1. Introduction

The life of human being is highly dependent on energy consumption (IEA, 2011). In people’s daily lives, energy provides essential benefits for cooking, heating, lighting, food production and storage, industrial production, education, and transportation. In modern times, no country has managed to substantially reduce poverty without increasing energy resources and its efficient utilization (Rao et al., 2009). Energy consumption level is a good indicator of economic development level of a country because the energy sector has strong impact on poverty reduction through income and the environment linkages (Sayin et al., 2005). Today, in African countries, reliance on and appliances of traditional biomass energy could be a problem for sustainability of energy resource which leads to hold back economic development (Karekezi, 2002). For many Sub-Saharan Africa (SSA) countries including Ethiopia, the energy consumption and demand is continuously increasing as development progresses and population growth is faster increasing. However, the modern domestic energy supply is disproportionate with its demand (Amigun et al., 2008). About 83 % of the total population in SSA countries and 91 % in least developed countries have no access to modern fuels (Legros et al., 2009). Like other SSA countries, Ethiopia is highly dependent on traditional biomass for domestic energy (for cooking, heating and lighting); more than 93 % of its population obtains energy from biomass (WHO, 2006). The interest of having access to modern and renewable energy in Ethiopia has been increasing as the rural community is suffering from energy crisis and ever increasing cost of chemical fertilizers (Mengistu et al., 2016). The use of chemical fertilizers becomes dominant and its volume is growing up annually with unaffordable prices (Mengistu et al., 2016; Eshete et al., 2006).

Many Ethiopians face quality of life and livelihood challenges associated with sub-optimal sanitation, dependence on biomass energy, and decreasing agricultural productivity (Abadi et al., 2017). Rural domestic energy supply in Ethiopia is (virtually) entirely biomass based. Firewood has been used to supply the needs for cooking in rural Ethiopia. The country experiences an energy and environmental crisis due to the sustained reliance on woody biomass to satisfy its energy needs. This situation could be improved by using biogas (Kamp and Forn, 2016). Furthermore, biomass fuel is becoming scarce and household productivity is being affected by the reallocation of time and labor from yield bearing activities to the collection of biomass energy, which have led to reduced rural economy (Amare, 2014). In combination with the increasing pressure of the rural population, this has led to rapid depletion of natural resources and degradation of the environment in large areas of the country (Eshete et al., 2006). Due to the ongoing deforestation and shortage of firewood, households need to look for other energy sources where a large number of people are use residues from agriculture (straw, manure) instead. However, both straw and manure also have a function in agriculture for soil improvement (Bewket, 2012). Using all the straw and manure will seriously affect the food production. Rural households require about five to seven Giga Joule energy for cooking annually. Up to 4 ha of land or 15 cows are needed to provide enough straw and manure to cook on the traditional three stone fires. When more efficient techniques are used (briquetting, biogas) this can be reduced to 2 ha and six cows. This indicates that the use of improved energy conversion technology can help to save about 60 % biomass. However, a large variation in resource availability exists between households. About 80 % of the households
own less than 2 ha and 70% holds less than four cows. This means that, even when modern, energy efficient techniques are used, the largest share of the population is not able to generate enough energy for cooking (Tucho and Nonhebel, 2015). The deployment of biogas energy as alternative energy source can have the potential to fill the gap in the energy needs of the rural community if it is effectively managed and appropriately utilized (Kelebe et al., 2017). Bio-energy is a major energy source providing more than 80% of the energy demand in Ethiopia. Biogas is the emerging bio-energy in the rural area of Ethiopia through biogas development program for potential households (Gabisa and Gheewala, 2019).

SNV is supporting the implementation of market-based domestic biogas programs in different countries in Asia and Africa with a view to establish a commercially viable biogas sector (Ghimire, 2013). Economic viability of the biogas plants are measured by comparing prior expenditure (before implementing biogas plant) for firewood, kerosene, and other conventional sources. Economic viability refers to an estimator that not only seeks to maximize the effectiveness of financial viability but also considers environmental externalities. Although economic viability of biogas is sensitive to kerosene price, firewood availability, this study reveals that biogas is economically more attractive when women could render their saved cooking time for other income generating green jobs. Biogas plant results a number of income generating new green employments for the rural community in Bangladesh (Chakrabarty et al., 2013). Individual households judge profitability of biogas plants primarily from monetary surplus gained from utilizing biogas and bio-fertilizer in relation to the cost of the plants. Economic cost-benefit analysis is the most efficient and widely used tools for measuring whether any investment would be beneficial or not along with their environmental and social concern (Chakrabarty et al., 2013; Gwavuya et al., 2012).

As most of the rural households are involved in (subsistence) farming, integrating agriculture and animal husbandry, domestic biogas could theoretically not only foresee in the need for cooking energy, but also provide a good source for organic fertilizer (Eshete et al., 2006). Therefore, biogas energy is appropriate technology for rural community of Ethiopia as it has multiple benefits such as use of clean energy for cooking and lighting, use of bio-slurry as organic fertilizer and income generation through reducing the use of purchased fuels (firewood, charcoal and kerosene) and chemical fertilizers (Erdogdu, 2008; Bewket, 2012). Technical issues like the availability of feedstock (water and cow dung), and existence of conducive temperature for operation of biogas production make Ethiopia a country with abundant potential for biogas installation (Eshete et al., 2006). Thus, Ethiopia has launched National Biogas Program (NBPE) in 2009, for dissemination of domestic biogas technology through a subsidy modality for at least one million households. Despite the numerous dissemination efforts, the economic potential of the technology has been largely remained indefinable, household are still doubtful to invest in it.

Limited success in promoting improved energy sources, such as biogas, in rural areas of developing countries has been partly blamed on insufficient understanding of household energy use patterns (Gwavuya et al., 2012). In studying the cost-benefit analysis and financial viability of biogas plant installation and post-installation incomes generated in terms of a monetary value should be listed as benefits: expenditure saved by the substitution of other energy sources with biogas, income from the sale of biogas (when applicable), replacing cost of using chemical fertilizer by slurry, income from the sale of slurry (when applicable), time

Electronic copy available at: https://ssrn.com/abstract=3634030
saved for collecting and preparing previously used fuel materials (when applicable) (Garfi et al., 2012), time saved for cooking after utilizing biogas (when this time can be used to generate income), improved indoor air quality and consequent reductions in medical expenditure for respiratory infections. The biogas and bio-fertilizer produced can alleviate poverty, by improving health conditions, increasing crops productivity and saving working time and burden for women and children (Garfi et al., 2012). Similarly, the most important costs associated with biogas plant installation are manufacturing or acquisition costs (production costs) that includes capital costs. The production costs include all expenses and lost income which are necessary for the installation of the biogas plant e.g. the land, excavation work, cost of material for building the digester, gasholder and displacement pit (cement, bricks, blocks), gas stove, the piping system, the dung storage system etc. Operation and maintenance costs mean running costs including cost of raw dung or foregone revenue from sale of raw dung (Chakrabarty et al., 2013).

Installation of biogas plants for improving energy security and bio-slurry for increasing agricultural production are the two most important purposes behind domesticating biogas technology in rural Ethiopia besides that the technology is important for improving environmental health, reducing deforestation, and mitigating greenhouse gas emission. The installation of plants has both costs and incomes; installation and maintenance service demand financial costs but reduces costs for purchasing firewood, kerosene and chemical fertilizers regarded as benefits or incomes. In Ethiopia, there are scanty studies investigating the cost-benefit analysis and financial viability related to biogas plant installation and post installation costs and incomes. This study evaluated the cost-benefit analysis and financial viability of costs and incomes of biogas plant installation and post installation at household level in Aleta Wondo District, Southern Ethiopia.

2 Materials and methods

2.1 Description of the study area

Aleta Wondo District, the study area, is one of the 19 Districts in Sidama zone of the southern Ethiopia. It is administratively divided into 27 rural Kebeles1 with the total of 32,309 households. It is located at 337 km to the south of Addis Ababa, the country’s capital city and 62 km from Hawassa, the capital city of the regional state. It is located between 6°35’ and 6°40’ N latitude, and between 38°23’ and 38°26’ E longitude. According to the Central Statistical Agency (CSA) of Ethiopia, Aleta Wondo has a land area of 567.2 km² with a population of 191,592 of whom 97,364 are males and 94,228 are females while 175,055 rural and 16,537 are urban population (CSA, 2013).

Please insert Figure 1 here

1 “Kebele” is the smallest administrative unit in an Ethiopian Administrative Structure.
2.2 Sampling design and sample size

A multi-stage sampling technique was used for selecting sample households to be surveyed. First, the Aleta Wondo District was selected purposively for being the home of the largest number of biogas installations during the survey time. Secondly, the three Kebeles adopting biogas technology were selected purposively from 27 rural Kebeles based on the availability of biogas plants and the number of potential biogas adopting households relatively with higher experience in biogas energy generation and utilization. Finally, from each Kebeles’ 105 respondent households were selected randomly through simple lottery method.

Both qualitative and quantitative research techniques were applied in this study, including personal observations, focus group discussion, key informant interviews and questionnaire survey to gather primary data. Secondary data were collected from relevant published and unpublished sources like books, journal articles, internet, CSA of Ethiopia, reports from the District Energy office and Kebele administration offices.

2.3 Methods of Data Analysis

The collected raw data were coded, edited and organized using a Microsoft Excel. Then, the organized data were entered and analyzed using STATA version 13.1 at \( \alpha = 0.05 \). The qualitative and quantitative data were analyzed by using analytical methods such as descriptive statistics, inferential statistics, and economic analysis. The monetary benefits of household biogas plant were analyzed by paired-samples t-test. The cost of installation and maintenance service of biogas plant were analyzed using mean.

2.3.1 Estimation of costs and benefits

The cost and the benefits associated with the biogas plant were quantified and estimated on the basis of the valuation of the kerosene used, firewood used, and chemical fertilizer. The cost of locally available material was valued at current price of local market, while those of tradable components were valued at the current retail market prices. Annual maintenance cost was estimated as:

\[
M_c = 0.04C \quad (2.1)
\]

Where \( M_c \) is maintenance cost, \( C \) is the total installation cost.

In this study, the monetary benefits of biogas plant were computed only for the saved costs on firewood and kerosene substituted by biogas energy and saved costs on chemical fertilizer substituted by bio-slurry because of in the study area; there is no direct selling of biogas and bio-slurry in a market. The time saved due to biogas technology was not estimated because time saving as a result of redundant wood collection and cooking practices is categorized as an economic value (shadow prices), not monetary benefit (Lutz and Howarth, 2015).

The firewood consumptions per household in the study area were gathered in unit of bundle/week, and later converted into kg/week then kg per year. Thus, estimated by following the formulas of Bala and Hossain (1992) as:
\[ \text{TAB}_f = 52.143(\text{WF}_{\text{cb}} - \text{WF}_{\text{ca}}) \times \text{P}_{\text{fw}} \]  

Where \( \text{TAB}_f \) represents annual monetary benefits from firewood saved, 52.143 refers to 52.143 weeks/year, \( \text{WF}_{\text{cb}} \) is represent the weekly firewood (kg) consumption before adopting biogas technology and \( \text{WF}_{\text{ca}} \) is the weekly firewood (kg) consumption after adopted biogas technology per household and \( \text{P}_{\text{fw}} \), the current (2017) price of firewood per kg.

The data of kerosene consumption in the study area were counted in unit of bottle/week and later converted to litre (l). Consequently, cost saved from kerosene consumption was calculated by following the formulas of Bala and Hossain (1992) as:

\[ \text{TAB}_k = 52.143(\text{WK}_{\text{cb}} - \text{WK}_{\text{ca}}) \times \text{P}_k \]  

Where \( \text{TAB}_k \) represents annual monetary benefits from kerosene saved, 52.143 refers to 52.143 weeks/year, \( \text{WK}_{\text{cb}} \) is represent weekly kerosene consumption (l) before adopting biogas technology and \( \text{WK}_{\text{ca}} \), is the weekly kerosene consumption (l) after adopted biogas technology/household and \( \text{P}_k \), the current (2017) price of kerosene/l.

Following Biswas and Lucas (1997), the monetary benefit of bio-slurry was estimated by existing cost of chemical fertilizers used and computed as:  

\[ \text{TAB}_s = (\text{ACh}_b - \text{ACh}_a) \times \text{p}_{\text{ch}} \]  

Where \( \text{TAB}_s \) represent annual benefits from bio-slurry used, \( \text{ACh}_b \) represent the annual amount of chemical fertilizers used/household before adopting biogas, \( \text{ACh}_a \) is annual amount of chemical fertilizers used/household after adopted biogas and \( \text{p}_{\text{ch}} \), is the farmers’ association official price of current (2017) chemical fertilizers (This formula services for both DAP and Urea).

By combining the above formulae, the total annual monetary benefits of household biogas plants (TAB) could be estimated as follows:

\[ \text{TAB} = \text{TAB}_f + \text{TAB}_k + \text{TAB}_s \]  

The economic tools like Benefit Cost ratio (BCR), Pay Back Period (PBP) and Net Present Value (NPV) were employed for the economic analysis of the biogas plant installation and operation. A fixed dome biogas model (local name \( \text{SINIDU} \), meaning “ready”), and 6 m\(^3\) and 8 m\(^3\) biogas plant sizes were selected for financial analysis because they were the most commonly used model and size in the study area.

**2.3.2 Undiscounted Payback Period (UPBP)**

In this study, the annual net revenue is assumed to be equal therefore UPBP was used in the analysis because a constant rate is suitable for computations were annual benefits and maintenance costs are assumed uniform over the useful economic life of a plant. Thus, the UPBP can be calculated as:
\[ \text{UPBP} = \frac{CI}{Ap}. \]

Where CI is total installation costs, AP is annual profit which is annual monetary benefits (biogas)

### 2.3.3 Net Present Value (NPV)

According to Mmopelwa (2006) NPV is given by the following formula:

\[ \text{NPV} = \sum_{t=1}^{n} \frac{B_t - C_t}{(1 + r)^t}. \]

Where \(B_t\) is the benefit obtained from the biogas plant (biogas, bio-slurry) in each year, \(C_t\) is the costs in each year, \(t\) is the expected useful economic life of a fixed-dome biogas plant from the present; \(t = (1, 2 \ldots 15)\) and \(r\) is discount rate. \(B_t\) and \(C_t\) were assumed uniform over the expected useful economic life of biogas plant and discounted through all years. A useful economic life of a fixed-dome plant was assumed 15 years; based on quality of masons and materials used in the study area. A discount rate of 10% has been assumed based on the recent minimum lending interest rate for long-term; provided by Development Bank of Ethiopia (DBE) to farmers’ association (MoFEC, 2016).

The internal rate of return (IRR) is the discount rate that makes the present value of future benefits equal to the present value of any costs, thereby causing NPV to equal zero. Payback period is the period of time over which the accumulated cash flows will equal the initial outlay, i.e. payback period is the amount of time that takes for a project to recover its initial investment. A short payback period may be desirable to ensure that the capital expenditure is quickly recovered and repatriated so that at least the initial investment will have been recovered. An investment is profitable when its NPV is zero, the bigger NPV the better (von Braun, 2013; Sathe and Bhosale, 2013; Sinha and Kandpal, 1990).

### 2.3.4 Benefits - Cost Ratio (BCR)

The BCR is the ratio of benefits per unit of cost and estimated as follows (Rahman and Kholilullah, 2017): (Amigun and Von Blottnitz, 2009)

\[ BCR = \frac{TB_t / (1 + r)^t}{TC_t / (1 + r)^t}. \]

Where \(TB_t\) is the total financial benefits obtained from the biogas plant (biogas, bio-slurry), \(TC_t\) is total costs (installation costs and annual maintenance costs) of biogas plant. \(TB_t\) and \(TC_t\) were discounted only at the initial year of investment \((t = 1)\) because it used to measures the present value of returns per money (ETB) invested.

### 2.3.5 Sensitivity Analysis of Selected Variables

Electronic copy available at: https://ssrn.com/abstract=3634030
Sensitivity analysis is required to identify those input variables that are important in terms of contributing to predict the output variation and in quantifying how changes in the values of input parameters alter value of the output variable. Sensitivity of variables is often a non-linear, complex and unsteady process, so it is difficult to derive a linear formula to represent influence of all variables in the process. Furthermore, simplifying the nature of analysis using a linear model would lead to unreliable results in practical applications of this research. Therefore, the neural network is used as an alternative way of sensitivity analysis because it considers linearity and non-linearity; it is faster, accurate, viable and efficient alternative against the traditional techniques of sensitivity analysis (Costa et al., 2013; Dilidili et al., 2011).

In cost-benefit analysis, the result is always influenced by several uncertainties. Sensitivity analysis helps to know how sensitive the NPV is to change in those uncertain factors (key variables) (Díaz-Balteiro and Romero, 2004; Gwavuya et al., 2012). Therefore, sensitivity analysis was conducted to quantify the impact of key (selected) variables change on the estimates of NPV to determine the financial stability of household biogas investment in the study area. In this study, the key variables were grouped into three sensitivity scenarios: input price scenario, level of expenditure savings scenario (savings of firewood, kerosene and chemical fertilizer) and discount rate scenario.

3 Results and Discussion

3.1 Costs of Household Biogas Plants

The costs of household biogas system consist of digester installation costs and operational costs. The installation cost covers the materials used for bio-digester construction, such as cement, bricks, sand, and PVC planks. The total costs of the most commonly used fixed-dome household biogas plants of 6 m³ and 8 m³ biogas plant sizes were computed as total installation costs (Table 1) and maintenance costs (Table 2). According to the survey data and secondary data obtained from Aleta Wondo District Water, Mine and Energy Office (AWDWMEO) (AWDWMEO, 2017), all biogas owners acquired a loan from OMO Microfinance Institution (with repayment period of 2 years and 15 % interest rate) and subsidized under the coordination of the National Biogas Programme of Ethiopia (NBPE). Since 2010, AWDWEMO has been endorsing a subsidy of ETB 6,000 for each household biogas plant. The subsidies (ETB 2,420) were considered in the form of costs of supply line including costs of biogas stove, biogas lamp with its accessory, valves (main gas, drain and gas tap) and connectors, and electric wires while ETB 3,580 was for biogas mason payment. The same subsidy was provided equally for all households and plant sizes. The cost paid for masons by households was already determined as per plant size (ETB 1,300 for 6 m³ and ETB 1,600 for 8 m³) starting from 2010 to the time of the execution of this study (2017).

Please insert Table 1 here

Please insert Table 2 here
As the plant size increases, the installation cost also proportionally increases. There is a proportional increase in costs between plant size and installation cost (Table 2). This is consistent with Lutz and Howarth (2015) that as biogas plant size increases so is the cost per m$^3$ of plant. Though the cost of inputs is naturally increasing, the present installation cost is so much close to same cost calculated during the 2008 baseline survey of NBPE which was about ETB 13,000 for 6 m$^3$ size (Eshete et al., 2006). The reason might be that installation used local construction materials. In addition, households hire no labor from outside and use household members for labor related works, including excavation-work. Thus, the use of local material with no external costs and the lack of labor wages are the factors that avoided inflation in installation costs.

3.2 Monetary benefit from firewood consumption replacement

Regardless of the differences in accessibility and households’ choices, a variety of household energy sources were utilized in the study areas. These energy sources were firewood, crop residues, kerosene and biogas. Firewood was utilized by the entire sample households for cooking. Some sample households sell firewood while others purchase trees or logs for firewood. According to the Ministry of Agriculture (MoA) of Ethiopia, one bundle of firewood weights on average 32 kg (MoA, 1996). On average, one bundle of firewood in the area was about ETB 46.97 (at local retail market, January 27, 2017, when 1 USD=22.46 as National Bank of Ethiopia (NBE)); hence, the 2017 price of firewood was ETB 1.47 per kg.

The weekly average firewood consumption of the biogas adopter households before adopting biogas technology was 103.53 Kg per household (HH) and 107.29 kg per HH for 6 m$^3$ and 8 m$^3$ plant sizes, respectively (Table 3). Whereas, it was 51.76 Kg per HH and 52.39 kg per HH for 6 m$^3$ and 8 m$^3$ plant sizes, respectively, after adoption. As a result, adopter households were able to save firewood consumption by 2,699.44 kg per HH and 2,862.65 kg/HH for 6 m$^3$ and 8 m$^3$ biogas plants, respectively, annually (Table 3). Therefore, the annual monetary benefit from substitution of firewood by biogas energy for adopter households was ETB 3,968.18 per HH and ETB 4208.09 per HH for 6 m$^3$ and 8 m$^3$ plants, respectively, after adoption. A previous study conducted in rural Ethiopia reported a similar finding that, the average amount of firewood saved by the biogas adopter households was 3319 kg per year (Gwavuya et al., 2012) and was 1730.1 kg per year with equivalent amount of money saved ETB 1903.11 per year after adoption of the technology (Alemneh, 2011). The difference in the balance between the current result and previous results attributes to the fact that the biogas adopter households in the study area use no charcoal and kerosene stove for cooking; they rather mostly use firewood for cooking.

3.3 Monetary benefit from kerosene consumption replacement

In the study area, households use kerosene lamp for lighting purpose. Data on kerosene consumption was counted in a unit of bottle per week and was later converted to litre (L), 1 bottle ≈ 0.33 L or 3 bottles ≈1 L. The local retail market price of 1 litre of kerosene was ETB 27 (when 1 US$=22.46, January 27, 2017). Adopter households had completely replaced kerosene consumption with biogas energy. Accordingly, they were able to save about 84.99 L per HH and 89.69 L per HH kerosene consumption annually for 6 m$^3$ and 8 m$^3$ plants, respectively (Table 4). Therefore, after adoption, substitution of kerosene with biogas energy generated an annual income of ETB 2,294.81 per HH for 6 m$^3$ and ETB 2,421.52 per HH for the 8 m$^3$ plant.
Results from a previous study conducted in North Ethiopia reported a similar finding that the average amount of energy saved from kerosene replacement by the biogas energy by adopter households was 10,538.9 L per year (Mengistu et al., 2016) and the maximum amount of money saved by the biogas user households from kerosene replacement was ETB 4493 per year (Claudia and Addis, 2011).

3.4 Monetary benefit obtained from the cost saved from chemical fertilizers purchase

Households buy chemical fertilizers at the price of ETB 1,486 per 100 kg of DAP and ETB 1,374 per 100 kg of urea at the time of conducting this study. Regardless of plant size, adopters did not completely abandon the use of DAP and urea because the bio-slurry yielded from both plant sizes was inadequate to cover all farmlands. After adoption of the biogas technology, households were able to save 154.90 kg per HH per year and 162.26 kg per HH per year of DAP consumption from 6 m$^3$ and 8 m$^3$ plants, respectively (Table 5). Accordingly, adopters’ annual monetary benefit when DAP was substituted by a bio-slurry was ETB 2,301.81 per HH and ETB 2,411.18 per HH from 6 m$^3$ and 8 m$^3$ plants, respectively (Table 5). There was a high significance difference (p<0.01) between DAP consumption of biogas adopter households before and after adoption of both 6 m$^3$ and 8 m$^3$ plants. The amount of urea saved by adopter households was 85.78 kg per HH per year from 6 m$^3$ and 94.60 kg per HH per year from 8 m$^3$ plants (Table 5). Accordingly, the annual monetary benefit adopters obtained from the cost spent on urea when substituted by a bio-slurry was ETB 1,178.62 per HH and 1,299.80 per HH from 6 m$^3$ and 8 m$^3$ plants, respectively. Annually, 103.26 kg of chemical fertilizers was saved which is equivalent to annual monetary saving of 717.66 ETB per HH per year with average local rate of ETB 695 per 100 kg (Amare, 2014). Thus, this result is highly dependent on bio-slurry being effectively used as a source of fertilizer and on the price of the replaced energy source. Thus, the promotion of bio-slurry use as fertilizer must be an integral part of a successful biogas program in Ethiopia (Gwavuya et al., 2012).

Please insert Table 3 here

Please insert Table 4 here

Please insert Table 5 here

Please insert Table 6 here

3.5 Financial viability of household biogas plants

The financial estimation in this study considers only the costs and monetary benefits of biogas investment, not including some other external costs and benefits. The survey result showed that all installed biogas plants were subsidized. For this reason, the financial viability of households’ investment into biogas plant installation was evaluated as with a subsidy (base assumption) and without a subsidy. Under without subsidy situation, no external financial incentive was incorporated into the calculation of a biogas plant. Without
subsidy estimation of a biogas plant offered the actual cost to be incurred for installation of a biogas plant. Such an arrangement seems to attract interested households into investing in biogas installation. Particularly, households who for financial limitation could not adopt will be potential beneficiaries of subsidies. While with subsidy estimation of a biogas plant provided that a subsidy plays vital role in increasing the adoption rate and in attracting low income households to biogas technology adoption. Hence, for the financial estimation of a biogas plant installation with a subsidy, the finance allocated (ETB 6000) was subtracted from the calculated cost of installation for each biogas plant.

3.5.1 Undiscounted Payback Period (UPBP)

Biogas plant with subsidy in both sizes repaid the original cost of investment in shorter period than biogas plant without subsidy. Investing 6 m$^3$ biogas plant with subsidy recovered the installation cost within 0.73 year, while the 8 m$^3$ plant recovered within 0.97 year (Table 7). This implies that a household with a 6 m$^3$ size would take few months to recover the original cost of investment through the annual net cash revenues it generates than the 8 m$^3$ plant.

Under the assumption of without subsidy, the payback period of 6 m$^3$ biogas plant was shorter than 8 m$^3$ biogas plant (Table 7). However, in both plants it takes a long period when compared with subsidized one to recover the initial investment costs, which was 1.38 years for 6 m$^3$ and 1.59 years for 8 m$^3$ biogas plant. Therefore, considering subsidy arrangement to biogas adopters, based on the UPBP results, the 6 m$^3$ plant with a shorter period was more financially viable than the 8 m$^3$ plants. This implies that, as the size of the biogas plant increases, the UPBP also increases. The 8 m$^3$ biogas plants had higher installation costs than the 6 m$^3$ plants.

Please insert Table 7 here

3.5.2 Net Present Value (NPV)

The NPV is a way of comparing the present and future values of cash flows by using the discount rate and a time constraint. Under both assumptions with and without subsidy, the NPV results for 6 m$^3$ and 8 m$^3$ biogas plant sizes turn out positive (Table 8). Positive NPV means that the biogas investment is preferable and profitable for continuing the investment for the future. It implies that the cost invested for the respective plant size was smaller than the income generated. The NPV for 6 m$^3$ biogas plant was ETB 56508 and ETB 55674 for 8 m$^3$ under assumption with subsidy while the NPV under assumption without subsidy was ETB 51053 for 6 m$^3$ biogas plant and ETB 50219 for 8 m$^3$ plant (Table 8). This implies that, a 6 m$^3$ biogas plant; under both assumptions with and without subsidy would be more sensitive to changes in financial parameters and profitable than the 8 m$^3$ size. The biogas investment without subsidy in both 6 m$^3$ and 8 m$^3$ plants are less viable.
than of biogas investment with subsidy (Table 8). Such economic performance of biogas plants is an important factor for households who consider biogas plants as an investment.

Please insert Table 8 here

This result is in line with Gwavuya et al. (2012) that the small sizes of biogas plant in Ethiopia were more profitable than the large sizes. Kabir et al. (2012) showed that under assumption with subsidy, biogas users in Bangladesh obtain better financial results compared to assumption without subsidy. However, under both assumptions biogas investment yields positive NPVs. Households largely collect their own fuel. By investing in biogas plants, they could save time and energy, and have a supply of bio-slurry that can be used as fertilizer in agricultural production. A cost-benefit analysis of biogas plants yields positive net present values for households collecting their own energy sources. Even higher net present values are obtained for households purchasing all of their energy needs; these households stand to gain significantly from the financial benefits of energy cost savings with biogas technology. Results are highly dependent on bio-slurry being effectively used as a source of fertilizer and on the price of the replaced energy source. Thus, the promotion of bio-slurry use as fertilizer must be an integral part of a successful biogas program in Ethiopia. Another important issue is that at present, biogas plants are highly subsidized and thus the above conditions hold under the assumptions of subsidies. When analyzed without subsidies, indicators are still positive, yet amortization periods are significantly longer and close to the depreciation point, so that investment risks increase (Gwavuya et al., 2012).

3.5.3 Benefit - Cost Ratio (BCR)

The BCR was used to measures the present value of returns per ETB invested. The financial analysis of BCR under assumption with subsidy was found to be 1.34 and 1.10 at 10 % discount rate for 6 m$^3$ and 8 m$^3$ plants, respectively (Table 9). This means that the investment in the biogas by ETB 1.0 would provide return (profit) of 34 cents from 6 m$^3$ and 10 cents from 8 m$^3$ plants. Therefore, the use of biogas plant was more viable as cost associated with it is outweighed by the benefit obtained. The results of BCR also showed 6 m$^3$ biogas plant was more financially profitable than 8 m$^3$ plant. In both biogas plant sizes, biogas investment was more financially profitable under the assumption with subsidy while it was unprofitable under the assumption without subsidy in the initial year (Table 9).

Please insert Table 9 here
The impact of the biogas subsidy on NPV was analyzed and respective trends were found. Break-even is reached during the seventh year for households purchasing firewood. For households collecting firewood and dung, break-even is during the 18th and 14th year, respectively, without subsidy. The greatest effect of the subsidy is realized for households collecting firewood. The break-even point is abridged by a factor of about eight years for households collecting firewood compared with a factor of about six years for dung combustion and two years for purchasing firewood. Without subsidy, households collecting firewood only start to realize positive NPV value in the 18th year for the 4 m$^3$ plant and 16th year for the 6 m$^3$ plant (Gwavuya et al., 2012).

### 3.6 Sensitivity Analysis

Sensitivity analysis was conducted in three scenarios: input price scenario, level of expenditure savings scenario and discount rate scenario. The base case; which is standard for this study was used as reference for the comparison of the changes in NPV of biogas plants as the scenarios will be changed. For level of expenditure savings scenario, the minimum (for decreasing), average (for base case) and maximum (for increasing) values of expenditure savings obtained from household survey were used as input data. Based on these data, the level of expenditure savings were assumed on average 10% decreasing and 10% increasing from base case. The input price scenario was taken based on market price assessment of local markets of Aleta Wondo town, the past price (for decreasing), current (for base case) and foreseeable future price (for increasing) values. Thus, it was assumed as 10% of decreasing and 20% of increasing prices. Based on the researcher logical basis of market situation changes in demand and supply for money, the discount rate scenario was assumed as 10% for decrease discount rate and 20% for increase discount rate from base case (the standard for the study is 10%). Sensitivity analysis was conducted to determine changes in cost of biogas investment as price of construction materials and maintenance cost could be sensitive to change. Sensitivity analysis was also conducted to determine changes to benefits accumulating to households under different conditions for level of expenditure savings of firewood, kerosene and chemical fertilizers. The level of expenditures savings may be changed as households ‘consumption changed, similarly, as level of savings changed the monetary benefits generated from biogas plant will be changed. Sensitivity analysis results of NPV of biogas investment were presented (Table 10). Price increases a lot in terms of shadow prices and market prices of replaced fuel for households collecting dung and for households collecting firewood. This indicates the importance of opportunity costs of labor in determining the anticipated benefits of investing in a biogas plant. Thus, well-off households stand to benefit more than poorer households. A trend similar to the 4 m$^3$ plant is observed for a 6 m$^3$ plant. Percentage change in benefits accruing with a 6 m$^3$ plant is higher for increases in shadow price of replaced fuel compared to 4 m$^3$ plant but lower when it comes to levels of expenditure and time savings. Differences are larger for households collecting firewood and dung compared to households purchasing firewood (Gwavuya et al., 2012).

The NPV for the 6 m$^3$ plant was highly sensitive to input prices, level of expenditure savings and discount rates than that of 8 m$^3$ plant across three scenarios, which could give the discounted return at the shorter time period (Table 10). A similar result was reported that compared to larger sizes, the NPV for 4 m$^3$ plant type was highly sensitive to time savings, construction costs, expenditure levels and the price of replaced fuel across household scenarios. These variables are under the household status sensitivity scenario and indicate the importance of household variables especially for households collecting firewood and dung (Gwavuya et al., 2012). Likewise, as these key variables would be changed the NPVs also changed, assuming the other variables remain constant such as economic life of biogas plant. The same is true; the magnitude of NPV in both plant sizes and assumptions (with and without subsidy) would be changed. Therefore, the best scenario of NPV was happened, if the level of expenditure savings would be increased, and input prices and discount rates...
would be decreased. The bad scenario of NPV was occurred, if input prices and discount rate would be increased, and level of expenditure savings would be decreased. The result is supported by Verdone (2015) states that, discounting is making events at different point in the time that long economic life of the projects is sensitive to the choice of discount rate. Therefore, the choice of appropriate discount rate highly important to ensure the future project returns. As input prices and level of expenditures would be changed the NPVs were sensitive to changed (Gwavuya et al., 2012).

Please insert Table 10 here

4 Conclusion and Recommendations

The study specifically focused on the fixed dome model of biogas plants of 6 m$^3$ and 8 m$^3$ sizes and estimated their cost-benefit analysis and financial viability at household level. Although biogas technology has continued to be adopted by households through incentives, its financial viability was unidentified among the rural households of Aleta Wondo District. The total costs of biogas investment were ETB 13,286 and ETB 16,079, for 6 m$^3$ and 8 m$^3$ plant sizes, respectively. The respective benefits obtained from the two sizes were ETB 9,744 and ETB 10,341, showing that the costs are higher than the benefits. Likewise, the corresponding installation costs were ETB 12,775 and ETB 15,460. Proportionately, the installation cost was the leading investment cost that primarily hindered the successful dissemination of biogas technology in the study area. Adoption of biogas technology not only substantially reduces the consumption of firewood, kerosene and chemical fertilizers but also markedly enhances household’s income by saving their purchasing costs. The financial analysis of both plant sizes, installed with subsidy, had higher NPV value, UPBP of less than one year and BCR value of greater than one. The results from this analysis indicates that investing in both plant sizes is financially viable and profitable at 10% discount rate. Nevertheless, both plant sizes, installed without subsidy, had smaller NPV values and UDBP values greater than one year, making this scenario financially less viable. Distinctly, the 6 m$^3$ size is highly profitable than the 8 m$^3$ size. This implies that subsidy is important to enhance biogas plant installation, particularly of larger sizes. Moreover, sensitivity analysis showed that the profitability of biogas investment, expressed in NPV, is highly sensitive to variation in discount rates, level of expenditure savings and input prices. Households estimate profitability of biogas plant installation primarily from monetary surplus gained from utilizing biogas energy and bio-slurry in association with the cost of the plants. Households are often motivated by subsidy and loan which attract the engagement of low-income households in biogas plant installation. Furthermore, household’s investment in biogas plant installation is more financially viable under assumption with subsidy than without subsidy. Therefore, for the successful dissemination of the biogas technology and further popularization of the technology, the operating subsidy scheme, being offered by the NBPE and SNV-Ethiopia, should continue at least for a certain period and until the biogas benefits are effectively familiarized among rural households.

Acknowledgments

We would like to thank NORHED – EnPe, a collaborative project between Hawassa University, Mekelle University and Norwegian University of Life Sciences (NMBU), for providing financial support. We owe due
appreciation to all respondent households, group discussants and key informants who provided invaluable information. We also offer due respect to all organizations and their staff for providing invaluable data. Particularly, we would like to thank the following organizations: South Region Biogas Programme coordination Unit, Aleta Wondo District Energy and Mines Office, Aleta Wondo District Agriculture and Rural Development Office, Aleta Wondo District Administration Office, and Kebele Administrations.

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.

Alemneh, Z. (2011). The contribution of biogas production from cattle manure at household level for forest conservation and soil fertility improvement. Unpublished MSc Thesis, Science Faculty, Addis Ababa University.

Amare, Z. Y. (2014). The role of Biogas Energy Production and Use in Greenhouse Gas Emission Reduction; the case of Amhara National Regional State, Fogera District, Ethiopia. benefits 1(5).

Amigun, B., Sigamoney, R. & von Blottnitz, H. (2008). Commercialisation of biofuel industry in Africa: a review. Renewable and Sustainable Energy Reviews 12(3): 690-711.

Amigun, B. & Von Blottnitz, H. (2009). Capital cost prediction for biogas installations in Africa: Lang factor approach. Environmental Progress & Sustainable Energy: An Official Publication of the American Institute of Chemical Engineers 28(1): 134-142.

AWDWMEO (2017). Aleta Wondo District Water, Mine and Energy Office (AWDWMEO), Aleta Wondo, Southern Ethiopia.

Bala, B. & Hossain, M. (1992). Economics of biogas digesters in Bangladesh. Energy 17(10): 939-944.

Bewket, W. (2012). Climate change perceptions and adaptive responses of smallholder farmers in central highlands of Ethiopia. International Journal of environmental studies 69(3): 507-523.

Biswas, W. K. & Lucas, N. (1997). Economic viability of biogas technology in a Bangladesh village. Energy 22(8): 763-770.

Chakrabarty, S., Boksh, F. M. & Chakraborty, A. (2013). Economic viability of biogas and green self-employment opportunities. Renewable and Sustainable Energy Reviews 28: 757-766.

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

Costa, S. P., de Andrade Lima, F. R., Lapa, C. M. F., de Abreu Mól, A. C. & de Oliveira Lira, C. A. B. (2013). The artificial neural network used in the study of sensitivities in the IRIS reactor pressurizer. Progress in Nuclear Energy 69: 64-70.

CSA (2013). Population Projection of Ethiopia for all regions at district level (2014-2017). Central Statistics Agency (CSA), Addis Ababa, Ethiopia.

Díaz-Balteiro, L. & Romero, C. (2004). In search of a natural systems sustainability index. Ecological Economics 49(3): 401-405.

Dilidili, J., Polinga, C., Ararao-Pelle, R. & Sangalang, R. (2011). Biogas technology in Philippines: A synthesis of various readings on biogas technology. Cavite.

Erdogdu, E. (2008). An expose of bioenergy and its potential and utilization in Turkey. Energy Policy 36(6): 2182-2190.

Eshete, G., Sonder, K. & ter Heegde, F. (2006). Report on the feasibility study of a national programme for domestic biogas in Ethiopia. SNV Netherlands Development Organization: Addis Ababa, Ethiopia.
Verdone, M. (2015). A cost-benefit framework for analyzing forest landscape restoration decisions. *IUCN (International Union for Conservation of Nature), Gland, Switzerland.*

von Braun, J. (2013). Bioeconomy–science and technology policy for agricultural development and food security. In *Festschrift seminar in honor of Per Pinstrup-Andersen on “New directions in the fight against hunger and malnutrition”. Cornell University.*

WHO (2006). *UNAIDS: Air quality guidelines: global update 2005.* World Health Organization.