Biogas Plant Distribution for Rural Household Sustainable Energy Supply in Africa
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ABSTRACT
A sustainable rural energy supply is one of the ways of reacting to the increasing global, national, and local environmental problems. Dissemination of biogas plants as an alternative rural energy source has significant environmental benefits. The main objective of the study is to assess the dissemination process of biogas plants in the Tigray region of Ethiopia. It analyses the current biogas development program of the region in line with its environmental aspects. The study has employed a descriptive research type with mixed research approaches. Questionnaires, key informant interviews, observation, and archival analysis were the instruments used to collect data. Nonprobability sampling (Judgmental) method was used to select sampling frames, and snowball sampling techniques were employed to select the final respondents. Collected data were analyzed in narrative and descriptive ways. Most biogas adopters were male households with an average age of 47 years old, and most of them were married with an average household size of 6. Regarding their educational level, most of the biogas adopters were illiterate. In this study, it is found that the first biogas plant in the Tigray region was planted in 2009 through the National Biogas Program of Ethiopia. During the last seven years more than 3,600 biogas plants were installed in the region with an increasing annual biogas installation rate. However, the distribution was uneven as merely seven countries account for 70.85% of the global energy market. Although the medium-term market report of 2020 states that renewable sources of energy are in a good stand to lead the world’s energy supply and now represent more than 45% of overall supply, the distribution is uneven as merely seven countries account for 70.85% of the global solar and wind energy: China, United States, Germany, Japan, India, Italy, and Spain.

There is a growing demand for power supply in Africa. The demand in sub-Saharan Africa alone has risen by 45% since 2000. This implies that more built capacity is required to meet the demand of the outrunning population.

Currently, the African Biogas Partnership Program (ABPP), with technical assistance from SNV (Netherlands Development Organization), is developing the biogas sector by promoting quality standards, results-based financial solutions, awareness campaigns, and advocating for appropriate government support and policy. The program is being implemented in five countries of Africa: Uganda, Kenya, Tanzania, Ethiopia, and Burkina Faso.

Landfill gas is the other unexploited source of renewable energy in Africa. The Ethiopian Electric Power Authority estimated that a total of 24 MW power can be produced from landfill gases. However, there are currently no well-managed landfill sites, and almost all the current sites are non-engineered open dump sites.

Africa’s energy situation illustrates the necessity and urgency of investing in the development of decentralized renewable energy technologies for rural and poor communities. Ethiopia is no exception to this situation. A large number of studies, stretching over 25 years, have attempted to understand either the environmentally concerned individual or environmentally friendly behavior. A majority of the studies were concerned with creating
a profile of an environmentally friendly consumer based on either demographic or personality variables. Research evidence available in the case of demographic variables is very inconsistent; while some studies report a positive relationship, there are others that dispute this claim.2

Ethiopia has the largest cattle population in Africa. This indicates that the nation has higher potential to make use of biogas for rural energy supply. Thus understanding how individuals make decisions is important for researchers and intervention designers concerned with the impact of human behavior on energy use and the environment.8 To understand future energy use with the intention of delivering achievable acceptable emissions of carbon, it is necessary to understand all the external and internal influences around energy use, the technologies or processes, the adopters of such processes, and the environment in which they reside.9 Hence, policy makers will be able to implement sound policy, and practitioners will be able to deliver lasting solutions.

This study deals with environmental aspects and dissemination processes of biogas, including the promotion, financing, construction, operation, and after sales services of the plant. According to Mendis and Van Nes,10 promotion in biogas leads to awareness; information to evaluation; and persuasion to adoption. After adoption, financing and construction lead to installation of the biogas plant. Proper operation and after sales service are critical to keep the biogas plants functioning well, which is a precondition for future credible promotion. This theoretical framework is used as a conceptual model to analyze dissemination of biogas plants at the household level.

The dissemination process of biogas plants highly determines the use and adoption of biogas plants in rural areas. Therefore, the main objective of the study is to assess the dissemination process of biogas plants in rural households of the Tigray region. Particularly, the study aims to explain the current status of the biogas development program; assess the key steps in the dissemination process of biogas plants; and examine the environmental aspect of biogas use in the region.

2. Research design

The main objective of the study is to assess the dissemination process of biogas plants in the Tigray region, Ethiopia. To achieve the objectives of the study, descriptive research, which incorporates both qualitative and quantitative research approaches, was applied. This is mainly to describe the existing realities and phenomena numerically and in a meaningful way. To efficiently collect factual data from the sampled population using questionnaires, a survey research strategy was employed. Moreover, an approximation of a longitudinal study with cross-sectional design was used for the time dimension of the study so as to solicit data about the past.

2.1. Methods of data collection

To flexibly view the units to be observed and to capture data about environmental aspects of biogas development, unstructured observation (with flexible schedules) was used and planted biogases were observed. Semistructured interviews were used to acquire data from the head office of the regional biogas program coordination office. This was essentially to make the interview guided by flexible schedules for asking elaboration and to make the interviewee more relaxed. This technique was used to gather data on the trend and current status of biogas development, the biogas dissemination process, and financing mechanisms of biogas development.

Both open and closed-ended questions were administered to sampled biogas adopters. This is to obtain structured responses and self-expressed opinions from the biogas users concerning the data that are important to analyze environmental and technical aspects of biogas development.

Data regarding total number of biogas plants and the requirements for biogas plant adoption in the region were generated from archives such as reports, brochures, promotional materials, and training manuals available at the Tigray Region Biogas Program Coordination Office.

2.2. Sampling techniques

A nonprobability sampling method was the sampling technique adopted for this study. A purposive sampling technique, which is one type of the nonprobability sampling methods, was used to select the target population from which the sample for the study was taken. This was basically to gather pertinent data and to achieve objectives of the study. Furthermore, a snowball sampling technique was employed to select respondents from the total biogas users. This was due mainly to the scattered location of the biogas users.

2.2.1. Population

The Tigray region is one of the nine regions of Ethiopia, found in the northernmost part in an astronomical location of 14° 10’ N and 38° 50’ E. The region has 34 districts (the lower administrative sector next to region and zone). According to the 2015 population projection data, the region has an estimated 5.4 million population. Persistent erosion, deforestation, and overgrazing have left the region with dry and treeless plains, hills, and plateaus. Nevertheless, the region has an amazing landscape of chains of mountains ranging from 3,250–3,500 meters. The climate of the region is characterized as semi-arid (39%), warm temperate (49%), and temperate (12%). The average annual rainfall is between 450–980 mm. According to 2011 survey data, the region has a cattle population of 3,630,957.

According to the Tigray Region Biogas Program Coordination Office, there are more than 3,600 biogas plants in Tigray, of which more than 1,500 biogas plants are found in two districts of the region (i.e., Hintalo Wajirat and Ofla districts). The sample for the study was selected based on the total number of biogas plants found in each district. Thus the research was limited to four districts of the region with a higher number of biogas plants. Accordingly, Hintalo Wajirat, Ofla, Kilte Awlaelo, and Enderta districts were selected for drawing the sample size of the study.

2.2.2. Sample size

There were a total of 2,202 biogas plants in the selected four districts. Based on Godden,11 if the population is less than
50,000, the following sample size determination formula is appropriate when dealing with descriptive statistics. Therefore, the following formula was adopted to determine the number of respondents for the study.

Sample size = \( Z^2 \times P (1-P)/C^2 \), where \( Z = \) confidence level, \( P = \) percentage of population picking a choice and \( C = \) confidence interval. New sample size will be:

Sample size/1+ (sample size-1)/population. Assuming 95% of confidence level, the sample size for this study is calculated as:

\[ 1.96^2 \times 0.5 (1-0.5)/0.7^2 = 196. \]

The final sample size will be:

\[ 196/1 + (196-1)/2202 = 180.14. \]

Therefore, 180 was the final sample size for the study. As depicted in Table 1, the distribution of this final sample size to each district was proportionate.

### 3. Results and discussion

#### 3.1. Profile of biogas adopters

Socioeconomic and demographic characteristics of households are important determinants of biogas adoption behavior. Most (68.13%) of the biogas users in the study area were males. The rest (31.67%) were female biogas users.

As shown in Table 2, the average age of biogas users was found to be 47. The minimum and maximum age of biogas users during the survey was 15 and 79 years old, respectively. Further, the average household size was 6, with maximum household size of 12 and minimum household size of 1.

Regarding the marital status of biogas users, the majority (91.2%) of the biogas users were married. Very few (1.1%) of the biogas users were widowed, whereas the rest (4.4%) and (3.3%) of the biogas users were single and divorced, respectively. Most of the biogas adopters were illiterate (51.6%) and in primary level of education (43%). Only a few (5.5%) of the biogas users were in secondary level of education and above (Figure 1).

#### 3.2. Current status of biogas development program in Tigray

Different countries have adopted various biogas development programs. Asia’s biogas program aims at developing a market for biogas as a sustainable energy source in selected countries such as Vietnam, Cambodia, and Bangladesh. A total of 299,908 biogas plants have been installed since 1992 in Asia and Africa. In 2009, a total of 53,617 biogas plants were installed, which is about 50% more than that installed in 2008. Due to the high investment costs, limited access to credit facilities, insufficient awareness-raising activities, and lower purchasing power of potential households, biogas development in Africa has been modest compared to Asian countries.

The government of Ethiopia in general and the regional government in particular are striving for rapid economic growth and better living standards of the people via adopting policies viable for poverty reduction and food self-sufficiency. These policies encourage the participation of private-sector and nongovernmental organizations.

Expansion and advancement of alternative energy sources is one of the accentuated developmental programs of Ethiopia. In view of the fact that biogas is one of the alternative renewable energy sources, the regional government of Tigray had launched a 5-year project plan to adopt 3,400 biogas plants in the first phase of the Growth and Transformation Plan. Of these planned adoptions, 3,000 biogas plants are installed in the region. Furthermore, the regional government has planned an adoption of 7,000 extra biogas plants for the second phase of the Growth and Transformation Plan.

The first biogas plant in Ghana was constructed in 1986 by the Ministry of Energy at the Greater Accra Region, with support from the Chinese government. Comparatively, biogas development is more recent in Ethiopia. The first biogas plant installation attempt in the Tigray region was made in 2005 by World Vision International Ethiopia. But the earnest endeavor failed for unidentified reasons. Four years later, the first successful installation of biogas plants came to exist in 2009 when 25 biogas plants were constructed in Hintalo Wajirat (13 biogas plants) and Ofa (12 biogas plants) districts. These biogas plants were installed by the National Biogas Program of Ethiopia. The program was designed with five years of implementation with the aim of developing a commercially viable domestic biogas sector in Ethiopia. Specifically, the program was designed to:

- Attract and strengthen institutions and organizations for the development of a national biogas sector;
- Construct 14,000 biogas plants in the four selected regions over a period of 5 years;

### Table 1. Sample size distribution along selected study sites.

| Name of district | Total biogas adopters | Percentage share | Final sample size |
|------------------|-----------------------|------------------|------------------|
| Hintalo Wajirat  | 1050                  | 47.68            | 86               |
| Ofa              | 516                   | 23.43            | 42               |
| Kilte Awlaelo    | 349                   | 15.85            | 29               |
| Enderta          | 287                   | 13.04            | 23               |
| Total            | 2202                  | 100              | 180              |

### Table 2. Age and household size of biogas plant adopters.

| Age of Respondents | N  | Valid | Missing | Mean | Minimum | Maximum |
|--------------------|----|-------|---------|------|---------|---------|
| 92                 |    |       | 47.08   | 15   | 79      |
| Household Size of Respondents | 93 | 0 | 6.02 | 1 | 12 |
• Ensure continued operation of the biogas plants installed under the program; and
• Maximize the benefits of all biogas plants installed.

Nowadays, there are more than 3,600 biogas plants installed in Tigray region. Table 3 illustrates the total number of installed biogas plants in Tigray region districts since 2009.

Table 3 shows that biogas plants are unevenly distributed along the region; 60.16% of biogas plants of the region are found in only four districts. Contrary to this, the Tahtay Adiabo and Tsegde districts did not have any biogas plants installed so far. The Hintalo Wajirat district has the highest (28.68%) number of biogas plants, followed by the Ofa district with a 14.09% share. This is because these two districts were the first to be selected for the first phase of uptake of domestic biogas plants by the National Biogas Program of Ethiopia. Their selection was based on the number of human and livestock population; the loss of vegetative cover as a consequence of severe deforestation, resulting in a huge rural household energy imbalance; the districts’ status with regard to educated human resources and technology adoption experience; the availability of relatively well-documented information; and a woody biomass consumption that exceeds annual production in more than two-thirds of the districts.16

Regarding the trend in annual biogas plant increments, Figure 2 shows that the total number of biogas plants installed each year has been growing at an increasing rate till 2014. The rate of growth goes down for the year of 2015. As per the coordinator of the Tigray Region Biogas Program, the diminishing rate happened partly because the El Niño–driven drought occurred in that year. The largest numbers of installed biogas plants was recorded during 2014, in which 862 biogas plants were installed during that year. In line with this, the highest biogas plants growth rate was recorded during 2010.

Figure 3 shows that most (34.5%) of the biogas users are recent adopters of biogas plants, while 25.8% and 27.7% of the biogas users have used biogas plants for six and five years, respectively.

There is a proven use of biogas to fuel a combustion engine to produce electricity.17 Cooking and lighting are the two sole functions of biogas in Tigray. Of these biogas users, 43% of them have been using biogas for both cooking and lighting; and 10.8% of them have been using biogas for cooking only. The remaining 3.2% of the users have been using biogas for lighting only. In spite of this fact, 43% of the biogas adopters have not started biogas use yet due to incomplete installation and technical problems of the biogas plant.

### 3.3. Dissemination of biogas plants in Tigray

Biogas system use in Tigray is recent, and it has certain requirements for biogas plant installation. Biogas plant demanders in Tigray need to fulfill the following requirements so as to adopt a biogas plant:

- Owning at least 4 cows/oxen;
- Near access to water supply;
-Able to produce electricity.

### Table 4: Purpose of biogas use.

| For what purpose do you use biogas? | Frequency | Percent | Valid Percent | Cumulative Percent |
|-------------------------------------|-----------|---------|---------------|--------------------|
| Valid                               |           |         |               |                    |
| For cooking                         | 10        | 10.8    | 18.9          | 18.9               |
| For lighting                        | 3         | 3.2     | 5.7           | 24.5               |
| For both cooking and lighting       | 40        | 43.0    | 75.5          | 100.0              |
| Total                               | 53        | 57.0    | 100.0         |                    |
| Missing                             | 99        | 100.0   |               |                    |

Source: Tigray Region Mines and Energy Agency, 2016.
Sufficient area for biogas plant installment;
Access to construction materials (sand, crushed and dry stone); and
Physical capability to excavate the pit for biogas plant, to muddle up the manure with water, to enter the manure and put out the slurry from the digester.

Specifically, the requirements vary based on the needed gas production as depicted in Table 5.

As an apex organization, Ethiopian Rural Energy Development and Promotion Center (EREDPC) is responsible for monitoring and evaluation of the overall biogas program activities. The center is also responsible for the approval of annual plans and reports.

For the day-to-day coordination of the program, EREDPC will delegate responsibilities to a semi-autonomous National Biogas Program Coordination Office (NBPCO). This office initiates, coordinates, and monitors the activities within the biogas sector, and it is responsible for accounting, financial procedures, and staff management. Reporting to EREDPC, the NBPCO will work with both the private and public sectors of the program stakeholders/partners. Representatives of the main national-level program actors will form a Biogas Sector Steering Committee for advising on policy and program matters that relate to program implementation.

Table 5. Required inputs for biogas plant installation.

| Requirements                          | Amount of gas production |
|--------------------------------------|--------------------------|
|                                      | 6m³ | 8m³ | 10m³ |
| Construction stone in m³             | 4.5 | 5   | 6    |
| Number of cattle Released (graze outside) | 6   | 8   | 10   |
|                                      | 4   | 6   | 8    |
| Sand in m³                           | 2.3 | 2.5 | 2.8  |
| Water tube                           | 2   | 2   | 2    |
| Required amount of manure for the first fill up in quintal | 23 | 30 | 38 |
| PVC (110 mm) tube in meters          | 4   | 4   | 4    |
| Steel (8 mm)                         | 4   | 4   | 5    |

Source: Tigray Mines and Energy Agency, Biogas Coordination Program (2016).

SNV-Ethiopia and other local capacity-builders will provide technical assistance through advisory services, resource mobilization, and knowledge brokering.

At the regional level, the Mines and Energy Agency or Energy Departments will play a role comparable to that of EREDPC, while the regional Biogas Program Coordination Offices will coordinate, facilitate, and monitor day-to-day program activities; also, they will establish partnerships with the Bureaus of Agriculture and Rural Development (BoARDS) for the promotion of biogas technology through the extension network of the BoARDS at the zonal, district levels. In a similar way as at a national level, all biogas activities will be periodically monitored and advised by a regional Biogas Sector Steering Committee (RBSSC).

In the Tigray region, considering the multiple benefits of biogas, several stakeholders are involved in the dissemination process of biogas plant. At a regional level, the Bureau of Water Resources, Mines, and Energy Agency, the Bureau of Agriculture and Rural Development, the Bureau of Health, the Bureau of Gender, and financial institutions are the current stakeholders of biogas development. The Tigray Biogas Program Coordination Office leads the integration among these stakeholders. Furthermore, micro-financial institutes, private sectors, and NGOs cooperate with biogas users at the district level.

Figure 4 depicts the institutional arrangement of biogas development in federal, regional, and district levels.

Clearly, despite the promising features of biogas development, the dissemination of a domestic biogas program is not “plain sailing.” SNV-Ethiopia has identified the important constraints of the biogas dissemination process:16 the low level of disposable income of most rural households; the scarce availability of water; the very limited rural dissemination infrastructure in combination with the scattered population pattern; the gender imbalance in decision making at the household level; and the low awareness of alternative energy technology in general and domestic biogas in particular.

While discussing the biogas dissemination process, it is important to analyze how the key dissemination steps in the biogas plant market are passed through. According to Mendis and van Nes,10 the key dissemination steps in biogas development are identified. In the Tigray region, these biogas plant dissemination processes are discussed below.

3.3.1. Promotion
An essential part of any marketing strategy for biogas plants is the quality of the product and the services. As the investment for a biogas plant is high, low-quality plants with a short lifespan is not advisable. Furthermore, a well-functioning plant is the best possible promotional tool and the satisfied user the best possible promoter for biogas technology. Therefore, control of quality regarding plant sizing, construction, user training on operation and maintenance, and after-sales services will be of utmost importance, especially during the pilot phase of the program. Countries such as China and India benefit much from the massive campaigns they made to popularize the technology.17

In the Tigray region, the media is the main promotional tool in endorsing biogas use. Radio and newspapers are among the widely used tools to promote biogas use. The office of Biogas
Coordination Program has a 15-minute weekly radio program to endorse biogas promotional works. Workshops, satisfied customers telling friends, demonstrations, and field visits are the other tools used to promote biogas use.

In Nepal, investment subsidies are the most important element of the promotion program. In the Tigray region, the National Biogas Program of Ethiopia, 2014.
also, potential biogas adopters are told about the subsidies given to biogas adopters.

Adoption behavior of potential biogas plant users plays an important role in the dissemination of biogas plants. Because of changes in user behavior, five complete patterns of biogas production and digester management were established in Bolivia. In the Tigray region, the “satisfied customer telling friends” approach could be used as an important promotional tool. Data from the field survey indicate that 79% of the biogas plant adopters were comfortable with biogas use. Those satisfied users have a prominent role in further mounting biogas plant particularly to their neighborhood.

Table 6 shows that 42 satisfied customers have promoted biogas use for 350 potential users, and 192 of them have adopted biogas plants. This means that one satisfied user has promoted biogas use for an average of eight potential users, and an average of five individuals have adopted biogas due to the promotion. Table 6 reveals that one satisfied user has promoted biogas use to up to 50 potential users, and 20 of them have adopted biogas plants.

### 3.3.2. Information

In the Tigray region, personal observation, house-to-house promotion, and training are the basic strategies used to inform potential biogas users.

Table 7 shows that most (30.1%) biogas adopters become aware of biogas plants via personal observation, and 24.7% of them come to know biogas via house-to-house promotion conducted by the agency for Biogas Program Coordination. On the contrary, limited number of adopters becomes aware of biogas via media and local meetings.

### 3.3.3. Persuasion

The Biogas Program Coordination Office uses demonstration for the sake of convincing potential users beyond the tools used to inform users. The field survey indicates that most (96.1%) biogas users were influenced by the information they gained from the training, media, and house-to-house promotion.

### 3.3.4. Decision/Adoption

Age and formal education level of household head, household size, number of cattle owned by the household, and the costs of fuel wood and kerosene are the important determinants of biogas adoption behavior in Uganda. If users agree to adopt biogas plants, they need to ensure that they have fulfilled the requirements needed for biogas plant installation, that is, sufficient area to install the biogas; sufficient number of cattle; access to water and construction inputs (sand, stone, and cement), and physical capability of handling the biogas operation. After fulfilling all these requirements, biogas adopters need to register for construction. After the concerned bodies ensure that the potential adopter is eligible for installation, the adopter will be advised by technical experts on how to dig the pit for placing the plant. The data obtained from the field survey indicates that all biogas users had more than three cows/oxen before their biogas plant installation.

### 3.3.5. Financing

Effective and widespread implementation of domestic biogas technology depends on government subsidy on planning, design, construction, operation, and maintenance of biogas plants. In Kenya, tubular reactors, owing to their sustainability, attracted a higher subsidy grant (84%) compared to fixed dome and floating drum reactors, which is 50% and nil, respectively. Biogas development in Ethiopia is a half-funded investment. The price of a biogas plant varies based on location and season, but the average price of a single biogas plant is estimated to be ETB 13,000 (582.7 USD) for a biogas plant with a 6 m³ gas volume, ETB 13,500 (605.1 USD) for a biogas plant with a 8 m³ gas volume, and ETB 14,000 (627.5 USD) for a biogas plant with a 10 m³ gas volume. Of which, half of the price is subsidized by the federal government (10%), the regional government (5%), and the rest of the payment is funded by the Africa Biogas Partnership Program. SNV, on the other side, provides the technical support. Subsidies are given in the form of appliances (lamp, stove, iron bar, gas hose, and cement) that are crucial for the proper functioning of biogas plant.

Local biogas adopters need to cover rest of the work, which is estimated to be half of the price of a biogas plant. These include the cost of construction inputs such as sand, crushed and dry stone, and labor cost. For those who are unable to afford the price, loan opportunities are arranged by the Dedebit Micro Finance of the respective districts.

### 3.3.6. Construction

A domestic biogas plant is a simple structure constructed under the ground to convert animal dung and human excrement into a valuable quantity of biogas, composed mainly of methane and carbon dioxide. Many different types of biogas reactors are in use throughout the world. The general designs used in developing countries are low-rate digesters that are simpler than those in more developed countries and lacking heating and stirring capability. In Ghana, there are three main types of biogas designs that have been disseminated: the fixed-domed, floating

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**Table 7. Ways of biogas promotion.**

| How did you become aware of biogas plant? | Frequency | Percent | Valid Percent | Cumulative Percent |
|------------------------------------------|-----------|---------|---------------|--------------------|
| Valid                                    |           |         |               |                    |
| Training                                | 16        | 17.2    | 19.8          | 19.8               |
| Media                                   | 4         | 4.3     | 4.9           | 24.7               |
| Personal observation                     | 28        | 30.1    | 34.6          | 59.3               |
| House to house promotion                 | 23        | 24.7    | 28.4          | 87.7               |
| Rumor                                   | 7         | 7.5     | 8.6           | 96.3               |
| Local meeting                           | 3         | 3.2     | 3.7           | 100.0              |
| Total                                   | 81        | 87.1    | 100.0         |                    |

**Table 6. Effectiveness of “satisfied customer telling friends” promotional approach.**

| Number of potential users advised by satisfied users | Sum | Mean | Minimum | Maximum | % of Total Sum |
|-----------------------------------------------------|-----|------|---------|---------|----------------|
| Number of installed biogas by the advisee           | 350 | 8.33 | 1       | 50      | 100.0%         |
| Total number of installed biogas by the advisee     | 192 | 4.57 | 0       | 20      | 100.0%         |
drum, and Puxin digester. Similarly, floating drum, fixed dome, and inflatable tubular reactors are the three types of tested biogas plants operating in Kenya.

A fixed-dome biogas plant is the only biogas design in Ethiopia that comprises a dome-shaped digester with a fixed gasholder. Household scaled biogas plants in Ethiopia are classified according to their gas volume: biogas plants with a gas volume of 6 m³, 8 m³, and 10 m³. More than 90% of the sampled biogas plants were with 6 m³ of gas volume. These biogas plants are based on cow manure and have 160–190 cm of length of outlet and 50–62 cm radius of digester. The height of the digester wall ranges from 85–95 cm. The biogas plant with higher length of outlet, radius, and height of digester are those that produce higher biogas volume.

An important factor in the development of a biogas plant is the quality and design of its construction. Most parts of the biogas construction are done by the biogas plant adopter. However, the technical part of the construction is assisted by experts hired by the coordination office for the biogas program.

Biogas stove, lamp and its appliances, gas controller, and payment for builders are the assistance forms given during construction of a biogas plant. Data obtained from the field survey indicate that most (92.5%) of the biogas users claimed that they have gained external assistance during their biogas plant construction.

Table 8 shows that most (21.2% and 20.8%) of the assistance was technical and material, respectively, whereas training and financial assistance has accounted for 12.3% and 11.2%, respectively.

### 3.3.7. Operation

The successful operation and maintenance of biogas plants is a common responsibility of the owner and technical builder. Technical experts check the startup and operation of installed biogas plants. However, the field survey results reveal that most biogas plants are out of use. Table 9 shows that most (58.1%) of the installed biogas plants are nonoperational. Similarly, a survey of biogas plants in Bangladesh found that 3% were functioning without defect, 76% were defective but functioning, and 21% were defective and not functioning.

As per Figure 5, the main reason for the abandonment of biogas plants is found to be technical maintenance–related causes. This is linked to the lack of regular follow-up and inadequate emphasis on maintenance of these plants. For the same reason, up to 50% of biogas plants in many other developing countries are non-functional.

Lack of sufficient manure to operate the biogas is the other reason to stop functioning of installed biogas plants. This happened after adopters sold their cattle for many reasons. Lack of complete appliances (lamp, stove, gas hose, and the related) is found to be the other reason for the stoppage of 9.2% of the disused biogas plants. According to the biogas users, this happened because of incomplete installation.

### 3.3.8. After sales service

The main aim of after sales service is to have good functioning biogas plants with satisfied and positive users, leading to farmer-to-farmer promotion. To ensure the success of biogas plants, an after sales service program is required to follow. In Nepal, the required after sales service consists of:

- One-year guarantee on pipes, fittings, and appliances;
- Six-year guarantee on the structure of the plant;
- An annual maintenance visit for five years of the guarantee period; and
- A response visit after the owner has lodged, in writing or verbally, a complaint at the office of the company valid for a period of six years.

In Tigray, a significant number (58.62%) of biogas adopters claimed that there was not any concerned body assigned to supervise their biogas plants and fix any biogas plant problems. Though some of the biogas adopters used to report for concerned bodies, they could not get any response. For this reason, most of the biogas users with abandoned biogas plants remain silent until experts are sent to fix their problem. Nevertheless, data gained from the Biogas Program Coordination Office indicates that planted biogases have a two-year guarantee in which ETB 200 (USD 8.95) is reserved for its maintenance during occasions of problems.

### 3.4. Environmental aspect of biogas development

One way of analyzing environmental aspects of any activity is to observe the life cycle of activities in the glass of environmental issues. To analyze the environmental aspects of biogas development, it is important to examine the life cycle of biogas operation. The main environmental issues linked with biogas operation are discussed in the following.

#### 3.4.1. Loss of green habitat

Apart from the feedstock utilization, biogas production is also associated with environmental resource depletion. The biogas plant installation process requires a considerably large area that is 9 m² with 110 cm of depth for the biogas plant placement and two pits of 2 m² with 100 cm of depth each for compost preparation. Since this requires an excavation process, biogas adopters prefer to place their biogas in non-stony and green areas. This causes the loss of green areas that can potentially regulate the climate.

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**Table 8. External assistance gained by biogas adopters during construction.**

| Types of external assistance | Material | Financial | Technical | Training | Other | Total |
|-----------------------------|----------|-----------|-----------|----------|-------|-------|
| Responses                   | 56       | 30        | 57        | 33       | 0     | 269   |
| Row %                       | 60.2%    | 32.3%     | 61.3%     | 35.5%    | 0.0%  | 100.0%|
| Row Responses %             | 20.8%    | 11.2%     | 21.2%     | 12.3%    | 0.0%  | 100.0%|

**Table 9. Current operational status of biogas plants.**

| Is your biogas plant operational now? | Frequency | Percent | Valid Percent | Cumulative Percent |
|---------------------------------------|-----------|---------|---------------|--------------------|
| Valid                                 | yes       | 39      | 41.9          | 41.9               | 41.9               |
| No                                    | 54        | 58.1    | 58.1          |                    | 100.0              |
| Total                                 | 93        | 100.0   |               |                    | 100.0              |

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3.4.2. Manure management

The disposal of dung and urine dispersedly is one of the major problems associated with raising cattle. Livestock-raising operations impact the environment through improper disposal of manure, which could emit greenhouse gases, especially methane and nitrous oxide. Most of these impacts occur exclusively on or near the farm. Methane emissions have a negative impact on air quality, human health, fauna and flora, and soil and water quality. However, the magnitude, complexity, duration, and frequency of the impact vary based on the scale of livestock numbers.

The use of animal dung to produce biogas is one of the solutions to minimize the risk. When manure is properly managed for biogas use, it can produce power for cooking and lighting. Furthermore, its nutrient content makes an excellent fertilizer, which promotes crop growth, increases soil organic matter, and improves overall soil fertility. In this regard, composting the manure and using it for crop production could be one option to mitigate the environmental pollution problem.

As shown in Table 10, most (48.4%) of the biogas users claimed that their manure management is improved after their biogas plant adoption.

| Does your biogas adoption contributed to your manure management? | Frequency | Percent | Valid Percent | Cumulative Percent |
|---------------------------------------------------------------|-----------|---------|---------------|--------------------|
| Valid                                                         | 45        | 48.4%   | 77.6%         | 77.6%              |
| No                                                            | 3         | 3.2%    | 5.2%          | 82.8%              |
| Not certain                                                   | 10        | 10.8%   | 17.2%         | 100.0%             |
| Total                                                         | 58        | 62.4%   | 100.0%        |                    |
| Valid                                                        | 35        | 37.6%   |               |                    |
| Missing                                                       | 93        | 100.0%  |               |                    |

3.4.3. Cut methane emissions

Biogas systems can be used to capture methane that would escape into the atmosphere, which has a warming effect that is 21 times greater than that of carbon dioxide and contributes to climate change, and use it to create energy instead. The 239 livestock biogas systems currently operating in the United States reduce methane emissions by approximately 2 million metric tons of carbon dioxide equivalent annually.

The diversion of organics from landfills, collection of landfill gas, and anaerobic digestion at wastewater treatment plants can also decrease methane production and release. This means that there is potentially a developing market demand for offsets from dairy and swine manure digester projects.

3.4.4. Reduced indoor air pollution

Households that adopt biogas plants are better off in terms of their food security status, less affected by indoor air pollution–related diseases, consume less fuel and dung, and use more inorganic fertilizer than their counterparts.

Most of the biogas users reported that the main advantage they received from biogas use is its reduced indoor emission and the limited time it requires for creating flames.

3.4.5. Reduce nitrous oxide emissions

Inorganic fertilizers have a larger physical footprint versus composting. Increased use of inorganic fertilizer in the past 50 years has dramatically boosted the atmospheric concentration of nitrous oxide, which is a major greenhouse stratospheric ozone-depleting gas contributing to global climate change. Using biogas slurry as a farming fertilizer can halt nitrous oxide emission from chemical fertilizers.

Study results indicate that biogas slurry is of superior quality to any other fertilizers. Crop productivity can be significantly increased if the bio-slurry is used appropriately. Field experiments carried out in China have produced the following result:

- Compared to the control, application of digested slurry increased the rice, barley, and rice yields by 44.3%, 79.8%, and 31%, respectively.
- Compared to FYM (farmyard manure), application of digested slurry increased the rice, maize, and wheat yields by 6.5%, 8.9%, and 15.2%, respectively.

The national bio-digester program in Vietnam has reported the following findings:

- Use of bio-slurry that replaced chemical fertilizer in tea farming improves quality of tea product and helps to increase yield by 11%.
- Use of bio-slurry to replace NPK (nitrogen, phosphorus, and potassium) in vegetable farming helps to increase the yield by 20% and to reduce the incidence of pest insects considerably.

Most biogas users (37.6%), as shown in Table 11, claimed that they use the slurry as fertilizer for their crop production. But many others did not use the bio-slurry as fertilizer partly because their recently adopted biogas plant did not start producing bio-slurry.

Bio-slurry is rich in important nutrients such as protein, cellulose, and lignin that are crucial for soil fertility, and it cannot be found in chemical fertilizers. This has great significance in maintaining ecological balance via nutrient recovery and recycling.

3.4.6. Reduction of carbon emissions

Biomass combustion in rural areas is the main source of carbon emissions. Biogas use replaces other carbon-based sources of energy such as fuel wood, coal, kerosene, and animal dung. The use of these sources of energy significantly emits carbon dioxide gas. Considering the carbon emission savings due to

| Table 11. Do you use the bio-slurry as fertilizer for your crop production? |
|-----------------------------------------------------------------------------|
| Frequency | Percent | Valid Percent | Cumulative Percent |
|-----------|---------|---------------|--------------------|
| Valid     | Yes     | 35            | 37.6%             | 62.5%              |
|           | No      | 21            | 22.6%             | 37.5%              |
|           | Total   | 56            | 60.2%             | 100.0%             |
| Missing   | 99      | 37            | 39.8%             |                    |
| Total     |         | 93            | 100.0%            |                    |
energy and fertilizer substitution, the annual CO₂ emission reduction potential of using biogas system is 1.25 tons.²⁷

A total of 299,908 biogas plants installed in 14 counties of Asia and Africa produce more than 600,000 m³ of biogas per day, which is equivalent to 3,000 tons of fuel wood or 900 megawatt-hours of electricity.¹⁴ As shown in Figure 6, most (88.3%) of the biogas adopters had been using fuel wood as their main source of energy. This indicates that the biogas system is averting a significant amount of carbon emission to the atmosphere from the combustion of 1.17 tons of fuel wood.

### 3.4.7. Protect the environment

Domestic biogas plants can help to achieve sustainable use of natural resources, as well as reduce greenhouse gas emissions, which protects the local and global environment. This plays an important role in ensuring environmental sustainability, which is one of the elements of Millennium Development Goals.

In addition to reducing greenhouse gas emissions, one of the many environmental benefits of a biogas system is the preservation of the environment by significantly reducing the rate of deforestation. Most African people rely on biomass as source of energy. Biomass is the chief source of energy in Malawi (94%), Tanzania (92%), and Sierra Leone (75%).²⁸ In Ghana, 72% of the primary energy supply emanates from wood fuel.¹⁵ Correspondingly, above 90% of Ethiopia’s energy supply rests primarily on biomass.

As shown in Table 12, the current biogas users were using fuel wood from three different sources: 31.2% biogas users were collecting fuel wood from personal plantations, and 12.9% of the biogas adopters were using fuel wood from public forests for the sake of their energy use. The rest were using a purchased fuel wood.

Furthermore, biogas plants are designed primarily to slot in human stool into the biogas plant. Table 13 shows that 76.3% of the biogas users’ toilets are connected with the biogas plant. This contributes greatly to environmental management.

### 4. Conclusions

The dissemination process of biogas plants highly determines the use and adoption of biogas plants in rural areas. For this purpose, the main objective of the study was to assess the dissemination process of biogas plants in rural households of the Tigray region. In line with this, the study attempted to explain the current status of biogas development in Tigray and to examine the environmental aspect of biogas use in the selected districts.

### Table 12. Source of fuel wood before biogas adoption.

| Source of fuel wood before biogas adoption | Frequency | Percent | Valid Percent | Cumulative Percent |
|------------------------------------------|-----------|---------|---------------|--------------------|
| Personal plantation                      | 29        | 31.2    | 53.7          | 53.7               |
| Public forest area                       | 12        | 12.9    | 22.2          | 75.9               |
| Purchasing                               | 13        | 14.0    | 24.1          | 100.0              |
| Total                                    | 54        | 58.1    | 100.0         |                    |
| Missing                                  | 39        | 41.9    |               |                    |
| Total                                    | 93        | 100.0   |               |                    |

The first biogas plant in Tigray was planted in 2009 at the Hintalo Wajirat and Ofa districts. At present, there are more than 3,600 biogas plants installed in the region. Most of these biogas plants were installed by the National Biogas Program, Ethiopia. This study disclosed that there is uneven distribution of biogas plants in the Tigray region. But the trend figure shows that the total number of biogas plants in Tigray is growing with an increasing rate. And the expansion of biogas plants to the other potential areas of the region is heartening. In this study, the main purpose of biogas plants is found to be cooking and lighting.

The Ethiopian Rural Energy Development and Promotion Center, Bureau of Water Resources, Mines, and Energy Agency, Bureau of Agriculture and Rural Development, Bureau of Health, Bureau of Gender, SNV-Ethiopia, Mines and Energy Departments, Bureaus of Agriculture and Rural Development, National Biogas Program Coordination Office, micro financial institutes, and private sectors are the main stakeholders of biogas development in the Tigray region.

The requirements that need to be fulfilled by potential biogas adopters for installation are: owning at least 4 cows/oxen; near access to water supply; sufficient area for biogas digester installment; access to construction materials (sand and stone); and physical capability to excavate the pit for biogas plant, to muddle up the manure with water, and to enter the manure and put out the slurry from the biogas plant.

In the Tigray region, biogas use is promoted through media (radio program), demonstrations, workshops, and satisfied customers telling friends. Findings of the study indicate that the “satisfied customer telling friends” approach is found to be an effective promotional tool. Personal observation was also found to be the tool that informed most of the biogas adopters about biogas system benefits.

The average price of a biogas plant ranges from ETB 13,000–14,000 (USD 582.7–627.5). Half of the price is funded by donors, the federal government, and the regional government in the form of appliances and technical builders’ payment, whereas the rest of the funds are provided by the adopters themselves, which are basically estimated to cover the construction part of the system. During the construction phase, most biogas users claimed that they have gained governmental assistance.

This study discovered that a significant number of biogas plants are not giving service mainly due to technical problems. And many of the adopters with disused biogases stated that there is not any concerned body to look after the biogas plants in case of problems.

Regarding the life-cycle analysis of the biogas system, it is found that loss of green habitat occurs during excavating pits for biogas plants. However, many other significant environmental benefits are found including reduced methane, carbon dioxide,
and nitrous oxide emissions and reduced indoor air pollution in general, connection of toilets with biogas digesters, use of bio-slurry as fertilizer, and preservation of the environment.

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