primary and secondary data sources were collected and used to achieve the objectives of the study.

(i). Primary Data Sources and Types

Primary data were collected from sample households using questionnaire, focus group discussion, and key informants interview and field observation. Primary data were mainly related to respondents' demographic characteristics, peoples' attitude towards biogas technology, the most commonly used tree species for domestic energy consumption and amount of fuel wood and biogas consumed per household.

(ii). Secondary Data Sources and Types

Secondary data were collected from Water, Mineral and Energy office of the district, Kebele administration offices, and other published and unpublished materials. Secondary data were used to provide information on the issues related to identifying adopter and non-adopter household heads in the target population.

2.2.3. Data Collection Methods

Both qualitative and quantitative approaches were employed to address objectives of the study. In this study, attitudes of selected households that assumed to have influenced adoption of biogas technology were assessed. Different methods were used to collect both qualitative and quantitative data. These include semi structured household survey, checklists for key informants interview and focus group discussion and field observations.

(i). Household Survey

The general description of the location of the persons who responded to the questionnaire in the households was 44 (28.95%) from Boneya Asabi, 69 (45.39%) from Tole and 39 (25.66%) from Inango Dambali kebeles. The household survey questionnaire guide has both open and closed ended questions. Open ended questions were prepared to ask information related the most commonly used tree species for domestic energy use by households, source of fuel wood and households socioeconomic characteristics and their relation to adoption of biogas technology. Closed ended questions were also asked to capture information mainly related to peoples' attitude towards role of biogas technology and some other dummy variables. The questionnaires were pre-tested among nine randomly selected households from sampled kebeles to detect misunderstandings, ambiguities, or other difficulties of participants. All questionnaires were distributed for expected 152 households and 100% of households' survey data was recorded.

(ii). Focus Group Discussion

According to May (1993) the advantage of this method is that it allows the interaction with a range of key informants and allows the researcher to focus on group norms and dynamics around the issue being investigated. In this study, FGDs were conducted among the people comprising 6

participants in each group. The members of focus group were selected from both adopters and non-adopters of biogas technology in each selected kebeles. According to Gill and Chadwick [19] a focus group discussion composed of between six and fourteen members is adequate. Some open-ended questions that play a vital role in addressing objectives of the study were prepared for discussions. From focus group discussions, qualitative information which is related to the most commonly used tree species for cooking and lighting; households' attitude towards biogas technology and other relevant questions for this study were collected.

(iii). Key Informants Interview

For this study the interview was carried out on governmental institute and stakeholders who work on biogas technology promotion and dissemination as well as experienced and knowledgeable persons on biogas technology. The interview was adopted as a method for data collection partly due to its cost effectiveness and its strength of capturing empirical data in both informal and formal settings [20]. KII was employed in order to support the data which were collected from household survey. Respondents were interviewed in their homes during weekend time. Eight key informants were selected (2 from energy expert, 2 from health expert, 2 from agriculture and 2 from climate change expert).

(iv). Field Observation

In this study, beside to key informants interview and Focus Group discussions, direct observations were also used to check whether each biogas plants are functional or not and to see the part of biogas which made the biogas digester not functional. The information which has been gathered using field observation was used to counter-check information provided by household respondents and focus group participants.

(v). Kitchen Performance Test Procedure

The quantity of woody biomass which can be saved by biogas technology utilization was estimated based on kitchen performance test. KPT is one specific type of performance test which is used to measure fuel saved when cooks switch from inefficient to efficient stoves [21]. According to Bailis & Edwards [22] one must choose families to act as the comparison group from a community that is similar in socioeconomic status, livelihood options, and climatic or environmental conditions. So that, Tole kebele was selected for KPT in this study. As a rule of thumb, if the target population is very small (e.g. less than 200 families), then the number of families covered by the initial survey between should be at least 20 [23]. There were 25 adopters of biogas technology in Tole kebele, so that all 25 test subjects were selected from adopter households. Equal amount of test subjects were also selected randomly from non-adopters of biogas technology for a cross-sectional study. Sample sizes need to be larger if there is a lot of variation in the amounts of fuel used and saved, which is often the case in KPTs. One

way to start is to simply assume a typical variation, expressed as COV.

The fuel wood used in the study was acquired from local sellers in the town of the Gimbi district. The sellers were purchasing fuel wood composed of different plant species. Then the researcher ordered the sellers to prepare the fuel wood only from eucalyptus tree species, which was the preferred wood type in the study communities. After provision of fuel wood, the tests were carried out for a period of three consecutive days and times like festivals or holidays were avoided, since more cooking is done than unusual. This is least testing period of KPT in according to Bailis *et al.* [23]. For undertaking KPT, primarily mass of wood for each sample household was weighted and at the end of the day the remaining wood was also be weighted. The test subjects were also informed to use fuel only from a designated stock which has been pre-weighted and they were visited at least twice a day to check that they are using only fuel from the weighed stock. The primary tools and hardware used in the KPT were: spring balance with 0-50 kg range, 1 m resolution rope, cart for wood transport, digital wood moisture meter and GPS 72H to obtain the coordination of participant household home position.

Finally, statistical analysis was conducted on the test results to estimate the mean fuel savings. Let \bar{y} denote the estimate of mean fuel savings calculated from the sample and SE_y be the standard error of this estimate. Then for a sample of size n , the estimated precision is given by the formula

$$\text{Precision} = 1.67 \times \frac{SE_y}{\bar{y}} \times 100 \quad (2)$$

Here 1.67 is used as an approximation to the critical value $t_{0.95, -1}$, which will vary between 1.75 and 1.64 as the sample size n increases from 15 to very large. In this KPT, COV for daily fuel wood consumption of biogas technology adopters and non-adopters were 0.23 and 0.13 respectively. Over more, the precision attained were 24.8%. This indicates that the sample size satisfy the 90/30 rule. Therefore, no additional sample size was required for KPT (Appendix 3).

The following formula was employed to estimate minimum sample sizes in the special case of Simple Random Sampling. Since the project and baseline samples are independent, then the standard error of the estimate is:

$$SE_y = \sqrt{\frac{s_b^2}{n_b} + \frac{s_p^2}{n_p}}$$

The minimum required sample size to achieve “90/ x ” precision with two independent samples is approximately equal to

$$\tilde{n} \geq \left(\frac{\sqrt{s_b^2 + s_p^2}}{\bar{y}_b - \bar{y}_p} \times \frac{1.67}{x/100} \right)^2 \quad \text{Adam and Amber (2011)}$$

$$\tilde{n} \geq \left(\frac{\sqrt{0.56^2 + 0.28^2}}{1.74 - 0.99} \times \frac{1.67}{30/100} \right)^2 \quad (3)$$

$$\tilde{n} \geq 21.6 \quad \tilde{n} \geq 22$$

Hence, the total required sample size in this case is thus $2\tilde{n}$ (2×22) = 44 test subjects for the two adoption categories. But, to reduce bias and make the samples more representative the whole tested subjects (25 households from each group) were considered for this study.

Fuel use and fuel savings were calculated in terms of kilograms per person per day by dividing the kilograms per household per day by household size. The number of person served on meals cooked during each day of the KPT was recorded through daily KPT survey. Over more, weighting factors were used to calculate SAEs. SAEs were determined using FAO standard adult weighting values shown in Table 4 below [24]. Finally, fuel wood consumption and savings were determined by per capita SAE.

Table 2. Standard adult equivalence factors.

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

2.2.4. Methods of Data Analysis

The data that was collected through questionnaire was coded and keyed into the Statistical Package for Social Scientist (SPSS 20.0) and exported to Stata, while experimental data was entered into Excel spreadsheets and exported to statistical software. Tables, pie-charts and graphs were used to present finalized results of the study. Descriptive statistics was employed to determine and assess the following aspects: respondents’ demographic and socioeconomic characteristics, their attitude towards biogas technology and to show proportion of the most commonly used tree species for household energy consumption. Independent sample t-test was also employed to test the existence of a significant difference between the mean of fuel wood consumption by adopters and non-adopters of biogas technology.

(i). Econometric Model

Besides to descriptive statistics, chi-square test and independent sample t-test, empirical investigation was employed to confirm the existence of the relationships among variables. The most commonly used econometric models in adoption studies are the limited dependent variable models such as logit and probit [25]. Probit regression model was used to determine the factors affecting adoption of biogas technology. In the present study the observations were coded “1” for adopters and “0” for non-adopters and were used as a dependent variable. The general form of adoption of biogas technology is specified as follows:

$$Bi = \beta_0 + \beta_1 (AGE) + \beta_2 (EDUC) + \beta_3 (SEX) + \beta_4 (TLU) + \beta_5 (FAMSIZE) + \beta_6 (FWDIST) + \beta_7 (INCOME) + \beta_8 (AWARENESS) + \beta_9 (ATTITUDE) + \beta_{10} (TECHAV) + \beta_{11} (WATERAV) + \epsilon_i \quad (4)$$

Where, B_i is binary dependent variables denoted as “1” if the household adopt biogas technology and “0” otherwise
“ B_i ” is vector parameters to be estimated.

“ C_i ” is the constant term.

Dependent variable

Adoption of biogas technology: it is a dummy dependent variable with a value of 1 if the household adopts the technology and has a value of 0 otherwise that their source of energy could be inefficient traditional type of source of energy (firewood, dung, crop residue and the likes).

Independent variables

Household income: it is a continuous variable measured in Ethiopian birr. It is expected who have higher income of household could participate in modern source of energy and using improved technologies than have lower income of household in the study area.

Age of household head: In this study age of household head is a continuous variable measured in years. It is expected that the younger families could participating in modern source of energy and using improved technologies than older generation due to emotional resistant.

Educational status of household head: it is a dummy variable with a value of 1 for those who were literate, 0 otherwise for those respondent illiterate. It is expected that literate household heads have better chance to participating in modern source of energy and using improved technologies than illiterate headed of household in the study area.

Sex of household head: it is a dummy variable with a value of 1 for male household heads, and 0 otherwise. It is expected that relatively male head of household could participating modern source of energy and using improved technologies than female headed of household.

Number of livestock owned: it is a continuous variable measured in TLU. It is expected that those household heads with larger number of cattle could be most probably used dung for source of energy than who had smaller number of cattle.

Household size: In this study it is a continuous variable; the number of family size live in the same household affects household energy consumption patterns due to the availability of active labour force in the household. It is expected that the larger family size could participating in modern source of energy and using improved technologies than smaller family size in the study area.

Fuel wood distance: it is a continuous variable measured in kilometers. It is expected that if the collecting fire wood far from the household resident, they could spent more time for collection fire wood and dung. It is expected that distance traveled to collect fuel wood will have positive effect on the time spent for collecting fuel wood.

Attitude: If the individuals know the advantages of biogas technology their attitude towards biogas would be positive and would adopt the technology.

Awareness: Individuals who have access to information could have also a better probability to adopt biogas

technology. Hence, the variable awareness was hypothesized to have a positive relationship with biogas adoption.

Technical availability (TECHAVA): As indicated by many researchers access to technical services can make the individuals to adopt biogas technology.

Water availability (WATERAV): Access to sufficient water is a key factor for adoption of biogas technology. Thus a positive relationship was also hypothesized between availability of sufficient water and adoption of biogas technology. Related to this model, the explanatory variables included in the empirical models are summarized in Table 6.

Multi-co linearity test

Before executing the econometric model, all the hypothesized continuous and dummy explanatory variables were checked for the existence of multi-co linearity problem. The problem of multicollinearity may arise due to a linear relationship among explanatory variables. Multicollinearity problem might cause the estimated regression coefficients to have wrong sign, smaller t-ratios for many of the variables in the regression and high R^2 value. Besides, it causes large variance and standard error with a wide confidence interval. Hence, it is quite difficult to estimate accurately the effect of each variable. Different methods are often used to detect the existence of multicollinearity problem. Among these, variance inflation factor (VIF) technique was employed in this study to detect the existence of multicollinearity in continuous explanatory variables and contingency coefficient (CC) for dummy variables [26]. According to Gujarati [26], VIF (X_i) can be defined as

$$VIF(X_i) = \frac{1}{1 - R_i^2} \quad (5)$$

Where: R_i^2 is the multiple correlation coefficients between X_i and other explanatory variables. Selected continuous explanatory variables, (X_i) were regressed on all other continuous explanatory variables, and the coefficient of determination (R_i^2) was constructed for each case. The larger the value of R_i^2 results in higher value of VIF (X_i) which causing higher collinearity between variables. For continuous variables, as a rule of thumb, value of VIF greater than 10, are often taken as indicator for the existence of multicollinearity problem in the model (if the value of R_i^2 is 1, it would result in higher VIF (∞) and cause perfect multicollinearity between the variables). Besides, the contingency coefficient (CC) was computed for dummy variables from chi-square (χ^2) value to detect the problem of multicollinearity (the degree of association between dummy variables). The dummy variables are said to be collinear if the value of contingency is greater than 0.75.

$$c.c = \sqrt{\frac{\chi^2}{n + \chi^2}} \quad (6)$$

Where: C.C is contingency coefficient,
n is sample size, χ^2 is chi-square values.

Table 3. Independent variables, their description, type and expected effects.

Variables	Description	Type	Expected effect
Age	Age of household head	continuous	+/- ve
Educ	Years in school expended by the head of household	dummy	+/- ve
Famsize	Number of family members	continuous	+/- ve
Sex	“1” stands for male household head and “0” stands for female	dummy	+/-ve
Income	Household’s average annual income	continuous	+ ve
Fwdist	Distance to firewood sources	continuous	+ ve
Awareness	“1” stands for aware and “0” otherwise	dummy	+ve
Attitude	“1” stands for households had positive attitude and “0” otherwise	dummy	+ ve
Tlu	Ownership of cattle	continuous	+ve
Techava	“1” stands for technical service available and “0” otherwise	dummy	+ ve
Waterav	“1” stands for sufficient water available and “0” otherwise	dummy	+ ve

(ii). Determination of Biogas Digester’s Role in Forest Area Conservation

Forest area saved can be obtained from amount of fuel wood saved. The amount of fuel wood which can be saved from all regularly functioning biogas digesters was determined. Tree height and DBH of most commonly used tree species for fuel wood purpose in the study area were considered and total dry biomass of a single tree was estimated. Then, the total biomass which can be saved from all regularly functioning biogas digesters was converted to its number of tree equivalent. Finally, the amount of forest saved by using biogas was estimated in hectare basis. Small sized eucalyptus tree, which is planted for construction and fuel wood purpose, has average height and diameter of 18 m and 12cm respectively [27]. According to Scott et al. [28], the total biomass of the tree can be calculated by using the equation below that could be considered as an average of all species.

For trees with $D < 11$ inches, the following equation is applied to calculate number of tree saved.

$$W_{\text{of one eucalyptus tree}} = 0.25 \times D^2 \times H \quad (7)$$

To determine the dry weight of the tree, multiply the weight of the tree by 72.5%.

$$DW = W \times 72.5\% \quad (8)$$

Where: W = Above-ground weight of the tree in kilogram, D = Diameter of the trunk at breast height in centimeter, H = Height of the tree in meter, DW = Dry weight of the tree in

kilogram.

According to Oballa et al.[29], Eucalyptus tree seedlings are planted within 2m×2m spacing so that it has 2500 tree seedlings per hectare for fuel wood purpose and out of this 70% (1750 trees) will become mature trees.

(iii). Estimation of Emission Reduction from Biogas Utilization

In this study, the role of biogas technology adoption in carbon emission reduction was assessed by estimating total fuel wood savings attained by biogas plants. The calculation was computed based on Clean Development Mechanism Methodology and United Nations Framework of Convention on Climate Change [30], default net calorific values, emission factors and carbon storage in forests by using the formula shown below.

$$ER_y = B_{y, \text{ savings}} \times f_{NRBY} \times NCV_{\text{biomass}} \times EF_{\text{projected-fossil fuel}}$$

Where:

ER_y , is emission reduction during the year in tones of carbon dioxide equivalent (tCO_2e).

$B_{y, \text{ savings}}$ is the quantity of woody biomass that is saved in tones or kilo gram per biogas.

f_{NRBY} , is the fraction of woody biomass saved during the year that can be established as non-renewable biomass, NCV_{biomass} , is the net calorific value of the non-renewable biomass.

$EF_{\text{projected-fossil fuel}}$, is emission factor for the substitution of the non-renewable woody biomass by similar consumers.

Table 4. Parameters for calculating carbon emission.

Parameter	Value	Source
Annual wood saving per biogas	KPT	Field survey
Emission factor of fuel wood	15 MJ/Kg	(IPCC, 2006)
Net calorific value of fuel wood (wet basis)	81.6 CO_2 t/TJ	UNFCCC, 2013
Conversion CO_2/C	3.667	Ratio of molecular weights
Fraction of non-renewable fuel wood	88%	(UNFCCC, 2012)

3. Results and Discussion

This part comprises the findings of the study and their brief respective discussions. Mainly it includes the most commonly used tree species for domestic energy

consumption; amount of forest conserved by using biogas plants; amount of fuel wood saved and carbon emission reduced by using biogas plants; peoples’ attitude towards biogas technology and factors influencing adoption of biogas technology.

Table 5. Socio-economic and demographic characteristics of respondents.

Sex	Adopters (n=54)		Non-adopters (n= 98)	
	Percent		Percent	χ^2 p-value
Female	14.8		23.5	1.606 0.205
Male	85.2		76.5	
Total	100		100	

Education	Adopters		Non-adopters	
	Percent		Percent	χ^2 p-value
Literate	66.7		50.0	3.923 0.048
Illiterate	33.3		50.0	
Total	100		100	

Out of the total adopter respondents, about 85.2% were male while 14.8 of the respondents were female household heads (Table 5). In addition, about 76.5% of non-adopters respondents were male and 23.5% were female household heads. The proportion of male respondents was higher than female respondents in both adoption categories. Regarding to educational status, 66.7% of adopter sample households were literate whereas 33.3% were illiterate. On the other hand, in the category of non-adopters the percentage of both literate and illiterate sample respondents was 50%. These result showed that most of adopter household heads in the study area are educated even though most of them have attended only primary school. Therefore, they are expected to have relatively a better access to information about biogas technology (Table 5).

Table 6. Socio-economic and demographic Characteristics of respondents ... Cont'd.

Variables	Adopters		Non-adopters		p-value
	Mean	SD	Mean	SD	
Age (year)	47	11	43	8	0.016*
Family size	7.67	2.07	6.29	1.92	< 0.001*
Farm size (ha)	0.48	0.25	0.47	0.23	0.715
TLU	5.08	2.21	1.94	1.91	< 0.001*

* Shows statistically significant at 5% level of significance Source: Field survey, 2020

The age structure result of the sample households showed that the average age of adopters and non adopters were 47 and 43 respectively. The mean age difference between the groups was found to be statistically significant at 5% significance level (Table 6).

In the study area, the average family size and standard deviation of adopter sample households were 7.67 and 2.07 persons respectively. On the other hand, the average family size and standard deviation for non-adopter sample households were 6.29 and 1.92 respectively. The t-test result

showed that there is a significant difference between the adopter and non-adopter sample households at 5% significance level. The result is consistent with other studies which reported that having a larger family is positively associated with adoption of fuel efficient new technology. This implies the presence of more labor enables households to the tendency of getting better income with larger number of adults in household.

The total farm size owned by households indicates the economic status of farmers. The survey results showed that the average total farm size holding by adopter sample households was about 0.48 ha. While the average total farm size holding by non-adopter sample households was 0.94 ha. The mean difference between the two categories was found to be statistically insignificant at 5% significance level (Table 6).

Livestock are sources of manure for biogas production. By using conversion factors determined by Storck et al. [31], the types of livestock owned by the sample households were converted into tropical livestock unit (TLU) to compare livestock holding between households easily. The independent sample t-test result showed that there is a significant mean difference in TLU between the two adoption categories at 5% level of significance (Table 6).

3.1. Domestic Energy Consumption Patterns

Table 7. Fuel wood collection patterns of family members.

Fuel wood collectors	Frequency	Percent
Mother	78	51.32
Father	12	7.89
Boys	18	11.84
Daughters	44	28.95
Total	152	100

Source: Field survey, 2020

The result of this study showed that the majority of fuel wood collectors (51.32%) are mothers followed by daughters (28.95%) and boys (11.84%). Among the family members, fathers have accounted the minimum proportion (7.89%) in participating on fuel wood collection activity. This result is in line with the finding of Warkaw [32] which indicated that to households with no access to modern fuel the proportion of mothers, daughters, child boys and fathers were about 34.33%, 29.85%, 17.91%, 13.43% respectively (Table 7). The above results clearly revealed that most of the time the responsibility of fuel wood collection in the study area has been given to female members of the family. This situation would create a trouble on education of daughter family members.

Table 8. Rank of households' use of energy sources for cooking purpose.

Energy sources	0		1		2		3		4		5	
	F	%	F	%	F	%	F	%	F	%	F	%
Fuel wood	26	17.11	13	8.55	20	13.2	19	12.5	45	29.61	29	19.1
Charcoal	43	28.29	14	9.21	19	12.5	30	19.7	32	21.05	14	9.21
Kerosene	142	93.42	6	3.95	4	2.63	0	0	0	0	0	0
Biogas	98	64.47	0	0	0	0	9	5.92	37	24.34	8	5.26
Crop residue	99	65.13	26	17.1	15	9.87	12	7.89	0	0	0	0
Dung cake	118	77.63	21	13.8	8	5.26	5	3.29	0	0	0	0

Energy sources	0		1		2		3		4		5	
	F	%	F	%	F	%	F	%	F	%	F	%
Solar	152	100	0	0	0	0	0	0	0	0	0	0
Electricity	135	88.82	0	0	17	11.2	0	0	0	0	0	0

Note: 5, 4, 3, 2, 1 and 0 stands for most important; important; moderate; less important; least important; and for not-used energy source whereas 'F' stands for frequency

The above table clearly showed that the rank of households' use of energy sources for cooking (preparing wet, making tea and coffee, boiling water, and so on) as per their order of importance for rural households. Accordingly, Fuel wood was found the first very important source of energy for cooking, followed by charcoal and biogas energy respectively. Key informants have confirmed that charcoal production is not a common practice in the area rather most

households have used charcoal through buying from the market. In contrast, the rank of households' electricity and solar energy consumption was found less important and not used energy sources for cooking purposes respectively. These results revealed that the rural households' energy consumption is still significantly relied on traditional energy sources.

Table 9. Rank of households' use of energy sources for baking purpose.

Energy sources	0		1		2		3		4		5	
	F	%	F	%	F	%	F	%	F	%	F	%
Fuel wood	0	0	0	0	13	8.55	10	6.6	14	9.2	115	76
Biogas	152	100	0	0	0	0	0	0	0	0	0	0
Crop residue	95	62.5	11	7.2	20	13.16	18	12	8	5.3	0	0
Dung cake	109	71.7	21	14	16	10.53	6	4	0	0	0	0
Electricity	152	100	0	0	0	0	0	0	0	0	0	0

Note: 5, 4, 3, 2, 1 and 0 stands for most important; important; moderate; less important; least important; and for not-used energy source whereas 'F' stands for frequency

As indicated on Table 9 fuel wood was found a very important energy source for baking Injera and bread followed by crop residue and dung cake. This result is not in line with the result of the study conducted by Warkaw [32] which reported that for households with no access to modern energy

sources dung and fuel wood are the first and second most important energy sources. The result of this study also revealed that biogas and electricity were found among energy sources which have not been used for baking injera and bread.

Table 10. Rank of households' use of energy sources for lighting purpose.

Energy sources	0		1		2		3		4		5	
	F	%	F	%	F	%	F	%	F	%	F	%
Fuel wood	140	92	9	5.9	3	2	0	0	0	0	0	0
Kerosene	59	39	15	9.9	36	24	26	17	11	7.2	5	3.3
Biogas	98	64	0	0	0	0	10	6.6	38	25	6	3.95
Crop residue	142	93	0	0	0	0	10	6.6	0	0	0	0
Solar	107	70	21	14	18	12	6	4	0	0	0	0
Electricity	0	0	0	0	12	7.9	93	61	29	19	18	12
Candle	36	24	52	34	45	30	16	11	3	2	0	0

Note: 5, 4, 3, 2, 1 and 0 stands for most important; important; moderate; less important; least important; and for not-used energy source whereas 'F' stands for frequency

Table 10 shows that electricity, biogas and kerosene are the first, second and third important sources of energy for lighting purpose by households. It also shows that solar energy is moderately important as compared to other energy sources. Over more, firewood and crop residues have been found rarely used energy sources for lighting purpose by households in the study area.

Among the total sampled households' biogas digesters 87.04% of them were functional whereas 12.96% of them were found non-functional. As reported by respondents Gas

lamp and Gas holder (Dome) are parts of biogas digester which fail mostly.

Table 11. Functional status of biogas digesters.

Status of biogas digesters	Frequency	Percent
Functional	47	87.04
Non-functional	7	12.96
Total	54	100

Table 12. Fuel wood distance and adoption of biogas technology.

Variable	Adoption categories	N	Mean \pm SD	t-value	P-value
Fuel wood distance (km)	Non-adopters	98	2.05 \pm 0.81	6.42	< 0.001**
	Adopters	54	2.93 \pm 0.82		

** indicates significant variation at 5% significance level Source: Field survey, 2020

The average distances from the residence of respondents to the source of fuel wood were 2.05 km and 2.93 km for non-adopters and adopters of biogas technology respectively. This result shows that most of non-adopter households are found

closer to the forest. The independent sample t-test result showed that there is a significant difference on the distance of fuel wood source between adopter and non-adopter households at 5% significance level.

Table 13. Awareness and adoption of biogas technology.

Do you have awareness About biogas technology?	Adopters		Non-adopters		χ^2	P-value
	Frequency	percent	Frequency	Percent		
Yes	42	77.8	49	50	11.18	0.001**
No	12	22.2	49	50		
Total	54	100	98	100		

** shows significant variation at 5% significance level Source: Field survey, 2020

The result of this study confirmed that about 77.8% and 50% of adopter and non-adopter respondents have awareness about biogas technology respectively. This implies that they have a better access to information. On the other hand, about 22.2% and 50% of adopter and non-adopter households didn't have awareness about the technology (Table 13). This

indicates that they were unable to get detailed information about the technology. The chi square result revealed that there is a significant difference on awareness about the technology between the two adoption categories at 5% significance level.

Table 14. Availability of technical services and adoption of biogas technology.

Variable	Adopters		Non-adopters		χ^2	P-value
	Frequency	percent	Frequency	Percent		
Availability of technical services					10.43	0.001**
Available	42	77.8	50	49		
Not available	12	22.2	48	51		
Total	54	100	98	100		

** indicates significant variation at 5% significance level Source: Field survey, 2020

As indicated on Table 14 above about 77.8% and 49% of adopter and non-adopter sampled households have access to technical services respectively. On the other hand, 22.2% and 51% of adopter and non-adopter households have not access

to technical services respectively. Furthermore, the chi-square result indicates that there is a significant difference between the two adoption categories.

Table 15. Availability of sufficient water and adoption of biogas technology.

Do you have sufficient water for biogas production?	Adopters		Non-adopters		χ^2	P-value
	Frequency	percent	Frequency	Percent		
Yes	37	68.5	35	35.7	15.03	< 0.001**
No	17	31.5	63	64.3		
Total	54	100	98	100		

** shows significant variation at 5% significance level Source: Field survey, 2020

Water is a key input for biogas technology operations. It serves to be mixed with feed stocks like cow dung before it is fed into a biogas plant. In the study site, about 68.5% and 35.7% of adopter and non-adopter respondents reported that they have sufficient water for biogas technology operations. According to key informants the main sources of water in the area are river water (used for irrigation purpose), water tap and water well. In contrast, 31.5% and 64.3% of adopter and non-adopter respondents didn't have sufficient water nearby their home for biogas production.

Table 16. Respondents' proportion by their feedstock type used.

Feedstock type	Frequency	Percent
Cow dung	8	14.81
Latrine (Defecates)	0	0
Household wastes	0	0
Cow dung and latrine	46	85.19
Total	54	100

Source: Field survey, 2020

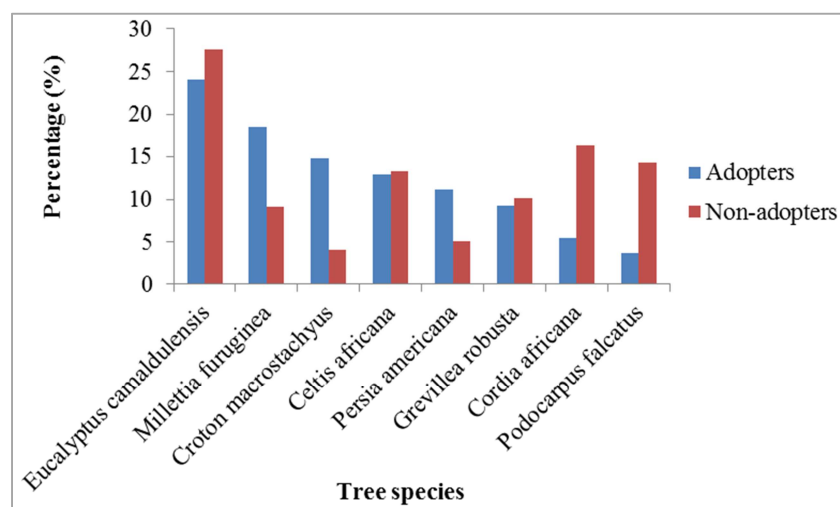
This study revealed that about 85.19% of respondents in

the study area have used both cow dung and latrine (Table 15). The proportions of respondents who have used only cow dung was 14.81%, where as latrine and household wastes were 0%. Interviews with respondents' and focus group discussants have confirmed that using latrine together with animal dung is vital to maximize the energy produced from biogas technology as compared to using only animal dung.

3.2. The Most Commonly Used Tree Species for Domestic Energy Use

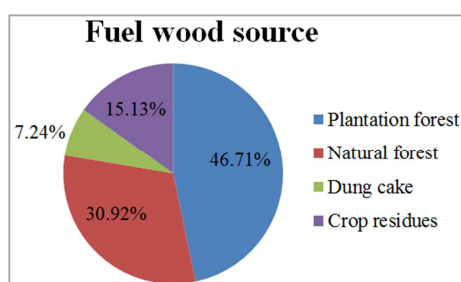
As indicated in Figure 3 *Eucalyptus camaldulensis* was the most commonly used tree species by both adopter and non-adopters of biogas technology. As key informants since monospecific stand is not common in the area the main reason for using *Eucalyptus camaldulensis* was its less allelopathic effects as compared to other *Eucalyptus* species

like *Eucalyptus globulus*. They also added that easily adaptive nature of the species on agro-ecology of the area is another most important factor. Next to *Eucalyptus camaldulensis*, *Cordia africana* and *Podocarpus falcatus* were among highly consumed tree species by non-adopters of biogas technology in the study area respectively. On the other hand, *Millettia furuginea* and *Croton macrostachyus* were the most commonly used tree species by adopters of the technology following *Eucalyptus camaldulensis*. According to IBC report, *Cordia africana* and *Podocarpus falcatus* are under the list of priority given and threatened tree species in Ethiopia. Due to this, the government has given due attention to these species to protect them from any destruction. However, the above result revealed that non-adopters of biogas technology have largely contributed to the loss of those species.



Source: Field survey, 2020

Figure 3. Most commonly used tree species for domestic energy use.



Source: Field survey, 2020

Figure 2. Distribution of respondents by their fuel wood source.

In the study area, from the total of 152 respondents about 71 (46.71%) of them confirmed that their major fuel wood source was plantation forest. The second major fuel wood source was found to be natural forest. In addition to these, the result obtained from this study revealed that 47 (30.92%) of the households used natural forests as their fuel wood source for their domestic energy consumption. Crop residues and dung cake were also found to be the least fuel wood energy source which were used by 23 (15.13%) and 11 (7.24%) of households respectively in the study area.

Table 17. Respondents' perception on the status of fuel wood sources.

Status of fuel wood sources	Non-adopters		Adopters	
	Frequency	Percent	Frequency	Percent
Decreasing	83	84.7	46	85.19
Increasing	11	11.22	5	9.26
No change	4	4.08	3	5.56

Source: Field survey, 2020

Most of adopter and non-adopter respondents (about 85.19% and 84.7% respectively) perceived that fuel wood sources have been *becoming* decreasing for the last years. For most of the respondents' the reasons on decrement of fuel wood sources were related to an increasing number of population and land use change in the study site. In addition to this key informants also added that the main reason for decrement of fuel wood source is the great emphasis given to

natural forests by the government to make them protected from over-exploitation. On the other hand, a small amount of adopter and non-adopter households (about 9.26% and 11.22% respectively) perceived that fuel wood sources have been increasing over the past years. The proportions of respondents who have perceived no change on fuel wood sources were also accounted 5.56% and 4.08% for adopters and non-adopters of the technology respectively (Table 17).

Table 18. Mean (\pm SD) of annual income, household size and Standard adult equivalents.

Variables	Adopters (n=25)	Non-adopters (n=25)	p-value
	Mean \pm SD	Mean \pm SD	
Annual income (birr)	35600 \pm 16103.83	34800 \pm 14767.64	0.86**
Family size	6.56 \pm 2.02	7.08 \pm 2.04	0.37**
Standard adult Equivalent	4.92 \pm 1.5	5.04 \pm 1.53	0.8**

NB: ** shows statistically not significant at 5% level of significance

In the study area, the average annual incomes of adopter and non-adopter sample households were 35600 and 34800 Ethiopian birr respectively. The average family size was also 6.56 and 7.08 persons for adopters and non-adopter households respectively. In addition to this, standard adult equivalents of adopter and non-adopter sample households were found to be 4.92 and 5.04 respectively. The independent

sample t-test result shows that there is no a statistical significant difference between the two adoption categories at 5% significance level (Table 18). This may be related to the fact that both adopter and non-adopter sample households were drawn from the same area having almost similar socio-economic characteristics.

Table 19. Household's daily and per capita fuel wood consumption (kg) of both adoption categories (n = 25).

variables	N	Ave. AME served (per HH/day)	Ave. fuel wood used (Kg/HH/day)	Per capita fuel wood used (kg/AME/day)
Non-adopters	25	5.14 \pm 1.49	8.34 \pm 2.20	1.74
Adopters	25	5.09 \pm 1.48	4.95 \pm 1.67	0.99
t-value			6.11	5.96
P-value			< 0.001**	< 0.001**

NB: ** indicate significant variation at 5% significance level Source: KPT survey, 2020

The average daily fuel wood consumption per household was found to be 4.95 kg and 8.34 kg for adopter and non-adopter tested subjects respectively. Biogas technology adopters have used fuel wood only for Injera and bread baking. Besides, the average adult mean equivalents served from cooked meal within 24 hours were 5.09 and 5.14 for adopter and non-adopter tested subjects respectively. Accordingly, the average per capita fuel wood consumption for adopter and non-adopter households was found 0.99 and 1.74 respectively. The results obtained from independent sample t-test revealed that there is a significant difference on average daily fuel wood consumption and per capita fuel wood consumption between adopters and non-adopters of biogas technology in the study site (Table 19). In addition to this, it shows 43.1% fuel wood saving potential of biogas technology as compared to traditional three-stone fire.

After per capita fuel wood consumption of households computed, it was extrapolated to yearly basis. Accordingly, per capita fuel wood consumption for non-adopter and adopter households were 635.1 kg and 361.35 kg respectively. Hence, annual fuel wood savings from adopting biogas technology per household per year was found to be 1423.06 kg. The result of this study is in line with a study conducted

by Salome [33] which confirmed that average monthly firewood consumption for adopter and non-adopter households were 187.5 kgs and 228.5 kgs respectively and approximately 1519.2 kgs of fuelwood was saved annually by those households using biogas which implies its role in conservation of forest cover.

3.3. The Role of Biogas Digester in Forest Conservation

The average annual Fuelwood savings from adopting biogas per household was 1423.06 kg. Hence, 76845.24 kg of fuel wood can be saved from 54 sampled households. In Gimbi district, there are a total of 145 functional and 21 non-functional biogas plants so that all functional biogas digesters can have a potential to save 206343.7 kg fuel wood per year. As it is shown on figure 3, the wood of Eucalyptus tree species, particularly *Eucalyptus camaldulensis*, was the most commonly used tree species for fuelwood purpose by sampled households. The total dry biomass of the tree for this study was 149.6 kg. Therefore, 206343.7 kg of woody biomass replaced by biogas energy was equivalent to 1379.3 trees. This result is also supported by Zebider [34] who reported that 859 biogas digesters have saved 25018.14 trees in Debre zeit town. The report by

Oromiya Forest and Wildlife Enterprise Finfine Firewood Project Office showed that one hectare of planted forest has 2500 trees seedlings. Out of this, 70 percent (1750 seedlings) will become mature trees. Therefore, the current number of biogas plants can conserve 0.79 hectare of forest annually. The result of this study indicated that biogas technology has the potential to remarkably conserving forests. After the forest resources are conserved, water resources will be available, clean air to breathe will be safe and income can be generated by selling the forest products. It may also help to increase the adaptive capacity of local people and help in climate change mitigation. Therefore switching to biogas is often assumed to automatically result in reduced deforestation (reduce the pressure on deforestation). If the dissemination of biogas technology increased in Gimbi district more conservation of forest area achieved.

3.4. Role of Biogas Technology in Carbon Emission Reduction

The quantitative fuel consumption survey result of this study showed that each biogas technology digester results in an average Fuelwood savings of 1423.06 kg (1.42 t) per year

as compared to traditional three-stone fire. The carbon dioxide emission reduction potential of biogas was estimated by using emission factor of fuel wood 15 MJ/Kg, net calorific value of fuel wood (wet basis) 81.6 t CO₂/TJ and fraction of non-renewable fuel wood 88% and hence about 1.53 t CO₂ e was reduced per biogas digester/year.

$$\begin{aligned} \text{ERY} &= B_{y, \text{ savings}} \times f_{\text{NRB}, y} \times \text{NCV}_{\text{biomass}} \times \text{EF}_{\text{projected-fossil fuel}} \\ &= 1.42 \text{ t} \times 0.88 \times 0.015 \text{ TJ/t} \times 81.6 \text{ t CO}_2/\text{TJ} \quad (9) \\ &= 1.53 \text{ t CO}_2 \text{ e per biogas digester/year} \end{aligned}$$

From 145 functional biogas digesters in the study area, a total of 221.85 tons of CO₂ e emission savings can be achieved. The above amount of CO₂ e was converted to carbon using a conversion factor of 3.667 (ratio of molecular weights of CO₂ and C). Accordingly, 60.50 tons of carbon was saved annually. If adopters were using biogas energy for baking Bread and 'Injera', the carbon emission savings would be more. The result of this study is smaller than findings of the study conducted by Winrock and Eco-Securities [35] which confirmed that carbon reduction per digester is 4.6 tons of carbon dioxide equivalents.

Table 20. Respondents' attitude towards biogas technology.

Attitude	Adopters		Non-adopters		χ^2	p-value
	Frequency	percent	Frequency	Percent		
Positive	37	68.5	61	62.2	0.598	0.277
Negative	17	31.5	37	37.8		
Total	54	100		100		

Source: Field survey, 2020

Most of adopter and non-adopter respondents (68.5% and 62.2%) have positive attitude towards biogas technology respectively. This is due to the fact that most adopter and non-adopter households believed that biogas technology plays a great role in solving fuel wood scarcity, reducing health problems which have been caused by the smoke of fuel wood burning. On the other hand, the proportions of adopter and non-adopter respondents who have negative attitude towards biogas technology were 31.5% and 37.8% respectively.

3.5. Respondents' Attitude Towards the Role of Biogas Technology

Attitude is a crucial element in implementation of the technology and it can be a powerful activator or a barrier towards adoption of a technology [36]. In this study,

respondents were asked some selected questions to assess their attitude towards biogas technology (Table 20). The above results show the scores of agreement and disagreement with the statements for both adopters and non-adopters of biogas technology. Most of adopter and non-adopter respondents have positive attitude towards the technology even though adopters' agreement score was a bit higher. This implies that adopters of the technology have a better access to get information about the advantages of biogas technology and they have positively influenced. About 94.44% and 82.6% of adopter and non-adopter respondents have agreed with the statement biogas technology reduces deforestation rate. On the other hand, the disagreement scores for both biogas adopter and non-adopter households was 0%. Overmore, the disagreement score was also 0% for the statements 2 and 4 (Table 20).

Table 21. Respondents' attitude towards the role of biogas technology.

Statements	Agree		Disagree		Neutral	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
	Percent	Percent	Percent	Percent	Percent	Percent
1. It provides cheaper energy	75.92	56.12	14.81	28.57	9.26	15.3
2. It solves fuel wood problem	100	86.73	0	0	0	13.27
3. It reduces deforestation rate	94.44	82.65	0	0	5.56	17.35
4. It improves health	77.78	69.39	0	0	22.22	30.61

Statements	Agree		Disagree		Neutral	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
	Percent	Percent	Percent	Percent	Percent	Percent
5. It serves as waste treatment system	70.37	56.12	7.4	32.65	22.22	11.22
6. It decreases workload	59.26	62.24	33.33	34.7	7.41	3.06
7. It is alternative energy for domestic use	100	95.9	0	0	0	4.1

Source: Field survey, 2020

The findings of this study further show that the proportion of respondents who perceived that biogas technology is alternative energy for domestic use was 100% and 95.9% by adopter and non-adopter households respectively. As it is clearly indicated table 21 above relatively a higher proportion of non-adopters of the technology couldn't be able to tell whether they agree or disagree with the above seven statements. This could be attributed due to the fact that the

level of awareness about the advantages of the technology by non-adopters is still low and hence it needs to be improved. In addition to this, non-adopters of the technology may not be sure to judge whether biogas technology have the advantages shown in the above table or not. The possible reasons for attitude of biogas technology adopters to be neutral for the above statements could be not stopping to use fuel wood energy sources after they have already adopted the technology.

3.6. Econometric Model Result

Table 22. Probit Regression Model Result.

Adoption	Coef.	Std. Err.	Z	P>z	dy/dx
Age	0.00040	0.02017	0.02	0.984	0.00132
Education	0.01213	0.32569	0.04	0.97	0.00397
Sex	-0.27175	0.45425	-0.6	0.55	-0.99314
TLU	0.32227	0.07222	4.46	0.000*	0.10558
Family size	0.11026	0.08668	1.27	0.203	0.03612
Fuelwood distance	0.51363	0.18039	2.85	0.004*	0.16827
Income	0.00000	0.00001	1.16	0.246	0.00000
Biogas awareness	0.63159	0.33124	1.91	0.057**	0.19687
Attitude	0.19679	0.31940	0.62	0.538	0.06324
Technical availability	0.79818	0.32685	2.44	0.015*	0.24396
Water availability	0.96408	0.31500	3.06	0.002*	0.31303
Constant	-5.28636	1.10556	-4.78	0.00	

* and ** show significant at 5% and 10% level respectively.

$y = \text{Pr}(\text{adoption}) = 0.27$; Number of observations = 152; Pseudo $R^2 = 0.54$; -Log likelihood = 45.92; LRchi²(11) = 105.96; Prob>chi² = 0

The result obtained from probit regression model revealed that livestock ownership (TLU) has a significant positive effect on adoption of biogas technology at 5% level of significance. The coefficient value for the variable was 0.32227. This result revealed that households who have a greater number of livestock are more likely to adopt biogas technology unlike those households owned with small number of livestock. The marginal effect value the variable was 0.10558 (Table 22). This result confirms that as livestock ownership increased by one tropical livestock unit (TLU), the probability of biogas technology adoption by households will increase by 10% (Table 22).

The distance from the residence of the household to fuel wood source has a positive and significant effect on the decision of households to adopt biogas technology at a significance level of 5%. This result is supported by the findings of Beyene [37] which reported that distance to the forest was found to have a significant positive association with the probability of purchasing fuel wood. The coefficient value was 0.51363. This result indicated that households whose residence is far from the fuel wood source are more likely to adopt biogas technology. This may be due to the fact that as the distance from the residence of the household to the fuel wood source increases, the time and energy needed to collect

the fuel wood also increase at the same time. As per the study conducted by Guta [38] the opportunity cost of gathering fuel wood increases with the increasing distance of its source away from home. Besides, the high cost they incur to buy fuel wood may also enforce them to adopt biogas technology. The marginal effect value was 0.16827. As the distance from the residence of the household head to fuel wood source increased by one kilometer, the probability of biogas technology adoption will be increased by 16.8%.

It is also clearly indicated in Table 22 that household's awareness about biogas technology has positive and significant effect on adoption of biogas technology at significance level of 10%. The coefficient for the variable was 0.63159. This result showed that households who had a better access to information sources are more likely to adopt biogas technology. This may be due to the fact that promotions on different public media would enable them to have a better understanding about the socioeconomic role of biogas technology. The marginal effect value was 0.19687 (Table 21). This result confirms that as household's access to information about biogas technology increased by one, the probability of biogas technology adoption will be increased by about 19.7%. This shows that household's access to information about the role of biogas technology from

extension services, neighbors and mass media promotions is vital for adoption of the technology. Technical availability was found among the variables which affects adoption of biogas technology positively and significantly at 5% confidence level (Table 22). The coefficient for the variable in the model was 0.79818. This value indicates that those individuals who had a better access to technical supports are more likely to adopt biogas technology. As it is shown in Table 21, the marginal effect value was 0.24396. This implies that as household's access to technical support services increased by one, the probability of adoption of biogas technology will be increased by about 24.4%.

Water availability (WATERAV): was also found among factors which have influenced adoption of biogas technology positively and significantly at 5% confidence level (Table 22). The coefficient for the variable in the model was 0.96408. This implies that households with a better access to sufficient water supply for biogas production are more likely to adopt the technology unlike those households with insufficient water supply. In addition to this, the marginal effect value was 0.31303. This value indicates that when household's access to sufficient water increased by one, the probability of biogas technology adoption will be increased by about 31.3%. In general, the report by focus group discussants confirmed that there is no a serious problem of water supply in the study area even though some households have owned water well and some others not. They also added that the area is endowed with river water which have been used for irrigation year round can be also dually used for biogas production.

4. Conclusion and Recommendations

In Gimbi district, the average wood fuel usage for non adopter household was 635.1 kg per year while for biogas adopter household was 361.35kg per year. Non adopter household used higher amounts of wood fuel per year than adopter biogas households. the average annual fuel wood saving from adopting biogas reduced 1423.06 kg (43.1%) per household. From the all 145 functional biogas digester 206343.7 kg of fuel wood per year can be saved which replaced 1379.3 mature trees (0.79 ha) per year from being destroyed with 60.5 tones of carbon emission reduced annually. This study also revealed that the most commonly used tree species as a source of domestic energy by biogas technology adopter and non adopter households was *Eucalyptus camaldulensis*. This study also found that adoption of biogas technology largely contributes to conserve tree species which has been considered to be threatened in Ethiopia. In the study area adoption of biogas technology plays a considerable role in saving fuel wood consumption and forest resources at large which results in reduction of carbon emission. Livestock holding (TLU), fuel wood distance, biogas awareness, technical availability and water availability were found the most important factors that affect adoption of biogas technology significantly in the study area. 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 program coordination office. Other stakeholder like the ministry of women, youth, and children's affairs should jointly work on its promotion. 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. Given that the adoption process begins with complex interactions between users and social-economic factors, it is necessary to understand these interactions from areas where it has been successfully adopted, and to create similar environments in areas where adoption is low. An Exchange visit for non adopter farmers to adopter farmer plants is recommended.

The government should try to address baking stoves timely for those households who have already adopted biogas technology. This situation, with no doubt, would have its part to reduce the pressure on deforestation and forest degradation. Since Gimbi area has a huge potential of water resources, awareness raising trainings should be given to rural households who owned enough amount of livestock. This situation will make them beneficiary from biogas technology. Promotion work through extension services, television and radio should be strengthened to maximize rural households' level of awareness especially whose access to information is relatively low about biogas technology. Further research works should focus on investigating the amount of methane emission reduced by using biogas technology.

Data Availability

All data supported the findings are included in the manuscript in tables and figures.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Weiland, P., 2010. Biogas production: current state and perspectives. *Applied microbiology and biotechnology*, 85(4), pp. 849-860.
- [2] Shakya, S. R., 2005. Application of renewable energy technology for greenhouse gas emission reduction in Nepalese context: A case study. *Nepalese Journal of Engineering*, 1(1), pp. 92-101.
- [3] IPCC 2001: Climate Change 2001. The scientific basis, In: J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell and C. A. Johnson (eds), *Contributions of working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

- [4] Bajgain, S. and Shakya, I. S., 2005. A successful model of public private partnership for rural household energy supply. Kigali, Rwanda: SNV.
- [5] (Green, C. E. S. C. R., 2011. Economy. *Federal Democratic Republic of Ethiopia*.
- [6] Ken K, Don A, Batmale JP, John B, Brad R, Dara S (2005). Biomethane from dairy waste: A sourcebook for the production and use of renewable natural gas in California. Prepared for Western United Dairymen. Funded in part through USDA Rural Development.
- [7] Lansing, S., Viquez, J., Martínez, H., Botero, R. and Martin, J., 2008. Quantifying electricity generation and waste transformations in a low-cost, plug-flow anaerobic digestion system. *ecological engineering*, 34(4), pp. 332-348.
- [8] Shin, H. C., Park, J. W., Kim, H. S. and Shin, E. S., 2005. Environmental and economic assessment of landfill gas electricity generation in Korea using LEAP model. *Energy policy*, 33(10), pp. 1261-1270.
- [9] Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., Angelsen, A. and Romijn, E., 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*, 7(4), p. 044009. IEA 2003a.
- [10] Gurung, A. and Oh, S. E., 2013. Conversion of traditional biomass into modern bioenergy systems: A review in context to improve the energy situation in Nepal. *Renewable Energy*, 50, pp. 206-213.
- [11] Skutsch, M., Torres, A. B., Mwampamba, T. H., Ghilardi, A. and Herold, M., 2011. Dealing with locally-driven degradation: A quick start option under REDD+. *Carbon balance and management*, 6(16), pp. 1-7.
- [12] Johnson, M. A., Pilco, V., Torres, R., Joshi, S., Shrestha, R. M., Yagnaraman, M., Lam, N. L., Doroski, B., Mitchell, J., Canuz, E. and Pennise, D., 2013. Impacts on household fuel consumption from biomass stove programs in India, Nepal, and Peru. *Energy for Sustainable Development*, 17(5), pp. 403-411.
- [13] Miles, L. and Dickson, B., 2010. REDD-plus and biodiversity: opportunities and challenges.
- [14] Brown, V. J., 2006. Biogas: a bright idea for Africa. *Environmental health perspectives*, 114(5), p. A300.
- [15] Bruce, N., Perez-Padilla, R. and Albalak, R., 2000. Indoor air pollution in developing countries: a major environmental and public health challenge. *Bulletin of the World Health organization*, 78(9), pp. 1078-1092.
- [16] Hilawe Semunegus, N. O. A. A., 2010, September. Moving towards an intercalibrated and homogenized SSM/I period of record. In *17th Conference on Satellite Meteorology and Oceanography*.
- [17] YAMANE, T., 1967, *Elementary Sampling Theory*, New Jersey: Prentice-Hall, Inc.
- [18] Israel, G. D., 2012. Determining Sample Size, Agricultural Education and Communication Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
- [19] Gill, P. and Chadwick, B. (2008) Analysing and presenting qualitative data. *British Dental Journal*, 204, 429-432. doi: 10.1038/sj.bdj.2008.292.
- [20] Kothari, S. K., Marschner, H. and George, E., 1990. Effect of VA mycorrhizal fungi and rhizosphere microorganisms on root and shoot morphology, growth and water relations in maize. *New Phytologist*, 116(2), pp. 303-311.
- [21] Adam, H., and Amber, T., 2007. Guidelines for performance tests of energy saving devices, *Kitchen Performance tests (KPTs)*.
- [22] Bailis R et al 2007 The Water Boiling Test (WBT) Version 3.0. p1–38.
- [23] Bailis R and Edwards R 2007 Kitchen Performance Test (KPT) p1–32.
- [24] Joseph, S., 1990. Guidelines for planning, monitoring and evaluating cookstove programmes. *Guidelines for planning, monitoring and evaluating cookstove programmes*.
- [25] Bekele, W., 2003. Economics of soil and water conservation (Vol. 411).
- [26] Gujarati, D. N. 2004. *Basic Econometrics* (4th edition) New work, NY: The McGraw Hill companies.
- [27] Fantu, W., 2005. Aboveground biomass allometric equations and fuelwood properties of six species grown in Ethiopia (Doctoral dissertation, University Putra Malaysia).
- [28] Scott, D., Scott, J., and Becky. E. (2005). *Heating With Wood: Producing, Harvesting and Processing Firewood*. University of Nebraska, Lincoln Extension, Institute of Agriculture and Natural Resource.
- [29] Oballa, P. O., Konuche, P. K., Muchiri, M. N. and Kigomo, B. N., 2010. Facts on growing and use of Eucalyptus in Kenya.
- [30] UNFCCC Summary Report. First Structured Expert Dialogue. 2013. http://unfccc.int/science/workshops_meetings/items/8477.php. Accessed 20 Jan 2015.
- [31] Storck, H. and Doppler, W., 1991. Farming systems and farm management practices of smallholders in the Hararghe Highlands. *Wissenschaftsverlag Vauk Kiel*.
- [32] Warkaw, L., 2011. Survey on Household Energy Consumption Patterns: the Case of Enderta Woreda, Tigray Regional State (Doctoral dissertation, Mekelle University).
- [33] Salome, J. P., Amutha, R., Jagannathan, P., Josiah, J. J. M., Berchmans, S. and Yegnaraman, V., 2009. Electrochemical assay of the nitrate and nitrite reductase activities of *Rhizobium japonicum*. *Biosensors and Bioelectronics*, 24(12), pp. 3487-3491.
- [34] Zebider, A., 2011. The contribution of biogas production from cattle manure at household level for forest conservation and soil fertility improvement. *Unpublished M. Sc. thesis, Addis Ababa University*.
- [35] ERICK, M. K., 2018. ADOPTION OF BIOGAS TECHNOLOGY AND ITS CONTRIBUTION TO LIVELIHOODS AND FOREST CONSERVATION IN ABOGETA DIVISION, MERU COUNTY, KENYA (Doctoral dissertation, Kenyatta University).
- [36] Abukhzam, M. and Lee, A., 2010. Workforce attitude on technology adoption and diffusion. *The Built & Human Environment Review*, 3(1), pp. 60-71.

- [37] Beyene, A. D., 2010. Property Rights and Choice of Fuel Wood Sources in Rural Ethiopia. economic factors on household bio based energy use and energy substitution in rural Ethiopia. *Energy policy*, 76, 217-22.
- [38] Guta, D. D. (2014). Effect of fuelwood scarcity and socio-