Biogas technology adoption and its potential of replacing biomass fuels, kerosene, and chemical fertilizer in rural Gonder, Northern Ethiopia

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ABSTRACT

The depletion of bioenergy sources has caused significant deforestation, low agricultural production, and energy crisis. This study evaluates factors associated with biogas technology adoption and the amount of biomass fuels, kerosene, and chemical fertilizer that can be replaced or saved upon adoption by rural households. Questionnaire household survey, key informant interview, focus group discussion and field observation were used for data collection. Biogas technology adoption reduced the use of firewood, charcoal, dung cake, and kerosene consumption by 58%, 36%, 71%, and 74%, respectively. It also reduced the use of chemical fertilizer by 94% and the combined use of chemical fertilizer and manure by 91%. Adoption turned the majority of households (65.4%) to use a combination of bio-slurry and chemical fertilizer as well. It helped the majority (89.95%) of adopters to construct and connect toilets to biogas operational system. In doing so, the adoption reduced defecation in the field and improved environmental sanitation and human health. It further enabled saving of about 38% of adopters’ time, which otherwise would be expended for firewood and dung collection. It similarly enhanced adopters’ income through decreasing expenses for chemical fertilizer, kerosene, and other fuel sources. Biogas technology has huge potential of replacing traditional fuel sources for domestic consumption, and of reducing the consumption of kerosene and chemical fertilizers as well as of increasing income and decreasing labor for biofuel collection. The adoption of biogas technology could also reduce deforestation rate, improve agricultural production and improve energy supply of rural households.

Background

Biogas is combustible mixture of gas. It consists mainly of methane and carbon dioxide and is made from decomposition of organic compounds by anaerobic bacteria. It is a methane rich fuel gas produced by anaerobic digestion of organic materials with the help of methanogenic bacteria. Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy needs (Molina et al., 2007). It provides an alternative energy source for the use of traditional fuel sources, which is dominantly used in most developing countries. Biogas technology serves two major purposes, biogas and bio-slurry. Biogas energy could replace the use of firewood, charcoal and kerosene for cooking, heating and lighting while bio-slurry could replace the use of chemical fertilizer for agricultural production (Sime et al., 2020).

Ethiopia is one of the developing countries that extremely relies on biomass for cooking and lighting (Sime et al., 2020). The predominant cooking biomass energy source is firewood (77%), followed by cow dung cake (13%), crop residues (9%), and charcoal (1%). Kerosene (56%) is the central energy source for lighting, followed by a rechargeable electric battery (14%) in rural Ethiopia. Over 92% of the domestic energy demands are met from biomass-based fuels. Unsustainable cutting down of trees for firewood has directly caused significant deforestation, land degradation and soil erosion. The use of crop residues and dung cakes as substitute of firewood has further intensified problems related to land degradation and agricultural underproduction (Sime et al., 2020).

Most of the previous studies conducted so far in Ethiopia are associated either with factors hindering or fostering the adoption of biogas technology (Abadi et al., 2017; Berhe et al., 2017; Kamp & Bermúdez Forn, 2016; Shallo et al., 2020; Shallo & Sime, 2019). In addition, other previous studies were dealt with prospects of domestic biogas technology (Desalegn, 2014) and contribution of biogas technology adoption to rural livelihood and
environment health improvement (Amare, 2015; Mengistu et al., 2016). None of these studies have offered detailed attention to the evaluation of the technical potential of biogas technology in replacing biomass fuels (firewood, charcoal, cow dung), kerosene and chemical fertilizer. Since 2015, the national biogas domestication program has been implemented in the present study area, Misrak and Mirab Este Districts in South Gonder zone in Northern Ethiopia. Although rural households in the study area have been adopted the technology, studies addressing the questions that the present study is attempting to answer are lacking. Therefore, the objective of this study is to evaluate the amount of biomass fuels, kerosene and chemical fertilizer that can be replaced or saved through adopting biogas technology in Northern Ethiopia. The specific research questions were: what is the amount of 1) firewood, charcoal and cow dung 2) kerosene, and 3) chemical fertilizers that can be replaced by a household upon adopting biogas technology? It also evaluated the association between biogas technology adoption and toilet construction, human and environmental health, and income generation.

The findings from this study are hypothesized to help the community realizing the multiple benefits of adopting biogas technology, including saving forests from cutting and crop residues for fuel consumption as well as lowering the expenses for buying kerosene and chemical fertilizers, among others. The government of Ethiopia, particularly policy-makers, also benefits from the findings of consolidating and promoting the undergoing National Biogas Program, Climate-resilient Green Economy Policy and Green Legacy Program. Above all, the findings from this study would directly contribute towards the government’s efforts of disseminating biogas technology to benefiting rural communities lacking access to the grid electric power supply and entirely depending on biomass fuels. Most such households reside in remote areas.

**Materials and methods**

**Description of the study area**

**Location**

The study areas, Misrak and Mirab Este Districts, are located in South Gonder zone, Amhara Regional State, Northern Ethiopia (Figure Figure 1). Misrak Este District is located at 7°40’ N latitude and 36°50’E longitude and at 96 kilometer from Bahir Dar, the capital city of Amhara Regional State and at 46 kilometer from Debre Tabor, the capital city of South Gonder zone. The District has 43 Kebele (5 urban and 38 rural villages), and is bordered by the Abay River in the South, by Dera district in the West, by Farta in the North and by Simada in the East. Mirab Este lies within 11°10’ to 11° 30’ North latitude and 37°45’ to 38° to 00’E longitudes. It is located at 148 kilometers from Bahir Dar, the capital city of Amhara Regional State.

![Figure 1. Physical map of study area.](image-url)
and at 91 kilometers from Debre Tabor, the capital city of South Gondar zone. This District has 24 Kebele (2 urban and 22 rural villages), and is bordered by Misrak Este in Northeast and by Abay River in the South and by Dera in the West.

**The topography**

The topography of Misrak and Mirab Este Districts comprises 41% plain, 47% plateau and 12% deep gorge and other features according to District Agriculture Office. It has wide variation in altitude, ranging from less than 1500 to more than 2300 meters above sea level.

**Agro-climatic conditions**

The Districts have three agro-ecological zones. They include Dega\(^2\) with an altitude of more than 2300 meter above sea level, Woina-dega\(^3\) with an altitude of 1500–2300 meters above sea level and Kolla\(^4\) with an altitude of less than 1500 meters above sea level. Dega, Woina-dega and Kolla cover about 3%, 91% and 6%, respectively. The maximum and minimum annual temperature is 25 °C and 8.3 °C, respectively.

**Demographic and socio-economic characteristics of the Districts**

The Central Statistical Agency (CSA) of Ethiopia indicated that Misrak Este has an estimated total population of 403,956, of whom 199,325 are men and 204,631 are women. With an estimated area of 2,368.13 m\(^2\), the District has an estimated population density of 170.6 people per m\(^2\). Teff, maize, barley, potato, bean and wheat are the major crops grown. The main livestock type are cattle, sheep, goat, poultry, mule and donkey (Central Statistics Agency (CSA)).

The total population size in the Mirab Este District is 137,767, out of which 70,077 are male and 67,690 are female. The District’s total size of land area is 98,216 hectares with population density of 173.3 people per m\(^2\). The main crops grown are teff, maize, barley, potato and bean. Livestock rearing is part of mixed of livestock—crop production system as the basis of the main source of livelihood. The main livestock types are cattle, sheep, goat, poultry, mule and donkey (Central Statistics Agency (CSA)). At the time of data collection, the total livestock holding size in Misrak and Mirab Este was 252,820 and 342,091, respectively (Table 1).

**Theoretical framework**

Energy is essential for economic and social development of a nation (Rambo, 2013). The energy policy of

| Livestock holding size | Misrak Este District | Mirab Este District |
|------------------------|----------------------|---------------------|
| Cattle                 | 78,964               | 89,608              |
| Sheep                  | 58,529               | 125,241             |
| Goat                   | 33,348               | 25,107              |
| Donkey                 | 8,111                | 8,835               |
| Mule                   | 4,539                | 974                 |
| Horse                  | 7,958                | 886                 |
| Poultry                | 61,371               | 73,440              |
| Total                  | 252,820              | 324,091             |

*Figure 2. Conceptual framework showing the technical potential of biogas energy systems, adapted from Wamuyu (2009).*
Ethiopia promotes the use of renewable energy. The domestication of biogas technology as a national program has started since 2009. Since then the program has been implemented in two rounds (2009–2013 and 2014–2017) and is currently at a stage of scaling up to all potential regions (Sime et al., 2020). The two main pillars of the biogas technology dissemination program in Ethiopia are ensuring sustainable energy and food security of rural communities who do not have access to electricity. The biogas technology supplies rural communities with clean and smokeless domestic energy as well as bio-slurry as organic fertilizer. The major socio-economic variables influencing the adoption of biogas technology among others include amount and availability of cow dung and toilet wastes as feedstock, distance to water sources for preparation of feedstock and size of labor. The biogas plants are constructed through subsidies by both government and non-government organizations. In addition to the energy and organic fertilizer supply, the biogas technology delivers multiple services to rural communities like saving time for cooking, avoiding indoor air pollution with direct health benefits, and reducing the dependence on forest for firewood and charcoal for cooking, and kerosene for lighting. The bio-slurry is a high quality organic fertilizer used for increasing agricultural production and ensuring food security (Figures 2 and 3). In this study, the term technical potential therefore refers to the potential of biogas technology of replacing traditional fuel sources for domestic consumption such as firewood, charcoal, cow dung, crop residues, of reducing the consumption of kerosene for lighting and chemical fertilizers for agricultural production, of increasing income and of decreasing time for biofuel collection from fields or forests. Despite all the available opportunities, there are also factors hindering the rate of adoption of the technology. The rate of adoption may depend on the family size, income, livestock size, the price of chemical fertilizer, distance to firewood sources, distance to water sources, maintenance services, training for awareness creation, availability of spare parts, and socio-cultural and institutional factors. These factors play key roles in determining whether the technology is to be adopted or not by a particular household. Farmers’ characteristics such as age, gender, education and experience influence the attitudes, knowledge, and value orientation, and determine their reasoning in acceptance of the technology. These characteristics of households contribute to the adoption decision of a technology. This study also looks at the inter-links among the fostering and limitations hindering the adoption of biogas technology. The adoption of biogas technology reduces the dependence on firewood, charcoal, kerosene and chemical fertilizers. At the same time, it also reduces the pressure on forest management.

**Approaches to data collection, sample size determination and sampling techniques**

The study districts were selected with a purposive sampling technique. This is because the National Biogas Program had been implemented only in these districts among other districts. On top of that there were only 74 households in the two districts adopting biogas.

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**Figure 3.** Biogas technology energy operating system, sourced from [https://www.bing.com/images/search](https://www.bing.com/images/search)
technology at the time of data collection. Thus, all the 74 biogas user households in 16 biogas user villages in both Districts were purposively considered (Table 2). Official list of the 16 biogas user villages and the 74 user household heads was provided by the respective Biogas Coordinators of Misrak and Mirab Este Districts. The most commonly domesticated and adopted biogas plant size was 6 m³. Biogas plant was installed by the government and nongovernmental organizations.

A research design incorporating both qualitative and quantitative research approaches were employed for data collection. The qualitative approach was employed for gathering information through undertaking a key informant interview, focus group discussion and field observation. The quantitative approach used household questionnaire survey for gathering quantitative data.

Primary data were therefore collected using questionnaires, semi-structured interviews, focus group discussion and field observation. All the 74 household heads were interviewed through administering the questionnaire. In addition, a total of seven key informants (five biogas users and two-biogas coordinators) were purposefully selected. Then, the key informants were interviewed upon their consent using interview checklists. Key informants are individuals who are knowledgeable, open-minded, articulate, and cooperative for the research interview purpose (Neergaard & Ulhøi, 2007). Focus group discussion was also held by group of biogas users belonging to different age and sex categories. Three focus group discussions per sample district were held. Each group has six members. The optimum size for a focus group discussion ranges from six to eight members (Bloor, 2001; Ritchie et al., 2013). Responses from both the interviews and discussion were recorded with a tape recorder. User voices were also recorded in videos upon their consent.

Among others, the most important questions addressed through the focus group discussion and key informant interviews were related to existing challenges and opportunities for biogas technology domestication (biogas technology for both energy and fertilizer utilization; feedstock preparation and human labor demand for biogas plant feeding; promotion of the technology and awareness creation of communities; existing energy policies; deforestation and major fuel sources for rural communities; chemical fertilizer application; benefits such as environmental sanitation, toilet construction, human health, etc.).

The field observations were conducted along with other data collection activities. Biogas plant feeding materials, major fuel sources, the market value of household fuel at local markets (charcoal, firewood, and kerosene and dung cake) and the use of chemical fertilizer and bio-slurry were observed.

The qualitative data collected through key informant interviews, focus group discussion and field observations were used for cross-checking the information collected through questionnaire survey.

Data analysis. All the data collected were entered into Microsoft Office and statistical analysis was done using SPSS-20 software. For the analysis of data, descriptive statistics, chi-square, and one sample t-test were used at the 95% confidence interval (at p-value < 0.05; Ioannidis, 2018). Specifically, the data collected through the qualitative were analyzed

### Table 2. Study Districts and Kebeles, and their corresponding number of installed biogas plants

| Kebele plants | Misrak Este District |   |   |   | Kebele plants | Mirab Este District |   |   |   |
|---------------|----------------------|---|---|---|---------------|---------------------|---|---|---|
| Agona Kositet | 4                    |   |   |   | Deriba Betanisa| 5                    |   |   |   |
| Debir Zewana  | 9                    |   |   |   | Gishina       | 4                    |   |   |   |
| Mekane Eyesus | 3                    |   |   |   | Merji Tenikot  | 4                    |   |   |   |
| Goshiberet    | 4                    |   |   |   | MesiBekilo Filega| 4                |   |   |   |
| Licha Anida   | 6                    |   |   |   | Sheme Masha    | 5                    |   |   |   |
| Liwaye Ashama | 7                    |   |   |   | Simet Sholaye  | 3                    |   |   |   |
| Mikrie Kuskum | 4                    |   |   |   | Yedi Digmegen  | 3                    |   |   |   |
| Jibasra Mariam| 5                    |   |   |   | Total number   | 28                   |   |   |   |
| Ziguara       | 4                    |   |   |   |                       |                      |   |   |   |
| Total number  | 46                   |   |   |   |                       |                      |   |   |   |

Note: The number of installed biogas plants is the same as the number of biogas user households

### Table 3. Sex and age of household heads

| Gender | Category | Frequency (N = 74) | Percent | One sample t-test |
|--------|----------|--------------------|---------|-------------------|
| Sex    | Male     | 67                 | 90.5    | P-value = 0.00    |
|        | Female   | 7                  | 9.5     | P-value = 0.00    |
| Age    | Total    | 74                 | 100.0   |                   |
|        | 26–36    | 4                  | 5.4     |                   |
|        | 37–46    | 20                 | 27.0    |                   |
|        | 47–57    | 36                 | 48.6    |                   |
|        | >57      | 14                 | 19      |                   |
|        | Total    | 74                 | 100.0   |                   |

significant at P-value < 0.05 (CI = 95%)

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through the narrative method, categorizing them into themes and subthemes (Chu et al., 2020).

**Results and discussion**

**Sex and age composition of adopters**

Concerning sex (Table 3), out of the 74 adopter households, 90.5% were male and the remaining were female headed. The adoption is dominated by the male headship, which shows that sex is a determinant factor in biogas technology adoption. One sample t-test indicates that sex has a significant positive relationship with the adoption of biogas technology (at \( p < 0.05 \)). Shallo & Sime (2019) reported that the sex of a household head significantly (at \( p < .05 \)) and positively influences biogas technology adoption in southern Ethiopia. In Ethiopia, household energy is primarily the duty of women in Ethiopia, nevertheless, men dominantly control household resources and often make the final decision at household level (EREDPC & SNV, 2008). Male-headed households are more likely to adopt a new technology because they are often more likely to get more information about new technology and take on risk than female-headed households. Thus, the male-headed households adopt biogas technology more than female headed households because of having access to controlling household assets and getting information.

The age category of adopter households was 5.4%, 27.0 %, 48.6% and 18.6 % fell in the range of 26–36, 37–46, 47–57 and greater than 57 years of age, respectively. In this regard, the majority (94.6 %) lies within 47–57 years of age (Table 3), which attributes to higher income generation and asset accumulation. One sample t-test result shows that age has a significant positive relationship with adoption of biogas technology (at \( p < 0.05 \)). Household heads with more capital accumulation and economic status are more likely to adopt biogas technology (Abadi et al., 2017; Mengistu et al., 2016). Hence, age of household heads has a positive influence on the adoption of biogas technology.

**Household size of adopters**

About 16.2 % of the households had a family size between 1–3 members. The majority (83.8 %) of biogas adopters had a family size in the range of 4–6 persons with an average family size of 5 per household. This is higher than the national average household size, which is 4.8 persons per household, for the adoption of biogas technology in Ethiopia (EREDPC & SNV, 2008). There is an adequate labor force for feedstock preparation and operation of biogas plants (Table 4). Large household size may mean having sufficient labor required to manage and operate biogas technology (Mengistu et al., 2016).

**Educational level of adopters**

Table 5 shows 28.4 % of the adopters were illiterate, 43.2 % could read and write, 25.7% had completed primary school and the remaining 2.7% completed secondary school. The majority of the biogas adopters are educated, which shows that educational status is a determinant factor in biogas technology adoption. One sample t-test shows that education level has a significant positive relation to biogas technology adoption (at \( p < 0.05 \)). There is a positive association between educational status of household heads and adoption of biogas technology (Kabir et al., 2013; Mwirigi et al., 2009). Surendra et al. (2014) reported that lack of education is among the most critical factors that limits the dissemination of biogas technology. Kabir et al. (2013) indicated that education plays a very important role in the biogas technology adoption, the more the household head is educated, the more it is likely to adopt biogas technology. Walekhwa et al. (2009) reported that household heads with higher educational level are less conservative, more informed and more knowledgeable.

There is a positive association between selected demographic variable and knowledge of biogas adopters before adoption. All the selected socio-demographic characteristics had a negative association (at \( p > 0.05 \)) with the knowledge of field defecation and its impacts on human and environmental health (Table 6). The awareness on proper management of field defecation and the possibility for producing biogas and bio-slurry from other sources like from domestic and kitchen wastes are lacking.
Table 6. Association between biogas technology adopters’ knowledge and selected demographic variables before adoption

| Knowledge statement                                                                 | Gender \( \chi^2 \) (P-value) | Age \( \chi^2 \) (P-value) | Education \( \chi^2 \) (P-value) |
|--------------------------------------------------------------------------------------|-------------------------------|-----------------------------|---------------------------------|
| Field defecation can pose challenge to human and environmental health if not properly managed | 0.250 (0.682a)              | 4.052 (0.670a)              | 7.167 (0.305a)                  |
| Field defecation may foster disease transmission, if not properly managed            | 2.468 (0.291a)               | 3.657 (0.723a)              | 5.053 (0.537a)                  |
| Possibility for biogas and bio-slurry production from other sources than from cow dung and toilet waste | 1.92 (0.383a)               | 6.183 (0.403a)              | 7.471 (0.280a)                  |

statistically significant at the P-value < 0.05 (CI = 95%)

Table 7. Cattle holding size of biogas user households

| Number of cattle | Frequency | Percent | One sample t-test result |
|------------------|-----------|---------|--------------------------|
| 1–3              | 41        | 55.4    | P-value = 0.00           |
| 4–5              | 24        | 32.4    |                          |
| 6–7              | 4         | 5.4     |                          |
| 7                | 5         | 6.8     |                          |
| Total            | 74        | 100.0   |                          |

Significant at p-value < 0.05

Cattle holding size

About 55.4%, 32%, 5.4%, and 6.8% of the households had cattle holding size ranging from 1–3, 4 – 5, 6–7 and > 7, respectively. The average cattle holding size was three cattle per household, which is less than the minimum standard set by the National Biogas Program of 4 cows for installing biogas plants (Table 7). One sample t-test result showed that livestock size has a significant (at p < 0.05) positive association with the adoption of biogas technology. Field observations of biogas plants also showed that the availability of sufficient cattle dung, which is the primary feedstock for biogas plants, is the most important factor in daily biogas operation. Thus, the quantity of dung available per day is critical in realizing the benefit and viability of biogas technology. Eshete et al. (2006) indicated that rural households in Ethiopia would need at least four cattle stabled during the night to get a minimum of 20 kg of fresh animal dung per plant per day, which is the size required to produce enough biogas energy for cooking or lighting (EREDPC & SNV, 2008). Other findings from previous studies indicated that cattle size has a significant positive association with the adoption of biogas technology (Kabir et al., 2013; Shallo & Sime, 2019; Walekhwa et al., 2009).

In terms of cattle grazing systems, about 31.1% of the households used free grazing on open field, 40.5% controlled grazing (zero grazing practices) and the remaining 28.4% used combined together free grazing on open field and controlled grazing. On the other hand, about 59.5% of the households got sufficient cattle dung while 40.5% lacked it for feeding biogas plants. The latter households had their cattle grazing freely moving on open fields. Furthermore, 40.5% of the households collected dung from various sources while the remaining 59.5% did not. Among those households collecting cow dung, 26.6% collected dung from the field, 43.3% from a stall (locally called Beret) and the remaining 30% of stall and field (Table 8). Field observation also showed that households practicing controlled grazing method have a better potential of adopting biogas technology than those practicing other methods of grazing types. Controlled grazing was observed to ease dung collection, lessen ing labor and time. Mwirigi et al. (2009) reported a significant positive relationship between grazing system and adoption of biogas technology in Kenya.

Traditional biomass energy use pattern

The energy use pattern showed that an extensive number of households use firewood (41.9%), followed by

Table 8. Grazing types and dung collection

| Variable                                                                 | Type of grazing                     | Frequency | Percent |
|-------------------------------------------------------------------------|-------------------------------------|-----------|---------|
| What grazing type do you use for feeding your cattle?                    | Free grazing on open field          | 23        | 31.1    |
|                                                                         | Controlled grazing                   | 30        | 40.5    |
|                                                                         | Free grazing on open field and controlled grazing | 21 | 28.4 |
|                                                                         | Total                               | 74        | 100.0   |
| Do you have sufficient cattle dung for biogas plants?                    | Yes                                 | 44        | 59.5    |
|                                                                         | No                                  | 30        | 40.5    |
|                                                                         | Total                               | 74        | 100.0   |
| Do you collect cattle dung from various sources?                         | Yes                                 | 30        | 40.5    |
|                                                                         | No                                  | 44        | 59.5    |
|                                                                         | Total                               | 74        | 100.0   |
| If Yes, from where do you collect cow dung?                              | Field                               | 8         | 26.6    |
|                                                                         | Stall (Beret)                       | 13        | 43.3    |
|                                                                         | Both field and stall                | 9         | 30.0    |
|                                                                         | Total                               | 30        | 100.0   |
dung cake (29.7%), charcoal (17.6%) and kerosene (10.8%) before biogas technology adoption (Figure 4). Firewood becomes an indispensable source of fuel for cooking, followed by charcoal. This shows that traditional biomass are major sources of domestic energy (89.2%) in the study areas. About 95% of the Ethiopian population rely on traditional biomass fuels for cooking (Sanbata et al., 2014). Gwavuya et al. (2012) reported that firewood holds the greatest share of energy sources for cooking in rural Ethiopia. Besides, kerosene was mainly used for lighting. Kerosene is the major energy source for lighting in rural areas in Ethiopia (Sime et al., 2020).

**Quantity of firewood consumption**

About 70.3% of households consumed 3–5 bundles of firewood, 23% consumed 6–7 bundles of firewood and 6.8% consumed 8–9 bundles of firewood per month. This is, on average, equivalent to the consumption of 57.6 bundles of firewood per year before adoption. After adoption, 81.1% of the households used 1–2 bundles of firewood, 10.8% used 3–4 bundles of firewood and 8.1% used 5–6 bundles of firewood per household per month. This is a reduction of 33.6 bundles of firewood per year. Thus, biogas technology adoption enabled the saving of 33.6 bundles of firewood annually. This is equivalent to saving 3010.56 ETB annually at a local price rate of 89.6 ETB per bundle of firewood (Table 9). In turn, this is equivalent saving 3833.22 ETB annually at local rate of 48.40 ETB per 32 kg per bundle. Amare (2015) reported that biogas technology adoption enabled a reduction of 70.47% of firewood per household per year. A reduction of 45% in firewood consumption was also reported because of partial replacement of traditional fuels with biogas energy (Abadi et al., 2017). Similarly, other previous studies also showed that biogas users tend to consume less firewood than non-users do (Christiaensen & Heltberg, 2014).

**Quantity of dung cake consumption**

Dung cake is regularly used as traditional fuel in traditional stoves in most parts of Ethiopia. Before adoption, the average consumption was 65.4 dung cakes per household per month. However, after adoption, the average consumption was 18.6 dung cakes per household per month. This is a reduction of 46.8 dung cakes per household per month. Thus, the adoption of biogas technology enabled the saving of 561.6 dung cakes per household per year. This is in turn equivalent to saving 1684.8 ETB per year at a local price rate of 3 ETB per
Table 10. Number of dung cake consumption of household per month before and after adoption of biogas technology

| Number of dung cake | Before plant installation | After plant installation |
|---------------------|---------------------------|--------------------------|
|                     | Frequency | Percent | Frequency | Percent |
| 60–65               | 74        | 100.0   | 61        | 82.4    |
| 66–70               | 24        | 32.4    | 21–25     | 10       |
| 71–75               | 8         | 10.8    | 36–30     | 4.1      |
| Total               | 100.0     |         | 100.0     |         |

Average = 65.4

Table 11. Quantity of charcoal consumption (in sacks) per household per month before and after biogas plant installation

| No. of sack | Before adoption | After adoption |
|-------------|-----------------|----------------|
|             | Frequency | Percent | Frequency | Percent |
| 1           | 44        | 59.4    | 0.25      | 70.3    |
| 1.5–2       | 25        | 33.7    | 0.5       | 28.4    |
| 2.25–2.5    | 5         | 6.7     | 1         | 1.4     |
| Total       | 74        |         | 74        | 100.0   |

Average = 1.4

Table 12. Time requirement before and after adoption of biogas technology

| Time requirement                              | Hour per week | Frequency | Percent |
|-----------------------------------------------|---------------|-----------|---------|
| How long does it take you to collect firewood| 8–9           | 43        | 58.1    |
| and cattle dung before biogas plant installation? Hour per week Average time = 12 hours/week | 10–11         | 17        | 23.0    |
|                                              | 12–13         | 14        | 18.9    |
|                                              | Total         | 74        | 100.0   |
|                                              | 3–4           | 48        | 64.9    |
|                                              | 5–6           | 14        | 18.9    |
|                                              | 7–8           | 12        | 16.2    |
|                                              | Total         | 74        | 100.0   |

dung cake (Table 10). Amare (2015) reported that adoption of biogas technology enabled a saving of 600 kg of dung cakes per year, which is equivalent to saving 1,662 ETB per year in Amhara Region in Northern Ethiopia.

**Quantity of charcoal consumption**

Table 11 presents consumption of charcoal (in sacks) before and after adoption of biogas technology. Accordingly, 59.4% of the households consumed 1 sack of charcoal, 33.7% consumed 1.5–2 sacks of charcoal and 6.7% consumed 2.25–2.5 sacks of charcoal per month, with an average consumption of 16.8 sacks of charcoal per year before adoption. After adoption, the majority of households (70.3%) consumed 0.25 sacks of charcoal, 28.4% consumed 0.5 sacks of charcoal and 1.4% consumed 1 sacks of charcoal per month, with an average consumption of 0.5 sacks of charcoal per household per month. This is a reduction of 10.8 sacks of charcoal per year (Table 11). In monetary terms, this is equivalent to saving 2872.8 ETB annually at local rate of 266 ETB per sack of charcoal. Amare (2015) reported that adoption of biogas technology enabled households replacing 12 sacks of charcoal per household per year, which is equivalent to saving 1,243.20 ETB per household per year at the local rate of 103.60 ETB.

**Analysis and estimation of time requirement for traditional fuel collection**

To collect firewood and cattle dung, about 58.1% of households took 8–9 h, 23.0% took 10–11 h and the remaining 18.9% took 12–13 h per household per week.
before the adoption of the biogas technology. This is on average equivalent to 12 h per household per week or 576 h per year. After adoption, about 64.9% of user households took 3–4 h, 18.9% took 5–6 h and the remaining 16.2% took 12–13 h to collect firewood and cow dung per household per week (Table 12). This is, on average, equivalent to 216 h per year. Thus, biogas technology adoption enabled biogas user to save an average time of 7.5 h per household per week, which is about 38%. Among household members, primarily women and girls are the ones who collect firewood from various sources and engage in cooking activities. Thus, adoption of biogas technology predominantly enables women and girls save time to be spent for firewood collection and cooking. The saved time enhanced women’s socioeconomic engagements: petty trading, executing agricultural activities and undertaking other social obligations. Adoption also increased the number girls attending schools. The time saved following biogas technology adoption is utilized for schooling or other productive purposes (Sime, 2020). The use of biogas narrowed the gap in educational status between males and females (Arthur et al., 2011; Sime, 2020). The reduced workload from women and children in association with firewood or cow dung collection and the availability of clean household energy lead to social and economic development (Garfi et al., 2012). Domestic biogas energy reduces the workload of women by reducing the need to collect firewood, tend fires and clean soot from cooking utensils (Amare, 2015; Esthe et al., 2006; Gwavuya et al., 2012).

### Table 13. Consumption of kerosene per household per month before and after adoption of biogas technology

| Question                                      | Frequency | Percent |
|-----------------------------------------------|-----------|---------|
| Do you purchase kerosene?                     |           |         |
| Yes                                           | 66        | 89.2    |
| No                                            | 8         | 10.8    |
| Total                                         | 74        | 100.0   |

If yes, at what price do you buy one liter of kerosene?
Average price was 19 ETB per liter

| Liter | Frequency | Percent |
|-------|-----------|---------|
| 16–18 | 26        | 39.4    |
| 19–21 | 33        | 50.0    |
| 22–23 | 7         | 10.6    |
| Total | 66        | 100.0   |

| Liter | Frequency | Percent |
|-------|-----------|---------|
| 1–2   | 29        | 43.9    |
| 3–4   | 30        | 45.5    |
| >4    | 7         | 10.5    |
| Total | 66        | 100.0   |

Average = 2.7

| Liter | Frequency | Percent |
|-------|-----------|---------|
| 0.25–0.5 | 34        | 51.5    |
| 0.75–1.0 | 18        | 28.3    |
| 1.5–1.75 | 14        | 21.2    |
| Total   | 66        | 100.0   |

Average = 0.7

### Table 14. Fertilizer use pattern before and after adoption of biogas technology

| Question                                      | Frequency | Percent |
|-----------------------------------------------|-----------|---------|
| What type of fertilizer do you use before biogas adoption? |           |         |
| Chemical fertilizer only                      | 31        | 41.9    |
| Compost                                       | 5         | 6.8     |
| Manure                                        | 2         | 2.7     |
| Chemical fertilizer and manure                | 35        | 47.3    |
| Chemical fertilizer and compost               | 3         | 4.1     |
| Total                                         | 74        | 100.0   |

| Fertilizer type                               | Frequency | Percent |
|------------------------------------------------|-----------|---------|
| Chemical fertilizer only                      | 31        | 41.9    |
| Compost                                       | 5         | 6.8     |
| Manure                                        | 2         | 2.7     |
| Chemical fertilizer and manure                | 35        | 47.3    |
| Chemical fertilizer and compost               | 3         | 4.1     |
| Total                                         | 74        | 100.0   |

| What type of fertilizer do you use after biogas adoption? |           |         |
|----------------------------------------------------------|-----------|---------|
| Fertilizer type                                           | Frequency | Percent |
| Chemical fertilizer only                                  | 2         | 2.7     |
| Bio-slurry and compost                                    | 26        | 35.1    |
| Manure and compost                                        | 6         | 8.1     |
| Chemical fertilizer and manure                           | 3         | 4.1     |
| Chemical fertilizer and bio-slurry                       | 37        | 50.0    |
| Total                                                     | 74        | 100.0   |
liter kerosene per year. This shows that biogas adoption enabled saving of 24 liter of kerosene per year. This is equivalent to saving 456 ETB annually at a local rate of 19 ETB per liter of kerosene. Simur (2012) estimated the daily consumption of kerosene of 0.13 liter per day per household, which is equivalent to saving 47.43 liter of kerosene per household per year and saving 617 ETB based on local price of 13 ETB per liter in Amhara Region in Northern Ethiopia.

**Quantity of chemical fertilizer consumption**

There are two kinds of chemical fertilizers that are widely used in Ethiopia. They are DAP and urea, the former is phosphorus fertilizer while the later one is nitrogen fertilizer. Before adoption, about 41.9% of the households used chemical fertilizer only while 47.3% of them used both chemical fertilizer and manure. The rest of the households used compost, manure or their combination. However, after adoption, 50% of the households used chemical fertilizer and bio-slurry, 35.1% used bio-slurry and compost and the remaining used chemical fertilizer only, manure and compost and chemical fertilizer and manure (Table 14). The use of chemical fertilizer was reduced 94%. Similarly, the combined use of chemical fertilizer and manure was reduced by 91%. Furthermore, field observations showed that the use of bio-slurry has increased following adoption. The majority of adopter households (65.4%) also used a combination of bio-slurry and chemical fertilizer together. Debebe and Itana (2016) reported that 15.4% biogas adopter households used chemical fertilizer only, 11.5% used cow dung, compost and chemical fertilizer, while the remaining 7.7% used bio-slurry, compost and chemical fertilizer.

Likewise, the majority of households (62.2%) used 4 sacks of DAP and 1 sack of urea, 37.8% used 5 sacks of DAP and 2 sacks of urea per hectare per year, with an average consumption of 4.5 sacks of DAP and 1.5 sacks of urea before adoption (1 sack weighs 50 kg). Whereas, after adoption, about 45.9% of the households used 1 sack of DAP and 0.25 sacks of urea. The majority of households (54.1%) used 2 sacks of DAP and 0.5 sacks of urea per hectare per year, with an average consumption of 1.5 sacks of DAP and 0.37 sacks of urea per household per hectare per year (Table 15). This is a reduction of 3 sacks of DAP and 1 sack of urea per household per hectare per year. Thus, adoption of the technology enabled the saving of 3 sacks of DAP and 1 sack of urea per hectare per year. In terms of monetary returns, this is equivalent to a saving of 2265.00 ETB from DAP and 695.00 ETB from urea purchase annually per hectare at local rate (1 sack or 50 kg DAP = 755 ETB, 1 sack per 50 kg urea = 695 ETB, at the time of data collection). Thus, the adoption has remarkably reduced the quantity of chemical fertilizer consumption. Debebe and Itana (2016) stated that chemical fertilizer is very expensive as compared to bio-slurry, 80.8% of the bio-slurry users saved 1000–2000 ETB per year and 19.2% saved 2000–3000 ETB per year. Similarly, Amare (2015) reported that the use of biogas offered an annual saving of 717.65 ETB and Claudia and Addis (2011) of 682 ETB from replacing inorganic chemical fertilizer with chemical fertilizer. The difference in the amount of money saved might infer to soil fertility, type of crop grown, and tradition of using chemical fertilizer and bio-slurry.

There is a direct causal relationship between biogas technology adoption and replacement for firewood, kerosene and chemical fertilizer. This is because the adoption of the technology enables the dependence on firewood for cooking and lighting. Not only a collection of firewood from forest or other sources is

| Table 15. Amount of chemical fertilizer used before and after biogas technology adoption |
|-----------------------------------|---------------------------------|----------------|--------|
| Question                          | Amount and type of fertilizer   | Frequency | Percent |
| How many sacks of chemical fertilizer do you use before biogas technology adoption per hectare per season? |
| Average = 4.5 sack DAP and 1.5 sack urea | 4 sack DAP and 1 sack urea | 46         | 62.2   |
| Average = 4.5 sack DAP and 1.5 sack urea | 5 sack DAP and 2 sack urea | 28         | 37.8   |
| Total                             | 74 | 100.0 |
| How many sacks of chemical fertilizer do you use after biogas technology adoption per hectare per season? |
| Average = 1.5 sack DAP and 0.37 sack urea | 1 sack DAP and 0.25 sack urea | 34         | 45.9   |
| Average = 1.5 sack DAP and 0.37 sack urea | 2 sack DAP and 0.5 sack urea | 40         | 54.1   |
| Total                             | 74 | 100.0 |
| How much is the price of one sack (50 kg) chemical fertilizer in your local market? |
| Average = 755 ETB DAP and 695 ETB urea | 750 ETB DAP and 690 ETB urea | 51         | 68.9   |
| Average = 755 ETB DAP and 695 ETB urea | 760 ETB DAP and 700 ETB urea | 23         | 31.1   |
| Total                             | 74 | 100.0 |

NB: The US Dollar (USD) to Ethiopian Birr (ETB) average exchange rate at the time of data collection was 27.6677 ETB
difficult, but also its availability has been readily decreasing in association to deforestations. Forests are the major sources of firewood, although cow dung and crop residues also provide their shares. Rural households use kerosene for lighting during the night. The adoption of biogas technology not only provides energy for, but also energy for lighting. Similarly, chemical fertilizers are used for increasing agricultural productivity, nevertheless, their availability and prices are always challenging households. The adoption of technology enables the provision of high quality organic fertilizers, bio-slurry, as its byproduct. Households can use bio-slurry, made from locally available organic wastes, for increasing agricultural production and income.

**Access to water sources**

The majority of the households (70.3%) lacked access to water sources. The water resources were mostly reached within 50 minutes of walking distance from their residence. Most of the households (62.5%) used water from rivers and 16.7% from water tap, and 12.5% from rain - water harvesting (Table 16). According to the standard set in the National Biogas Program document, for daily feeding of biogas plants, the source of water should be reached within a walking distance of 20 minutes to 30 minutes away from home in Ethiopia (EREDPC & SNV, 2008; Eshete et al., 2006). A distant water source had a negative influence on the functionality of biogas plants (Shallo & Sime, 2019). Tucho et al. (2016) also reported that meeting biogas plant’s water requirement remained a great challenge when distant water sources are considered. Since water is a basic substrate for biogas production, access to water sources is instrumental for the sustainable adoption of biogas technology. Thus, limited water availability is a basic constraint for the biogas plant operation in some African countries (Parawira, 2009; Surendra et al., 2014; Wawa, 2012).

| Source of water | Frequency | Percent |
|-----------------|-----------|---------|
| Do you get water at your home/ residence? | 22 | 29.7 |
| away from residence area? | 52 | 70.3 |
| If you do not get water in the nearest, from where do you fetch? | | |
| River | 30 | 62.5 |
| Water well | 4 | 8.3 |
| Water tap | 8 | 16.7 |
| Rainwater | 6 | 12.5 |
| Total | 48 | 100.0 |

### Table 17. Trend of using toilets and connecting toilets to biogas system

| Trend of using toilet | Before adoption | After adoption |
|-----------------------|-----------------|---------------|
| Frequency | Percent | Frequency | Percent |
| Good | 8 | 10.8 | 30 | 40.5 |
| Very good | 6 | 8.1 | 27 | 36.5 |
| Poor | 29 | 39.2 | 11 | 14.9 |
| Very poor | 31 | 41.9 | 6 | 8.1 |
| Total | 74 | 100.0 | 74 | 100.0 |

**Connection of toilet to biogas plants**

All biogas user households had toilets. About 89.2% of them connected their toilets to the biogas system. Before adoption, the trend of using the toilet was poor (39.2%), very poor (41.9%), good (10.8%) and very good (8.1%). Nevertheless, after adoption, the trend was soundly changed where about 40.5% were good, 36.5% were very good, 14.9% were poor and 8.1% were very poor (Table 17). Biogas technology adoption helped the majority of biogas users to construct toilets and reduce defecation in the field, with massive potential of improving environmental sanitation and human health.

Biogas technology improves health of rural households by providing a cleaner cooking fuel and a waste handling solution, thus, avoiding health problems (Amigun et al., 2012; Sime, 2020). Cooking with clean and odorless flame of biogas enabled the reduction of in-door pollution caused from the smell of kerosene or smoke of firewood burning (Baigain & Shakyra, 2005).

Results from the qualitative approach supported most of the results obtained from the survey. For instance, the use of biogas technology reduces exposure to indoor air pollution, deforestation, the use of chemical fertilizers for crop production, use of crop residues for fuel, use of kerosene for lighting, time for collecting cow dung from fields and firewood from the forest, etc. On one hand, the adoption of the technology promotes toilet construction because toilets provide organic wastes for feeding biogas plants and avoids field defecation. On the other hand, poor promotion strategies and availability of spare parts, maintenance services are among the persisting challenges to the full realization and exploitation of the technology.
Conclusion and recommendation

This study evaluated the technical potential of biogas technology to replace traditional fuel, kerosene and bio-slurry in northern Ethiopia. Biogas technology adoption soundly reduced households’ firewood, charcoal, dung cake and kerosene consumption by 58%, 36%, 71%, and 74%, respectively. It similarly reduced the use of chemical fertilizer and combination of chemical fertilizer and manure by 94%, and 91%, respectively. The technology also enhanced adopters’ annual income. Besides increasing the trend of constructing toilets, it reduced defecation in the field that massively improved environmental sanitation and human health. In conclusion, biogas technology offers a massive potential of reducing the consumption of firewood, charcoal, dung cake and kerosene, with huge implication for forest resource management and improvement of agricultural productivity, and human and environmental health. It has also huge potential in reducing the massive and widely practiced field defecation in rural areas through promoting the construction of toilets. This would in turn have an enormous implication for better environmental and human health management in rural settings. Future research needs to focus on rectifying other challenges influencing the realization of the technical potential of biogas technology dissemination in Ethiopia as well its huge potential for better management of forest resources.

Notes

1. “Kebele” is the smallest administrative division in Ethiopia. It is the same as a village.
2. Dega denotes a highland agro-climatic region.
3. Woina-dega denotes a midland agro-climatic region.
4. Kolla denotes a lowland agro-climatic region.
5. ETB (Ethiopian Birr) = Currency/money for Ethiopia.
   The US Dollar (USD) to Ethiopian Birr (ETB) average exchange rate at the time of data collection was 27.6677 ETB.

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Authors’ contributions

Both authors designed the research and conducted primary data collection and analysis for the studies. In addition, both authors edited and approved the final manuscript.

Data Availability Statement

All the processed data are contained within the manuscript itself. The raw data, whereas are deposited with Hawassa University database. www.hu.edu.et

References

Abadi, N., Gebrehiwot, K., Techane, A., & Nerea, H. (2017). Links between biogas technology adoption and health status of households in rural Tigray, Northern Ethiopia. Energy Policy, 101, 284–292. https://doi.org/10.1016/j.enpol.2016.11.015

Amare, Z. Y. (2015). The benefits of the use of biogas energy in rural areas in Ethiopia: A case study from the Amhara National Regional State, Fogera District. African Journal of Environmental Science and Technology, 9(4), 332–345. https://doi.org/10.5897/AJEST2014.1838

Amigun, B., Parawira, W., Musango, J., Aboyade, A., & Badmos, A. (2012). Anaerobic biogas generation for rural area energy provision in Africa. In S. Kumar (Ed.), Biogas (pp. 36–62). InTech.

Arthur, R., Baidoo, M. F., & Antwi, E. (2011). Biogas as a potential renewable energy source: A Ghanaian case study. Renewable Energy, 36(5), 1510–1516. https://doi.org/10.1016/j.renene.2010.11.012

Bajgain, S., & Shakyia, I. S. (2005). A successful model of public private partnership for rural household energy supply. SNV.

Berhe, T. G., Tesfauney, R. G., Desta, G. A., & Mekonnen, L. S. (2017). Biogas plant distribution for rural household sustainable energy supply in Africa. Energy and Policy Research, 4(1), 10–20. https://doi.org/10.1080/23815639.2017.1280432
Bloor, M. (2001). Focus groups in social research. Sage.

Central Statistics Agency (CSA). CSA 2015. Report on area and production of crop and utilization of Ethiopia, Addis Ababa.

Christiaensen, L., & Helteberg, R. (2014). Greening China's rural energy: New insights on the potential of smallholder biogas. *Environment and Development Economics, 19*(1), 8–29. https://doi.org/10.1017/S1355770X13000375

Chu, S. Y., Wen, C. C., & Lin, C. W. (2020). A qualitative study of clinical narrative competence of medical personnel. *BMC Medical Education, 20*(1), 1–13. https://doi.org/10.1186/s12909-020-02336-6

Claudia, B., & Addis, Y. (2011). Survey of biogas plants in four regional states of Ethiopia. SNV.

Debebe, Y., & Itana, F. (2016). Comparative study on the effect of applying biogas slurry and inorganic fertilizer on soil properties, growth, and yield of white cabbage (Brassica oleracea var. capitata f. alba). *Journal of Biology, Agriculture and Healthcare, 6*, 19–26 https://www.researchgate.net/

Desalegn, Z. (2014). *Studies on prospects and challenges of uptake of domestic biogas technology, The case of SNNPR, Ethiopia*. St. Mary’s University.

EREDPC & SNV. (2008). Ethiopian rural energy development and promotion center (EREDPC) and Netherlands development organization (SNV). In *National biogas programme Ethiopia: Programme implementation document* (pp. 1-118). EREDPC and SNV.

Eshete, G., Sonder, K., & Heegde, F. 2006. *Report on the feasibility study of a national programme for domestic biogas in Ethiopia*. SNV Netherlands Development Organization.

Garfi, M., Ferrer-Martí, L., Velo, E., & Ferrer, I. (2012). Evaluating benefits of low-cost household digesters for rural Andean communities. *Renewable and Sustainable Energy Reviews, 16* (1), 575–581. https://doi.org/10.1016/j.rser.2011.08.023

Gwavuya, S., Abele, S., Barfuss, I., Zeller, M., & Müller, J. (2012). Household energy economics in rural Ethiopia: A cost-benefit analysis of biogas energy. *Renewable Energy, 48*, 202–209. https://doi.org/10.1016/j.renene.2012.04.042

Ioannidis, J. P. (2018). The proposal to lower P value thresholds to 0.05. *Jama*, 319(14), 1429–1430. https://doi.org/10.1001/jama.2018.1536

Kabir, H., Yegbemey, R. N., & Bauer, S. (2013). Factors determinant of biogas adoption in Bangladesh. *Renewable and Sustainable Energy Reviews, 28*, 881–889. https://doi.org/10.1016/j.rser.2013.08.046

Kamp, L. M., & Bermúdez Forn, E. (2016). Ethiopia’s emerging domestic biogas sector: Current status, bottlenecks and drivers. *Renewable and Sustainable Energy Reviews, 60*, 475–488. https://doi.org/10.1016/j.rser.2016.01.068

Mengistu, M. G., Simane, B., Eshete, G., & Workneh, T. S. (2016). Factors affecting households’ decisions in biogas technology adoption, the case of Ofala and Mecha Districts, northern Ethiopia. *Renewable Energy, 93*, 215–227. https://doi.org/10.1016/j.renene.2016.02.066

Molina, F., Ruiz-filippi, G., García, C., Roca, E., & Lema, W. S. (2007). Winery effluent treatment at an anaerobic hybrid USBF pilot plant under normal and abnormal operation. *Water Science and Technology: A Journal of the International Association on Water Pollution Research, 56* (2), 25–31. https://doi.org/10.2166/wst.2007.468

Mwirigi, J. W., Makenzi, P. M., & Ochola, W. O. (2009). Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. *Energy for Sustainable Development, 13*(2), 106–115. https://doi.org/10.1016/j.esd.2009.05.002

Neergaard, H., & Ulhøi, J. P. (2007). *Handbook of qualitative research methods in entrepreneurship*. Edward Elgar Publishing.

Parawira, W. (2009). Biogas technology in sub-Saharan Africa: Status, prospects and constraints. *Reviews in Environmental Science and Bio/Technology, 8*(2), 187–200. https://doi.org/10.1007/s11157-009-9148-0

Rambo, C. M. (2013). Renewable energy project financing risks in developing countries: Options for Kenya towards the realization of vision 2030. *International Journal of Business and Finance Management Research, 1*(10), 1–10 http://www.bluepenjournals.org/ijbfmr

Ritchie, J., Lewis, J., Nicholls, C. M., &Ormston, R. (2013). *Qualitative research practice: A guide for social science students and researchers*. sage.

Sanbata, H., Asfaw, A., & Kumie, A. (2014). Indoor air pollution in slum neighbourhoods of Addis Ababa, Ethiopia. *Atmospheric Environment, 89*, 230–234. https://doi.org/10.1016/j.atmosenv.2014.01.003

Shallo, L., Ayele, M., & Sime, G. (2020). Determinants of biogas technology adoption in southern Ethiopia. *Energy, Sustainability and Society, 10*(1), 1–13. https://doi.org/10.1186/s13705-019-0236-x

Shallo, L., & Sime, G. (2019). Determinants of functional status of family size bio-digesters. Empirical evidence from southern Ethiopia. 38(5), 493–510 https://doi.org/10.1080/14786451.2018.1538145.

Sime, G. (2020). Technical and socioeconomic constraints to the domestication and functionality of biogas technology in rural areas of southern Ethiopia. *Cogent Engineering, 7*(1), 1765686. https://doi.org/10.1080/23311916.2020.1765686

Sime, G., Tilahun, G., & Kebede, M. (2020). Assessment of biomass energy use pattern and biogas technology domestication programme in Ethiopia. *African Journal of Science, Technology, Innovation and Development 38*(5) , 493–510 https://doi.org/10.1080/14786451.2018.1538145.

Simur, A. (2012). The current status of traditional biomass energy utilization and its alternative renewable energy technology in Amhara MSc Thesis pp 1–104 https://www.diva-portal.org/.

Surendra, K., Takara, D., Hashimoto, A. G., & Khanal, S. K. (2014). Biogas as a sustainable energy source for developing countries: Opportunities and challenges. *Renewable and Sustainable Energy Reviews, 31*, 846–859. https://doi.org/10.1016/j.rser.2013.12.015

Tucho, G. T., Moll, H. C., Uiterkamp, A. J., & Nonhebel, M. S. (2016). Problems with biogas implementation in developing countries from the perspective of labor requirements. *Energies, 9*(9), 1–16. https://doi.org/10.3390/en9090750

Walekha, P. N., Mugisha, J., & Drake, L. (2009). Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. *Energy Policy, 37*(7), 2754–2762. https://doi.org/10.1016/j.enpol.2009.03.018

Wawa, A. I. 2012. *The Challenges of Promoting and Adopting Biogas Technology as Alternative Energy Source in Semi-Arid Areas of Tanzania: The Case of Kongwa and Bahi Districts of Dodoma Region.MSc thesis*, The Open University of Tanzania.