Technical Potential of Biogas Technology Adoption in Replacing Firewood, Kerosene and Chemical Fertilizer: The Case of Misrak and Mirab Estie Districts, in Northern Ethiopia

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Abstract

Background: The depletion of bioenergy sources has caused significant deforestation, low agricultural production and energy crisis. This study evaluates the technical potential of biogas technology adoption in replacing firewood, charcoal, kerosene and chemical fertilizer in Northern Ethiopia.

Methods: Questionnaire household survey, key informant interview, focus group discussion and field obervation were used for data collection.

Results: 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 combination of bio-slurry and chemical fertilizer. It helped the majority (89.95%) of adopters to construct and connect toilets to biogas operational system. In doing so, 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.

Conclusions: 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 time for biofuel collection.

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 to 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 (Lakew, 2010, 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 meeting 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).

In the study area, scarcity of firewood has led to increased utilization of dung and agricultural residues for cooking, which otherwise would have been used to enhance forest cover, soil fertility and agricultural productivity. The undergoing biogas domestication activity in Ethiopia and the utilization of the potential of biogas technology has been low. The technical potential of biogas technology in replacing biomass resources for domestic energy utilization have not been studied. On the other hand, most of the previous studies conducted so far are associated with factors hindering or fostering the adoption of biogas technology (Shallo and Sime, 2019, Shallo et al., 2020, Abadi et al., 2017, Berhe et al., 2017, Kamp and Bermúdez Forn, 2016). Other studies include: prospects of domestic biogas technology (Desalegn, 2014), and contribution of biogas technology adoption to rural livelihood and environment health improvement (Mengistu et al., 2016 Amare, 2015). None of these studies have offered detailed attention to the evaluation of the technical potential of biogas technology in replacing firewood, charcoal, kerosene and chemical fertilizer. Thus, the objective of this study was to answer the technical potential of biogas technology in replacing firewood, charcoal, kerosene and chemical fertilizer in Southern Ethiopia.

Materials And Methods

Description of the study area

Location

Misrak and Mirab Estie Districts are located in South Gondar zone, Amhara Regional State, Northern Ethiopia (Fig. 1). Misrak Esite 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 Gondar zone. The District has 43 *Kebele* (5 urban and 38 rural villages), and is bordered by Abay River in the South, by Dera district in the West, by Farta in the North and by Simada in the East. Mirab Estie lies within 11^{0}10' to 11^{0} 30' North latitude and 37^{0}45' to 38^{0} to 00'E longitudes. It is located at 148 kilometers from Bahir Dar, the capital city of Amhara Regional State 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 Estie in Northeast and by Abay River in the South and by Dera in the West.

The topography

The topography of Misrak and Mirab Estie 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 meter above sea level.

Agro-climatic conditions

The Districts have three agro-ecological zones. They include *Dega* with an altitude of more than 2300 meter above sea level, *Woina-dega* with an altitude of 1500–2300 meter above sea level and *Kolla* with an altitude of less than 1500 meters above sea levels. *Dega, Woina-dega* and *Kolla* cover about 3%, 91% and 6%, respectively. The maximum and minimum annual temperature is 25 ^{0}C and 8.3 ^{0}C, respectively.

Demographic and socio-economic characteristics of the Districts

The Central Statistical Agency (CSA) of Ethiopia indicated that Misrak Estie 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 (CSA, 2015).

The total population size in Mirab Estie 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 hectare with population density of 173.3 person 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 (CSA, 2015).

Table 1
Size of livestock in study Districts

Livestock holding size	Misrak Estie District	Mirab Estie 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**

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

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

All the 74 biogas user households and all the 16 biogas user *Kebeles* in both Districts were considered in this study (Table 2). Official list of the 16 biogas user *Kebeles* and the 74 user household heads was provided by the respective Biogas Coordinators of Misrak and Mirab Estie Districts.

Table 3
Study Districts and *Kebeles*, and their corresponding number of installed biogas plants

Misrak Estie District		**Mirab Estie District**	
Kebele	**Installed biogas plants**	Kebele	**Installed biogas plants**
Agona Kositet	4	Deriba Betanisa	5
Debir Zewana	9	Gishina	4
Mekane Eyesus	3	Merji Tenikot	4
Goshiberet	4	MesiBekilo Filega	4
Licha Arida	6	Sheme Mosha	5
Liwaye Ashama	7	Simet Sholaye	3
Mikrie Kuskuam	4	Yedi Digmegn	3
Jibasra Mariam	5	**Total size**	**28**
Ziguara	4		
Total size	**46**		

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

Primary data were collected using questionnaires, semi-structure interview, focus group discussion and field observation. The 74 household heads were interviewed through administering 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 research interview purpose (Neergaard and Ulhøi, 2007). Focus group discussion was also held with group of biogas users belonging to different age and sex categories. Three focus group discussion 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.

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

Data analysis

All the data collected were entered into Microsoft Office and statistical analysis was done using SPSS-20 software. Descriptive statistics, chi-square, one sample t-test was used for analysis of data obtained from questionnaire at 95% confidence interval and p-value < 0.05.

Results And Discussion

Socio- economic characteristics of user households

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 3). One sample T- test result showed that livestock size has a significant (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 and SNV, 2008). Other findings from previous studies indicated that cattle size has a significant positive association with adoption of biogas technology (Walekhwa et al., 2009, Kabir et al., 2013, Shallo and Sime, 2019).

Table 3
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

In terms of cattle grazing systems, about 31.1% of the households used free grazing on open field, 40.5% controlled grazing (zero grazing practice) 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 sufficient cattle dung 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 field, 43.3% from stall (locally called *Beret*) and the remaining 30% from stall and field (Table 4). Field observation also showed that households practicing controlled grazing method have better potential of adopting biogas technology than those practicing other methods of grazing types. Controlled grazing was observed to ease dung collection, lessening labor and time. Mwirigi et al. (2009) reported a significant positive relationship between grazing system and adoption of biogas technology in Kenya.

Table 4
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**

Traditional biomass energy use pattern

The energy use pattern showed that an extensive number of households use firewood (41.9%), followed by dung cake (29.7%), charcoal (17.6%) and kerosene (10.8%) before biogas technology adoption (Fig. 2). 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 relies 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 4.8 bundles of firewood per household per month or 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, with an average consumption of 2.0 bundles of firewood per household per month. This is a reduction of more than 50% of the bundles of firewood used per household per month or 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 5). Amare (2015) reported that biogas technology adoption enabled a reduction of 70.47% of firewood per household per year. This is a reduction in annual firewood consumption, approximately of 79 bundles of firewood per household per year. In turn, this is equivalent saving 3833.22 ETB annually at local rate of 48.40 ETB per 32 kg per bundle. 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 and Heltberg, 2014).

Table 5
Number of bundles of firewood consumption per household per month before and after adoption of biogas technology

Before adoption			After adoption		
Number of bundle	**Frequency**	**Percent**	**Number of bundle**	**Frequency**	**Percent**
3–5	52	70.3	1–2	60	81.1
6–7	17	23.0	3–4	8	10.8
8–9	5	6.8	5–6	6	8.1
Total	**74**	**100.0**	**Total**	**74**	**100.0**
Average = 4.8			**Average = 2.0**		
How much is the price of one bundle in your local market (ETB)Amare (2015)?			**Price**	**Frequency**	**Percent**
			80–90	42	56.8
			91–100	31	41.9
			101–110	1	1.4
			Total	**74**	**100.0**
			Average = 89.6		

Quantity of dung cake consumption

Dung cake is regularly used as traditional fuel in traditional stoves in most parts of Ethiopia. Before adoption, about 56.8% of the households consumed 6,065 dung cakes, 32.4% consumed 66–70 dung cakes and the rest 10.8% consumed 71–75 dung cakes per month, with an average consumption of 65.4 dung cakes per household per month. However, after adoption, 82.8% of the households used 15–20 dung cakes, 13.5% used 21–25 dung cakes and 4.1% used 26–30 dung cakes per household per month, with an average consumption of 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 three ETB per dung cake (Table 6). 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 Norther Ethiopia.

Table 6
Number of dung cake consumption of household per month before and after adoption of biogas technology

Number of dung cake	Before plant installation		Number of dung cake	After plant installation	
	Frequency	Percent		Frequency	Percent
60–65	42	56.8	15–20	61	82.4
66–70	24	32.4	21–25	10	13.5
71–75	8	10.8	36 – 30	3	4.1
Total	**74**	**100.0**	**Total**	**74**	**100.0**
Average = 65.4			**Average = 18.6**		
How much is the price of one dung cake in your local market?			**Price (ETB)**	**Frequency**	**Percent**
Average price of one dung cake is three ETB			1–2	17	23.0
			3–4	55	74.3
			5–6	2	2.7
			Total	**74**	**100.0**

Quantity of charcoal consumption

Table 8 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 1.4 sacks of charcoal per household per month or 16.8 sacks of charcoal per year before adoption. After adoption, 70.3% (majority of biogas users) of households 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 0.9 sacks of charcoal per households per month or 10.8 sacks of charcoal per year (Table 7). 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.

Table 7
Quantity of charcoal consumption (in sacks) per household per month before and after biogas plant installation

Before adoption			After adoption		
No. of sack	**Frequency**	**Percent**	**No. of sack**	**Frequency**	**Percent**
1	44	59.4	0.25	52	70.3
1.5-2	25	33.7	0.5	21	28.4
2.25–2.5	5	6.7	1	1	1.4
Total	**74**		**Total**	**74**	**100.0**
Average = 1.4			**Average = 0.5**		
How much is the price of one sack of charcoal in your local market?			250–260	17	23
			261–270	34	45.9
			271–280	23	31.1
			Total	**74**	**100.0**
			Average = 266		

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 adoption of the biogas technology. This is on average equivalent to12 h per household per week, 48 h per household per month 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 8). This is, on average, equivalent to 4.5 h per household per week, 18 h per household per month or 216 h per year. Thus, biogas technology adoption enabled biogas user to save an average time of 7.5 h per household per week, 30 h per month or 360 h per year, 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 (Garfí 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 (Eshete et al., 2006, Gwavuya et al., 2012, Amare, 2015).

Table 8
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 and cattle dung before biogas plant installation? Hour per week **Average time = 12 hours/week**	**8–9**	**43**	**58.1**
	10–11	**17**	**23.0**
	12–13	**14**	**18.9**
	Total	**74**	**100.0**
How long does it take you to collect firewood and cattle dung after biogas plant installation? Hour per week **Average time = 4.5 hours/week**	3–4	48	64.9
	5–6	14	18.9
	7–8	12	16.2
	Total	**74**	**100**

Quantity of kerosene consumption

With regard to kerosene consumption, about 43.9% (the majority) of households consumed 1–2 liter of kerosene, 45.5% consumed 3–4 liters and only 10.5% consumed greater than 4 liter of kerosene per month, with an average consumption of 2.7 liter of kerosene per household per month or 32.4 liter of kerosene per year before adoption. However, after adoption, 51.5% of the households consumed 0.25–0.5 liter of kerosene, with an average consumption of 0.7 liter of kerosene per household per month (Table 9). This is a reduction of 2 liter kerosene per household per month or 24 liter kerosene per year. This shows that biogas adoption enabled saving of 24 liter of kerosene annually. This is equivalent to saving 456 ETB annually at a local rate of 19 ETB per liter of kerosene. Simur Asres (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.

Table 9
Consumption of kerosene per household per month before and after adoption of biogas technology

Question		**Variable**	**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					
		16–18	26	39.4	
		19–21	33	50.0	
		22–23	7	10.6	
		Total	**66**	**100.0**	
	Before adoption			**After adoption**	
Liter	**Frequency**	**Percent**	**Liter**	**Frequency**	**Percent**
1–2	29	43.9	0.25–0.5	34	51.5
3–4	30	45.5	0.75-1.0	18	28.3
> 4	7	10.5	1.5–1.75	14	21.2
Total	**66**	**100.0**	**Total**	**66**	**100.0**
Average = 2.7			**Average = 0.7**		

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 10). The use of chemical fertilizer was reduced from 41.9–2.7%, which is equivalent to 94% reduction. Similarly, the combined use of chemical fertilizer and manure was reduced from 47.3 to 4.1%, which is again equivalent to 91% reduction. Furthermore, field observations showed that the use of bio-slurry has increased following adoption. The majority of adopter households, which is about 65.4%, also used 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.

Table 10
Fertilizer use pattern before and after adoption of biogas technology

Question	Fertilizer type	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	1	1.4
	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**

Likewise, about 62.2% of households, which is the majority, used 4 sacks of DAP and 1sack 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 1sack of DAP and 0.25 sack of urea. About 54.1%, which is the majority, used 2 sacks of DAP and 0.5 sack of urea per hectare per year, with an average consumption of 1.5 sacks of DAP and 0.37 sack of urea per household per hectare per year (Table 11). This is a reduction of 3 sacks of DAP and 1 sack of urea per household per hectare per year. Thus, adoption 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 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.

Table 41
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 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
	5 sack DAP and 2 sack urea	28	37.8
	Total	**74**	**100.0**
How many sacks of chemical fertilizer do 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
	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**	**Price**	**Frequency**	**Percent**
	750 ETB DAP and 690 ETB urea	51	68.9
	760 ETB DAP and 700 ETB urea	23	31.1
	Total	**74**	**100.0**

Access to water sources

Though about 29.7% of the households had access to water sources around their home, the majority of the households, which is about 70.3%, lacked access to such water sources. The water resource was mostly reached within 50 minutes of walking distance from their residence. Consequently, the majority of the households, which is 62.5%, use water from rivers and 16.7% from water tap, and 12.5% from rain - water harvesting (Table 12). 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 walking distance of 20 minutes to 30 minutes away from home in Ethiopia (Eshete et al., 2006, EREDPC and SNV, 2008). Distant

water source had negative influence on the functionality of biogas plants (Shallo and 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 biogas operation in some African countries (Parawira, 2009, Wawa, 2012, Surendra et al., 2014).

Table 12
Accessibility and type of sources of water

Accessibility	Source of water	Frequency	Percent
Do you get water at your home/residence? or		22	29.7
away from residence area?		52	70.3
	Total	**74**	**100.0**
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**

Connection of toilet to biogas plants

All biogas user households had toilets. About 89.2% of them connected their toilets to the biogas system while 10.8% of them lacked such a connection. Before adoption, the trend of using toilet were 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 13). 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.

Table 5
Trend of using toilets and connection of toilets with 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**
Is your toilet connected to biogas operational system?		**Variable**	**Frequency**	**Percent**
		Yes	66	89.2
		No	8	10.8
		Total	**74**	**100.0**

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 reduction of in-door pollution caused from the smell of kerosene or smoke of firewood burning (Bajgain and Shakya, 2005).

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. Future research need to focus on rectifying other challenges influencing the realization of the technical potential of biogas technology dissemination in Ethiopia.

Declarations

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.

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Availability of data and materials

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

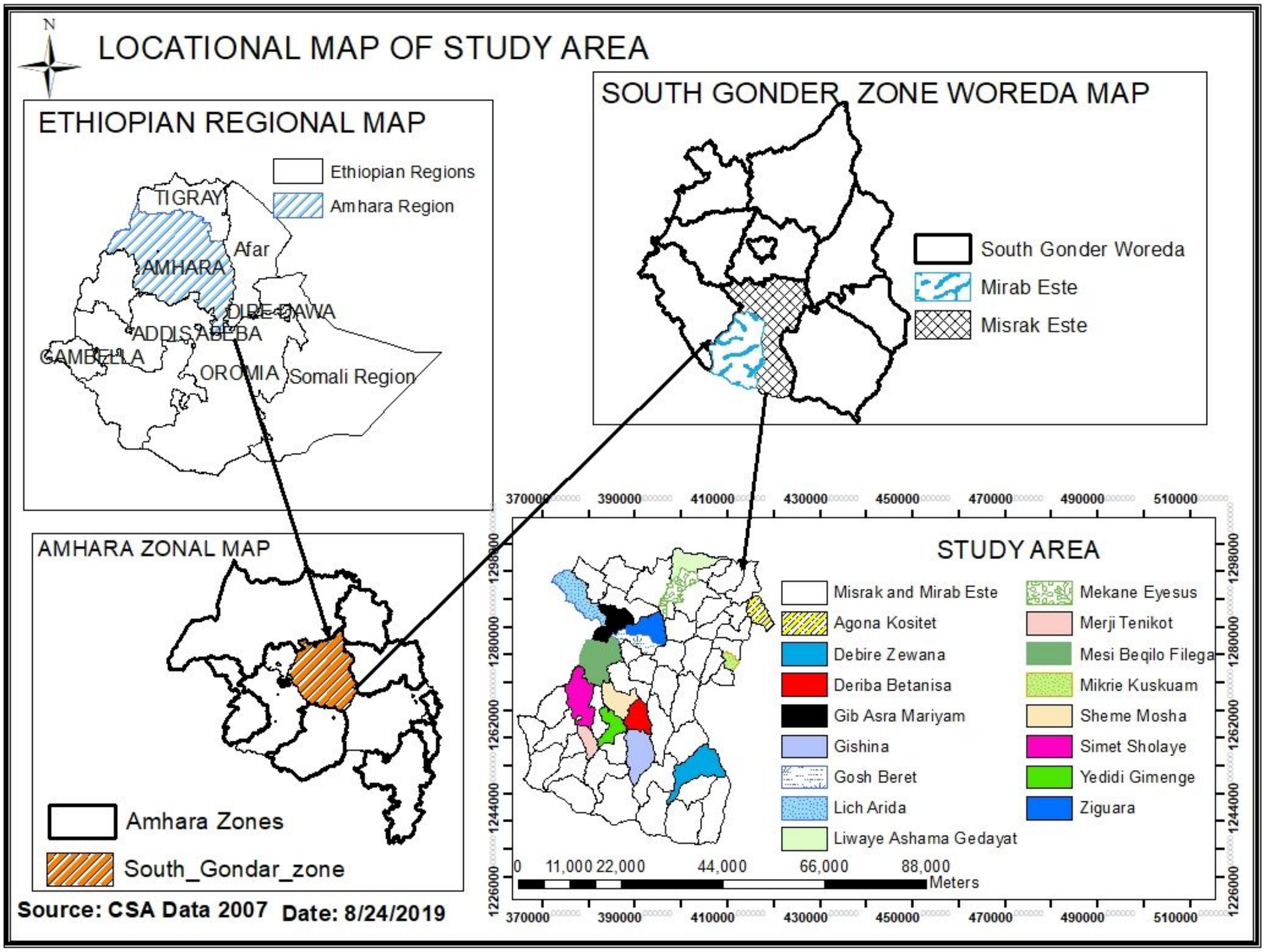

Figure 1

Physical map of study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

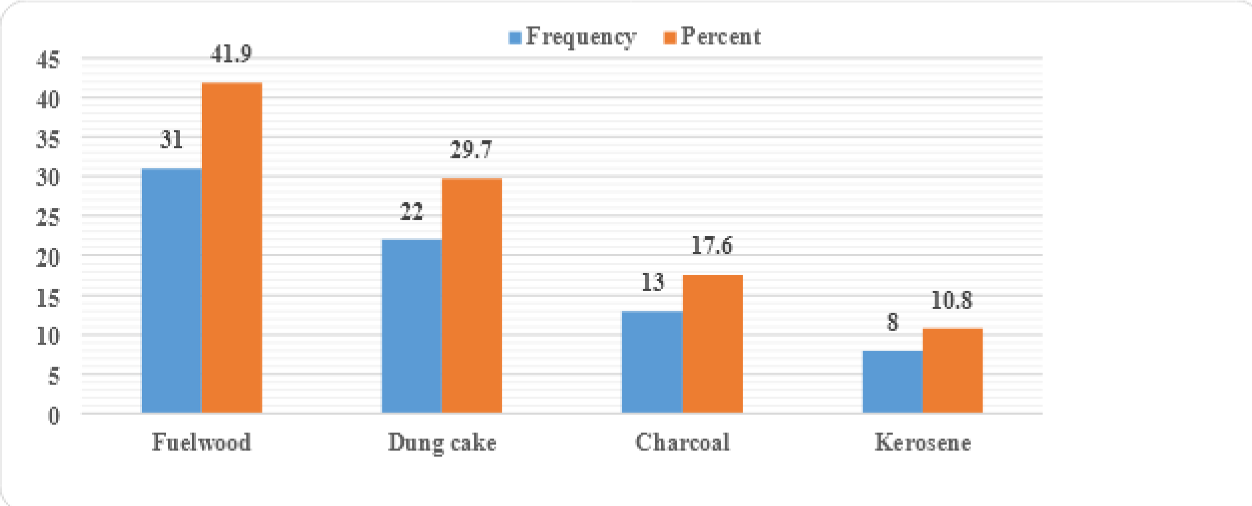

Figure 2

Biomass and kerosene use pattern before installation of biogas plants