Technical and socioeconomic constraints to the domestication and functionality of biogas technology in rural areas of southern Ethiopia

Getachew Sime

Cogent Engineering (2020), 7: 1765686
Technical and socioeconomic constraints to the domestication and functionality of biogas technology in rural areas of southern Ethiopia

Getachew Sime

Abstract: Although biogas technology has been introduced as a national program to respond to the ever-increasing energy demand in Ethiopia, empirical studies on the technical, institutional and socioeconomic constraints to the domestication and functionality of the technology are scant. Thus, this study provides an overview of these constraints. The study is based on, key-informant interviews, legislation and strategy documents, extensive literature reviews and observation of bio-digesters. Limitations in technical, economic, sociocultural and institutional perspectives are the major factors constraining the domestication and functionality of the technology. The constraints pertain to the adequacy of institutional follow-up; management of bio-slurry; availability and cost of maintenance service; price, availability and accessibility of appliances at local markets; availability of credit associations; adequacy of masons skill; skill and level of awareness of users; and sociocultural acceptance to connecting toilets to bio-digesters. Primarily, these constraints emanate from the weak organizational and institutional alignment among key stakeholders. Thus, for the realization of sustainable domestication of the

ABOUT THE AUTHOR
Getachew Sime currently works at Hawassa University. Getachew does research in climate change, rural food and energy security, climate-smart agriculture and traditional agricultural practices. The current article is part of the undergoing project titled Bioenergy – Ethiopia – Norway.

PUBLIC INTEREST STATEMENT
Several countries, particularly in Sub-Sahara and Asia, have been implementing national biogas programmes. Most of these countries have faced similar problems though they have range of potential in terms of available livestock size, feedstock type, family size and access to water sources. Among the multiple purposes of biogas technology are biogas energy for cooking and lighting and bio-slurry for fertilizer. Biogas energy is smokeless and neat energy, which improves health of women and children. These two major benefits have been popularized disproportionately. Furthermore, they are both underestimated and underutilized, particularly in mitigating greenhouse gas emission from deforestation for firewood. The major hindering factors include lack of focused policy, lack of adequate subsidies for bio-digester installation and maintenance services, low economic capacity of potential users, and absence of strong consortium of key stakeholders. These are, thus, essential areas of revisions indicating the policy implications for the sustainable use and the future adoption and functionality of bio-digesters.
technology and renewable energy policy, there is a need to emphasize on dissemination, monitoring and ownership strategies as well as on operationalizing institutional commitments.

Subjects: Engineering & Technology; Renewable Energy; Bio Energy; Renewable Energy; Politics & International Relations; Regulatory Policy; Energy Policy; Energy; Bioenergy

Keywords: Biogas technology; rural energy security; rural households; constraints; Ethiopia

1. Introduction

In many parts of the world, mostly in the rural areas of the Sub-Saharan Africa (SSA), energy poverty remains a major problem for human health, economic development and environmental sustainability (Kaygusuz, 2012). This is ironically due to lack of poor infrastructural support and appropriate technologies to harness especially renewable energy resources. Many rural African communities are remotely situated that makes centralized energy generation and transmission prohibitively costly and inefficient due to greater transmission and distribution losses. Thus, beyond certain break even distances from the centralized energy, implementation of decentralized energy generation, such as from biogas, could be more cost-effective (Amigun & Von Blottnitz, 2010). Because of its relative advantages, there is a great potential for biogas technology adoption in African countries (Parawira, 2009). Biogas production offers African countries a prospect of self-reliant energy supplies at national and local levels, with potential economic, environmental, agricultural and social benefits (Ghimire, 2013; Parawira, 2009; Roopnarain & Adeleke, 2017).

Biogas technology is considered to be an excellent tool to improve livelihoods, health, and ecosystem (Yousuf et al., 2016). It generates biogas energy through harnessing anaerobic degradation pathways controlled by a suite of microorganisms.

A biogas acts as an environmentally sustainable energy source, while providing a method for disposal of various organic wastes (Ghimire, 2013; Roopnarain & Adeleke, 2017). Anaerobic digestion of organic wastes results in the production of biogas and a nutrient-rich bio-slurry. The biogas that is produced through this process consists of methane (CH$_4$), carbon dioxide (CO$_2$) and minute amounts of other gases (Roopnarain & Adeleke, 2017). Biogas contains 50–70% CH$_4$ and 30–50% CO$_2$, and typically has a calorific value of 21–24 MJ m$^{-3}$ (Bond & Templeton, 2011). Methane, which forms the bulk of the biogas, is combustible. It can be used for the provision of heat and light and can even be converted to electricity (Roopnarain & Adeleke, 2017). Biogas can be effectively used in simple gas stoves for cooking and in lamps for lighting (Ghimire, 2013). This is of particular significance in Africa, where a dire energy crisis currently prevails (Roopnarain & Adeleke, 2017).

2. Domestic biogas technology in Africa

Though introduced a long time ago, remarkable involvement came later in 2008. Domestic biogas technology was introduced in some African countries in around four decades ago. For instance, some first bio-digesters were set up in the 1950s in South Africa and Kenya, in Tanzania in 1975 (Parawira, 2009), and in Ethiopia in 1979 (Eshete et al., 2006). The African Biogas Partnership Program (ABPP), the Netherlands Development Organization (SNV) and the Humanist Institute for Development Cooperation (HIVOS) are among the important initiatives and agencies that jointly work with the National Domestic Biogas Programs (NDBP) to promote biogas technology in Africa. The NDBP aims to create a sustainable and commercially viable biogas sector in target countries using a private sector strategy (Kamp & Bermúdez Forn, 2016). The ABPP was established in 2009 to promote adoption of bio-digesters by rural households in sub-Saharan Africa and has installed over 27,000 households bio-digesters in Kenya, Tanzania and Uganda (Clemens et al., 2018).

The National Biogas Programs have been implemented in Kenya, Uganda, Ethiopia, Tanzania, Rwanda, Cameroon, Burkina Faso and Benin (Roopnarain & Adeleke, 2017). In addition, the
technology has been disseminated in several other SSA countries including Burundi, Botswana, Cote D’Ivoire, Ghana, Guinea, Lesotho, Namibia, Nigeria, Zimbabwe, and South Africa (Kemausuor et al., 2018). However, the technology is still in its infancy in Africa, although recent initiatives have resulted in the promotion of the technology, accelerated awareness and dissemination, and the accelerated uptake of the technology in various African countries (Roopnarain & Adeleke, 2017). These countries have benefited significantly from the technology and serve as showpieces for African countries that have the ability to start up similar programs without outside assistance. Unlike other forms of renewable energy, biogas technology offers numerous advantages, one main advantage being waste management, which is a significant problem in Africa. The major hurdles to the implementation of biogas technology in Africa are the cost implications, lack of communication, lack of ownership and the negative image of the technology caused by past failures (Roopnarain & Adeleke, 2017). The provision of loans, government assistance, community workshops, wide-scale communication and the implementation of prefabricated digesters could have a significant impact on the increased uptake of the technology in Africa. The adoption of biogas technology in Africa would contribute to the well-being and economic prosperity of the continent as a whole (Roopnarain & Adeleke, 2017).

3. Potential of domestic biogas technology adoption in Africa
Households in SSA form the majority of over 2.7 billion people globally that rely predominantly on traditional biomass as cooking fuel (Kemausuor et al., 2018). The potential for biogas dissemination in Africa may be defined by biomass resources available for anaerobic digestion, its affordability and climate versatility (Mulinda et al., 2013). Many African countries have vast biomass resources that could serve as feedstock for CH₄ production through the adoption of commercial biogas plants. This potential is a projection of the data available on the number of livestock, agricultural residues, forest residues and municipal wastes (Mulinda et al., 2013). However, due to many inhibiting factors, these resources are underutilized. The trend now is that of increasing numbers of biogas installations across Africa. This is largely apparent in the domestic energy sector, which has in recent years seen the start of a number of national domestic biogas programs, each with national targets of over 10,000 domestic systems to be installed every 5 years (Kemausuor et al., 2018). This scenario shows that the biogas market in Africa is still potential, but there is limitation with materializing the making use of these potentialities.

4. Energy policy and biogas technology dissemination in Ethiopia
Ethiopia’s energy policy aims at maximizing the use of renewable energy sources that will reduce dependence on imported fuel and biomass energy sources. The country has updated its energy policy to emphasize on energy efficiency and conservation. Furthermore, the current climate change has presented the necessity and opportunity to switch to the use of renewable energy sources. Thus, the energy policy is aligned with the Climate Resilient Green Economy strategy of Ethiopia to protect the country against the adverse effect of climate change and to build a green economy. It is also part of the Growth and Transformation Plan of Ethiopia (M. G. Mengistu et al., 2015; Kamp & Bermúdez Forn, 2016). As part of Ethiopia’s renewable energy policy, the purpose of the NBPE program is to address the domestic energy needs of rural communities, promoting the use of domestic biogas energy at a household level. The program focuses on three major areas, including sanitation, energy, and organic fertilizer production. The target beneficiaries are households with four or more local breed cattle, residing within 30 min walking distance from a water source, and willing to pay in cash or through credit for the investment cost required in the installation of bio-digester with an optional toilet connection. Participant households finance approximately 60% of the construction investment of bio-digesters while the Ethiopian Government and donors finance the remaining 40% of the construction cost as an investment incentive. Specialized masons carry out the construction. The SNV gives technical assistance that focusing on four priority areas: management support, credit and financing mechanisms; private sector development; and bio-slurry development and promotion of food security. The program deploys digester volumes of 4, 6, 8 and 10 m³ (SNV, 2017). Cow dung is the primary source of the substrate for domestic bio-digesters. Over 77% of the
rural households in Ethiopia own cattle; hence, they are eligible for bio-digester installation. Rural households lead an integrated crop-livestock agricultural system. Consequently, the integration of the biogas technology with an adopter animal husbandry is central to the adoption process in Ethiopia (Eshete et al., 2006). On average, farmers keeping a minimum of three heads of stall-fed cattle can produce adequate cow dung and can generate sufficient biogas to meet daily basic cooking and lighting needs (Ghimire, 2013). In four populous regional states alone, namely Tigray, Amhara, Oromia, and Southern Regions where a feasibility study of the national domestic biogas program covered, the potential for mass dissemination of biogas technology ranges from 1.1 million to 3.5 million households (Eshete et al., 2006).

More than 80% of the Ethiopian population, which is currently over 100 million, rely on agriculture and livestock as its primary source of food and income, where about 12 million smallholder rural households account for an estimated 95% of agricultural production (FAO, 2017). This represents the largest segment of the Ethiopian population that experiences energy insecurity and environmental degradation due to the sustained reliance on woody biomass to satisfy energy needs (Kamp & Bermúdez Forn, 2016). Nearly all the country’s rural energy demands come from firewood and cow dung. However, because of many years of deforestation for firewood (being driven by massive population growth and rural poverty), firewood scarcity becomes a critical problem (Gebreegziabher & van Kooten, 2013). With the aid of appropriate strategies, biomass resources can, therefore, provide renewable energy such as the biogas energy, which can improve the prevailing energy insecurity in rural Ethiopia (Kamp & Bermúdez Forn, 2016).

Predominantly, the NBPE has been implemented in Amhara, Oromia, Southern Nations, Nationalities and People (SNNP), and Tigray, which are the four populous Regional States in Ethiopia. Beside their higher human population size, these regions possess better resource endowments such as water and livestock. Additionally, over 92% of the annual biomass energy is consumed in the four populous regions of Amhara (34%), Oromia (32%), SNNP (22%) and the Tigray (4%), with the other regions accounting for the remaining 8% of the biomass energy consumption (MoWIE, 2018; SNV, 2017). Recently, the country has completed the implementation of the second phase of the NBPE. With different efficiency of installation performances, the number of bio-digesters installations increased with implementation years across regions. Relative to the first phase, during the second phase, the number of installed bio-digesters increased thrice in Amhara and Tigray, and more than twice in Oromia and SNNP. The Amhara and Tigray regions performed well, followed by Oromia. Attempts to achieve planned targets varied with implementation year. The first phase met only 56% of its original plan. By the end of 2017, which is the end of the second phase, Ethiopia installed over 18,000 biodigesters. Only about 70% of the planned target was achieved in the two phases. Currently, all regions, including those with lower biomass energy consumption, but with higher livestock size are also participating in NBPE (MoWIE, 2018).

There are limited empirical evidence concerning to both its dissemination and the overall influences of the technology in Ethiopia. The dissemination of biogas technology and biodigester functionality are limited by factors such as economic instability, limitation in technical skills, poverty and illiteracy (Kamp & Bermúdez Forn, 2016; M. Mengistu et al., 2016), socioeconomic problems (Eshete et al., 2006; Kamp & Bermúdez Forn, 2016; Kelebe et al., 2017; Tucho et al., 2016), and institutional problem (Berhe et al., 2017; M. Mengistu et al., 2016). Most of these studies are, however, limited to the northern Ethiopia and to the first phase of the NBPE. Furthermore, studies investigating the details of technical and socioeconomic constraints to the implementation of the NBPE, particularly of the second phase of the NBPE are non-existent. Beyond, such studies have never been studied and documented in southern Ethiopia. The aim of this study is, thus, to evaluate the major technical and socioeconomic constraints to biogas technology domestication and bio-digester functionality in southern Ethiopia. The study is conducted through key informant interviews and desk study of energy policy legislation, and strategy documents, as well as an extensive review of the relevant literature and survey of bio-digesters operating households.
5. Methods, procedures and data analysis

Field surveys were conducted in seven districts in southern Ethiopia, with relatively higher biogas technology intervention. The districts surveyed were Wondo Genet, Aleta Wondo, Sodo Gurage, Meskan, Arba Minch Zuria, Wolaita Sodo Zuria and Arsi Negele. About 680 bio-digesters operating households were selected from these districts through random sampling technique. On top of that, key stakeholders were selected through purposive sampling technique: three informants from the National Biogas Technology Coordination Units (NBPE coordination office under the Ministry of Water, Irrigation and Electricity (MoWIE)), and two informants each from the Ministry of Agricultural and Natural Resources (MoANR) and the Ministry of Environment, Forest and Climate Change (MoEFCC), and 35 informants from the South Regional State Biogas Program Coordination Units (RBPCU)). Similarly, two informants each from research institutes (Horn of Africa Regional Environment Centre and Network (HOA-REC & N) and Ethiopian Development Research Initiative (EDRI)); international NGO (SNV); local NGOs (LEM-Ethiopia and Institute of Sustainable Development (ISD)), and one informant each from four R-Energy private companies and Selam Manufacturing Enterprises were interviewed. Furthermore, government legislation and strategy documents of the Ethiopian National Energy Policy and NBPE were evaluated, supplemented by an extensive review of relevant literature.

The purposive sampling technique for selecting the interviewees was to obtain comprehensive information about the technical and socioeconomic constraints to the domestication and functionality of biogas technology. Purposive sampling technique is widely used in qualitative research for the identification and selection of information-rich cases related to the phenomenon of interest (Palinkas et al., 2015). The random sampling technique used for selecting bio-digester operating household heads was to enable researchers selecting a sample representative of the population, with all individuals having a legitimate chance of being selected (Lewis, 2015).

While conducting the interviews and survey of bio-digester operating households, comprehensive field notes were hand-written in a small notebook by the researcher, complemented with audio taping. The field notes were typically written at the same time the interview took place. Moreover, short notes were taken from the government documents and were transcribed. The collected data were most importantly associated with features of bio-digester construction, evaluation and monitoring of bio-digester installation, availability of spare parts and credit service, effectiveness of operation and maintenance activities. Meanwhile, compatibility among household labor size, feedstock size, bio-digester size, access to water sources, and others associated socioeconomic factors were evaluated. Besides, after physically observing bio-digesters, data associated with the functionality of bio-digesters were assessed. Pictures of bio-digesters, cow dung preparation, bio-slurry application, livestock in shades, biogas lamp, biogas stove, key informants and focus group discussants were taken during field survey.

Most of the data collected were qualitative. The collected data were transcribed and translated using theoretical standpoints. Qualitative research can help researchers to access the thoughts and feelings of research participants, which can enable development of an understanding of the meaning that peoples ascribe to their experiences (Sutton & Austin, 2015). Then, the data were broken down into different themes and sub-themes for analysis. It was then analyzed using an inductive approach, without the presupposition of an existing theoretical framework. It is important to conduct this phase of analysis without the presupposition of a particular framework to allow flexibility in data exploration and discovery (Patton, 2002). Using coding techniques of the different themes and sub-themes, the transcripts were open coded (Corbin & Strauss, 1990). Open coding entailed holistically reviewing the data, reading line by line, reviewing each individual response, comparing and cross-checking the responses of participants to the same questions, labeling concepts, and breaking data further down into a theme that best fit the research questions. Axial coding involved exploring the data (i.e., open codes) for connecting between themes and sub-themes. Reflection and articulation were used for the analysis of the coded data. Finally, credibility and internal validity of the data were assured using multiple data sources for
6. Results and discussion

6.1. Major constraints to the domestication and functionality of bio-digesters

Key informants (RBPCU, NBPE, HoA-REC&N and SNV) described that technical and socioeconomic factors are the key barriers to the domestication and functionality of installed bio-digesters in Ethiopia. Bio-digesters do not function effectively when there is poor design, lack of regular feeding, and lack of regular maintenance service. The informants further described that technical standards related to raw materials, construction and design are critically instrumental in influencing the proper functioning of bio-digesters in Ethiopia. Moreover, the mal-functionality of bio-digesters mainly resulted from inadequate technical knowledge of user households, masons and energy technicians and is often the reason for the inefficient exploitation of biogas technology benefits in Ethiopia. Problems arising from poor construction of quality bio-digesters, poor user awareness, and poor maintenance services led to the abandonment of bio-digesters in few places in southern Ethiopia such as Aleta Wondo, Sodo Gurage, and Arba Minch districts, among others (Plate 1 in appendix).

6.2. Standardization of bio-digester quality and masons’ skill

The government NBPE documents indicate that masons’ skill is instrumental in the construction of standard bio-digesters meeting a single and approved standard of design and quality. Such a problem was a major concern in the dissemination of the technology in Ethiopia. Key informants (SNV, EDRI, NBPE) emphasized that most of the masons engaging in bio-digester construction in Ethiopia are not well trained and they lack adequate skills. Standardization that comprises the control of construction quality and maintenance service was designed to be one of the basic activities of the program (EREDPC & SNV, 2008). Furthermore, poor-quality construction of digesters, due to poorly skilled masons, use of low-cost construction materials and poor maintenance service, was found to reduce bio-digester functionality in southern Ethiopia. In the surveying areas, cracks in the dome and outside walls, gas leakage through pipelines and consequently insufficient gas for cooking and lighting were common faults associated with ensuring the approved bio-digester standard in NBPE (Plate 1 in appendix). Approximately, about 63% of users had this problem. Similarly, findings from previous studies also justified similar problems: the inadequate expertise of masons in constructing a standard bio-digester caused ineffective performances in African and Asian countries (Bensah and Brew-Hammond, 2010; Chen et al., 2010; Mwakaje, 2008).

Thus, standardization of biogas technology to a single approved design enabled quality control in SSA (J. Mwirigi et al., 2014; J. W. Mwirigi et al., 2009), and improved through the provision of follow-up services and training local masons (Huba & Paul, 2007; Mang et al., 2013). Failure to abate these constraints is principally ascribed to the MoWIE and key partners. Provision of training and adequately skilled and competent masons for bio-digester construction as well as provision of adequately skilled energy supervisors or technicians for consistent follow up and assurance of standard digester installations are among the major tasks of the MoWIE and specifically its RBPCU partners (as described in the NBPE implementation document).

6.3. Appliances and manufacturing companies, and quality control

There are no biogas appliance manufacturers in Ethiopia as witnessed by the key informants from NBPE and RBPCU. Procurement of appliances lacks standards and performance insurances. An independent institution or a company that inspects the quality of imported appliances was lacking. The government itself, which imports the appliances, carried out the inspection. The inspection and quality control of imported appliance is weak. However, the existence of domestic biogas companies could increase the attractiveness of the biogas technology through (1) increasing the availability and accessibility of appliances and (2) decreasing the costs for purchasing appliances with reasonably affordable prices. Moreover, such companies can provide, after sales service and user training as well as provide guarantees for reasonable years on appliances and fitting works. Thus, reconsideration of
this missing aspect of the biogas technology appears to robustly help achieve the targeted goals of the NBPE. Likewise, lack of appliance manufacturers limited biogas technology dissemination in Ghana (Bensah and Brew-Hammond, 2010; Arthur et al., 2011) in Uganda (Okello et al., 2013) and in Pakistan (Ilyas, 2006). Shortage of supply of spare parts and procurement mechanisms constrained the use of renewable energy technologies in SSA (Amigun et al., 2012; Karekezi, 2002; Parawira, 2009; J. W. Mwirigi et al., 2009). The standardization of biogas technology to biogas appliances was important to make quality control in SSA (J. Mwirigi et al., 2014; J. W. Mwirigi et al., 2009). Likewise, the availability of spare parts for replacement and technical problem influenced the sustainable biogas technology adoption in Asian countries (Abraham et al., 2007; Buysman & Mol, 2013; Chandrasekar & Kandpal, 2007; Jiang et al., 2011; Lin & Jiang, 2011).

Key informants from the NBPE informed that the availability of bio-digester spare parts within a reasonable distance is a key factor for the dissemination and utilization of the biogas technology. Spare parts, such as water pipes were widely available in the market at least at certain distances. However, appliances such as biogas lamp glasses and mantles were particularly unavailable at farmers close vicinity such as district office or local markets. Sometimes, these spare parts were only available in regional or federal offices. In this regard, a considerable number of households (22%) had broken biogas lamps, temporarily with no replacement. Such unwieldy condition, not only influences the functionality of bio-digesters but also discourages the promotion of the technology. The biogas lamps used in surveying areas in the southern Ethiopia were all imported and were locally unavailable. Despite the constraints with poor access to spare parts, lengthy procurement mechanisms and weak quality control, usually user households waited for longer periods (4–10 months) for the supply from regional offices. Regional offices received spare parts from the national office. On the other hand, ensuring the manufacturing of homemade appliances is the primary responsibility of the MoWIE, which is centrally coordinating the NBPE. Or else, the same responsibility goes to MoWIE for enabling independent institutions or companies importing appliances (as described in the NBPE implementation document) with an independent institution monitoring and ensuring the quality of imported appliances.

6.4. Maintenance services and mal-functionality of digesters
Key informants (RBPCU and SNV) stated that the availability of inadequate maintenance service is among the major barriers to biogas technology dissemination in Ethiopia. Energy supervisors were inadequately trained and skilled in providing adequate maintenance services. Despite user households’ limited knowledge of the operation of bio-digesters, digesters stop functioning because of problems such as damage to the water pipe and lamps, and drying-up of substrate in digesters. The maintenance service of such digesters usually demands high financial and labor costs and is therefore a challenge to bio-digester functionality. Nearly all of the surveying users had witnessed the prevailing absence of standby technicians for maintenance services (Plate 1 in appendix).

Furthermore, in surveying districts in the southern Ethiopia, among the smaller technical problems observed were damaged pipes (inlet and outlet pipes), damaged biogas lamps, leaking gas-hoses, dried substrate trapped in the digester and pipe, and lack of standby technical back-up services. Though they appear small technical problems, they do have major negative impacts on the promotion, functionality, and sustainable use of the technology. There were a considerable number of completely damaged, non-functional and abandoned bio-digesters (25%). Similar problems, including the absence of maintenance services and lack of operational knowledge were among the challenges constraining biogas technology use in Ghana (Bensah and Brew-Hammond, 2010). The availability of maintenance services influenced the sustainable biogas technology adoption (Buysman & Mol, 2013; Chandrasekar & Kandpal, 2007; Jiang et al., 2011; Lin & Jiang, 2011). Therefore, it is important to enhance the technical skill of user households and energy supervisors to resolve such problems with reasonably less time and investment. Such technical skill could increase the reputation of the technology among the potential adopting rural communities.
6.5. Management of subsidies and credits

The capital cost of bio-digesters in Ethiopia is high, which is a barrier for the biogas technology dissemination. It is contextually less attractive and mostly not affordable for a considerable number of rural households. It demands up to 570 USD initial investment cost for installation. About 40% of this cost is, however, covered by the government and donors. Thus, the NBPE implementation operates on a cost-sharing basis with other investors and donors. Findings from previous studies also showed the significance of credit service to increase the rate of biogas technology adoption: Reducing existing high installation costs of bio-digesters without compromising on quality and performance could make the technology more affordable to the users (Ghimire, 2013). Provision of loans had a significant impact on the increased uptake of biogas technology in Africa (Roopnarain & Adeleke, 2017).

The NBPE disseminated different volumes of digester, ranging from 4 m$^3$ to 10 m$^3$. However, in both phases; the NBPE allocated a fixed rate of financial subsidy, irrespective of bio-digester size, location, inflation, and adopter’s income status. The subsidy covered predetermined rate of payment for masons, costs to purchase biogas appliances and other construction inputs. It was witnessed by the NBPE informant that incremental prices of various biogas construction materials, such as cement, appliances and pipes, posed negative repercussions on the dissemination of the technology in Ethiopia. The investment cost of a bio-digester installation varied with the size of the bio-digesters, thus, dissemination of different designs and sizes for households can provide various affordable options (Kamp & Bermúdez Forn, 2016). Unlike in Ethiopia, investment costs of quality bio-digesters varied in Asian and African countries, depending on digester size, location of construction, availability and accessibility of construction materials, labor-wages, and end-use applications (Ghimire, 2013).

In relation to the economic status of rural households, the available bio-digester sizes were costly for poor households (68%) benefiting from subsidies. Thus, there needs to be a strategy where the cost can be reduced on subsidy basis and the technology is made affordable for the poor households. Findings from previous studies showed the significance of access to credit or subsidies in Africa and Asia: Unaffordability (75%) to the initial investment cost and lack of subsidy were among the constraints encountered in establishing bio-digesters in Tanzania (Mwakaje, 2008). A progressive subsidy structure was important to promote the use of biogas technology in Africa (Amigun & Von Blottnitz, 2010). Introduction of financial incentives such as soft loans (loan with no interest rate or below market rate of interest) and subsidies at the initial stage to overcome the financial component of the biogas technology program became important in Ghana (Arthur et al., 2011). Subsidies provided either in terms of capital grants (one time subsidy) or reduction in interest fees promoted the use of biogas technology in Nepal (Pokharel, 2003). Subsidies was one of the several reasons for the attraction of a biogas installation in Nepal and it cannot sustain itself without subsidies forever (Katuwal & Bohara, 2009). Access to micro-credit and subsidy made biogas technology more affordable in Asia and Africa (Ghimire, 2013).

6.6. Micro-finances in channeling loans

Proper channeling of subsidies, credits and/or loans could support the NBPE’s implementation plan successful and sustainable. The NBPE and the multilateral project (such as Hivos, the World Bank, etc.) recognized microfinance to provide loans for the dissemination of the biogas technology. Although about 57% of NBPE’s bio-digester installations utilized loans from microfinance institutions for initial investment, the provision of loans has been decreasing from time to time. The NBPE and RBPCU informants also stated that the interest of the microfinance in providing loans or credits for financing biogas constructions has been poor. The microfinance encountered limitations to monitor interests and manage loans or credits provided for installations. Moreover, nearly all user households are discouraged with the high interest rate for the loans or credits from micro-finances. Adopter households did not pay the interest (45%) as per agreement sometimes reached due to financial crises such as poor market for their agricultural produce or agricultural underproduction for unfavorable climatic factors (Plate 4 in appendix). This caused disinterest among NBPE, adopters and micro-finance
institutions in working on the biogas technology. J. Mwirigi et al. (2014) recommended mobilization of local and external funds to promote the biogas, to overcome the initial construction costs of bio-digesters, and to reduce costs. Originally, microfinance institutions were supposed to participate in the provision of credit for biogas construction (EREDPC & SNV, 2008).

The author’s perspective is that since the micro-finances are not properly functioning, it appears commendable, if banks (public or private) channel credits or loans to the bio-digester installations. Soft loans from a bank system with reasonably low interest rate on a long-time basis might be an available option that can resolve the problem. At present, public and/or private banks do not finance the installation of bio-digesters despite the significant expansion in coverage and the increasing banking systems in Ethiopia. In the surveying areas in the southern Ethiopia, the visited digester installations were all subsidized.

6.7. Technical problem related to Injera² baking

Domestic biogas energy did not able to provide a comprehensive share of a households energy demand for Injera baking in rural Ethiopia. That is, the existing biogas energy generated was unable to provide sufficient energy to perform baking Injera. Baking Injera may account up to 60% of the total energy consumption of a household in Ethiopia (Eshete et al., 2006). The informants confirmed that the available biogas stove has low combustion efficiency and, thus, is a pressing problem to biogas technology adoption in Ethiopia (Plate 3 in appendix). Technical incapability in baking Injera was a deeply rooted barrier that is unmanageable on the available biogas stoves (Kamp & Bermúdez Forn, 2016). The primary end use application of biogas is cooking; but, especially in remote rural areas where electricity is nonexistent, farmers use biogas for lighting too (Ghimire, 2013). It is expected that widespread adoption of the technology could lead to self-sufficiency in household energy provision for cooking (J. Mwirigi et al., 2014).

Along with the implementation of the NBPE, research institutes, universities and private enterprises have carried out research and development related to improving stoves for Injera baking. Importantly, private manufacturers such as, the Walta Workshop in Mekele town, Munic Engineering PLC in Bahir Dar Town and Selam Technical and Vocation Training Centre (at Addis Ababa and Hawassa) made attempts to produce and sell biogas stoves. Recently, improved stoves for baking Injera have somehow increased the combustion efficiency of biogas energy and are being tested in Ethiopia. It appeared that the private sector has a key role to play in promoting and making the biogas sector commercially sustainable and market oriented. National policy should attract more private companies to participate in the biogas sector (Ghimire, 2013). The availability of biogas lamps and mantles, efficient biogas stoves for baking Injera, and other appliances at the adopter household vicinity should be improved. As per the NBPE implementation document, user households would get access to these accessories at close vicinity. To do so, the implementation document also invites engagement of all relevant government ministries, NGOs and private companies. The MoWIE, as central coordination unit of the NBPE, is failed to accomplish this fundamental task.

6.8. Compatibility between bio-digester size and livestock holding size

The NBPE distributed bio-digester sizes of 4, 6, 8 and 10 m³. In surveying areas in southern Ethiopia, the proportion of their distribution was 4 m³ (6%), 6 m³ (39%), 8 m³ (31%) and 10 m³ (24%). Incompatibility between installed bio-digesters and households’ livestock holding size for available dung were among the common constraints in the surveyed areas (Plate 5 in appendix). About 22% of the bio-digesters had this problem. As a result, several adopter households were found using lower daily cow dung compared to the required dose. Such incompatibility limited the amount of biogas energy generated for cooking and lighting, as well as bio-slurry agricultural production. Sufficient livestock size to produce adequate cow dung and generate adequate energy is essential to meet household’s cooking requirements for biogas energy in Kenya (J. W. Mwirigi et al., 2009). In SSA, the availability of feedstock for effective bio-digester operation limited the scope of biogas technology. Small-scale farmers frequently lacked sufficient domestic animals to obtain enough cow dung for the bio-digester to produce sufficient energy for lighting and cooking (Parawira, 2009).
On top of that, the occurrence of extended droughts (e.g., 2016–2017) affected the livestock holding size, hence dis-proportioned the relationship between available dung and installed bio-digester size in the southern region. Furthermore, the cattle were poorly fed, especially during dry seasons and yielded inadequate dung available for feeding bio-digesters and were found to eventually affect bio-digesters’ functionality. User households witnessed that such problems often lead to malfunction of bio-digesters, insufficient biogas and bio-slurry production. Therefore, before installing a bio-digester, the compatibility between digester size and the available dung size requires due considerations. Insufficient cattle size was not the only key cause of not feeding the basics, but also low awareness of households. About 64% of the visited bio-digesters were underfed and thus, malfunctioning. Adopters’ inadequate knowledge on the appropriation of the cow dung and the required dose for proper functioning of digesters was observed to be common challenges.

6.9. Compatibility between household labor size and bio-digester size

The compatibility between a bio-digester size and household labor size of routine bio-digester operation was overlooked in several surveyed areas. Thus, daily routine feeding of a bio-digester was a challenge to a considerable number of adopting households in Ethiopia (Plate 1 in appendix). In many countries up to 50% of bio-digesters were non-functional mainly due to feeding problems (Bond & Templeton, 2011). The key informants (NBPE, RBPCU and SNV) described that inadequate feeding of bio-digesters results not only from incompatibility between labor size and digester size but also from obstruction of bio-digesters through unsuitable substrate, inability of daily feeding, and appropriation of the correct ratio of available water and cow dung. Such an incompatibility also resulted from prolonged droughts that affect the availability of both dung and water.

One of the main reasons for poor system functionality of bio-digesters was an incorrect daily operation (Christiaensen & Heltberg, 2012). The key factors that needed to be considered in selecting suitable bio-digester size for specific households include, feedstock availability, water supply, energy demand, construction materials and labour, and the level of commitment to operate and maintain the bio-digester effectively (Rupf et al., 2015). Incompatibility between household labor size and dung size (59%) was among the barriers adversely affecting bio-digester functionality in surveying districts in southern Ethiopia. The survey showed that several owners fail to charge their digesters appropriately. Mostly, male members of households involve in the routine bio-digester feeding. The routine operation of the bio-digester system needs much physical work and is usually laborious; making the biogas benefits less attractive (Amigun et al., 2012; Parawira, 2009). The regular average time spent on feedstock preparation and feeding bio-digesters was high that affected the time for executing another regular agricultural practice in the surveying areas.

6.10. Compatibility between access to water sources and bio-digester size

The key informants (SNV and NBPE) indicated that a bio-digester requires the same volume of water to process a given volume of dung, that is, 1 kg of dung requires 1 kg of water. A bio-digester typically requires water and substrate such as manure to be mixed in an equal ratio to produce sufficient energy for lighting and cooking, thus water availability poses a constraint for the biogas operation in some countries in SSA (Parawira, 2009). The NBPE set that access to water source is a precondition for installation of bio-digesters in Ethiopia. However, ensuring access to adequate water sources and the compatibility between available water and bio-digester size was underestimated during the selection of households for bio-digester installation. Observations in several surveying areas showed that bio-digester’s functionality is strongly influenced by the compatibility between bio-digester size and the available water for regular operation. Poor operation due to improper feeding, resulting from disproportional water and cow dung for feedstock preparation and digester size was commonly practiced by more than 68% of the households.

There were several installed bio-digesters, which were completely abandoned (36%) and malfunctioned (47%) due to shortage of water. This problem was worse during dry seasons and extensive droughts in the surveyed areas in southern Ethiopia. Extended drought was found to cause drying-up of water sources (streams, rivers, water wells, and ponds), which eventually had
made access to water a pressing barrier to a bio-digester functionality. In addition, such temporary water shortage was observed to cause drying up of substrate in bio-digesters with considerable contribution to the mal-functionality of bio-digesters. Previous studies have confirmed similar consequences in SSA that the availability of water for effective bio-digester operation limited the scope of the biogas technology in SSA (Amigun et al., 2012; Ghimire, 2013; Parawira, 2009) and in some Asian countries (Ghimire, 2013). The NBPE implementation document sets standards in ensuring compatibilities among different factors. In this regard, ensuring these standards and realizing the compatibility among household labor size, bio-digester size, availability of water sources, and livestock size is to be accomplished by the NBPE coordinating office, regional offices, energy supervisors, and adopting households. Particularly, ensuring the availability of water sources for regular digester feeding above all is to be executed by the NBPE’s regional offices. To resolve these constraints, it is commendable that all stakeholders discharge their responsibilities as per the NBPE documents.

6.11. Bio-slurry and management
The standard set in the NBPE indicated that farmers with four heads of cattle are eligible for biogas technology adoption so that all adopting households could be beneficiaries of bio-slurry. Bio-slurry as organic fertilizer is environmentally friendly, has no toxic or harmful effects and can easily reduce the use of chemical fertilizers. Bio-slurry is a 100% organic fertilizer most suitable for organic farming. Several households in the surveying areas used bio-slurry commonly for horticultural production around homesteads. Bio-slurry is proven to be the best fertilizer for farms, providing farmers with an improved organic fertilizer in Rwanda (Dekelver et al., 2005). The bio-slurry was used on farms as an alternative to chemical fertilizers in Nepal (Gautam et al., 2009) and increased agricultural productivity (Katuwal & Bohara, 2009). The bio-slurry can be used as a potent organic fertilizer to enhance agricultural productivity (Ghimire, 2013).

Nevertheless, the bio-slurry was perceived as a byproduct of the technology that hugely undermines one of the key benefits of the biogas technology. Key informants (LEM-Ethiopia, SNV, HoA-REC6N, ISD, and MoANR) viewed that the utilization of bio-slurry to soil fertility amendment, and crop production, and as an alternative to chemical fertilizers was underestimated in the NBPE. They added that more attention is given to the energy benefits (cooking and lightening) aspects of the biogas technology (Plate 3 in appendix). This underestimation has made the biogas technology less attractive with the prohibitive influence on the popularization of the technology. This might be that the agricultural sector was overlooked in the preparation of the program implementation document (PID) of the ENPE (EREDPC & SNV, 2008).

Furthermore, the little attention given to the bio-slurry aspects of the biogas technology was due to the limited involvement of the Ministry of Agriculture (MoANR). There was negligence to the bio-slurry extension into the NBPE institutional structure. The existing regional bio-slurry extension sector has remained nominal and inactive. Consequently, the agricultural and rural development sectors were mainly restrained to the regular duty of promoting compost utilization as an organic fertilizer supplement to the chemical fertilizers. The underestimation of the bio-slurry seemed to arise from a conflict of interest between the NBPE unit and agricultural and rural development sectors (Kamp & Bermúdez Forn, 2016; M. Mengistu et al., 2016). This study also realized the weak functional alignment among the NBPE, MoANR, and the agricultural and rural development sectors at regional, district, kebele and, levels and adopter households. Enhancing the use of one of the significant components of the biogas technology is indispensable in influencing the promotion and dissemination of the biogas technology. Such integration among stakeholders lacked in Ghana’s national biogas programs (Arthur et al., 2011).

Similarly, the involvement of NGOs in promoting the bio-slurry is also limited. Interested NGOs lacked support from the NBPE. Key informant from a local NGO (ISD) stated that it has provided bio-slurry trainings to about 800 model adopter households in all the four NBPE implementing regions. Due to lack of proper financial support from the NBPE, however, the trainings were limited
to these households with better wealth, experience and social acceptance. The assumption was that the skill, knowledge and experience could further be shared to other adopters in the form of a farmer-to-farmer extension. However, the key informant lacked the data on the impact the training has brought to the model farmers themselves. In addition, it lacked the information on the number of new farmers who have shared the knowledge and experiences through the presupposed farmer-to-farmer extension (Plate 4 in appendix).

The major technical problem associated with the bio-slurry management observed in the surveying districts was an outflow of bio-slurry before fermenting, backflow of bio-slurry to digesters and vulnerability of bio-slurry pits to flooding such as under heavy rain. Adopters also informed that there is a health-associated risk transiting from bad smells generating during preparation, transportation and application of bio-slurry. Moreover, a considerable number (83%) of households were dissatisfied with the preparation, transportation and application of bio-slurry; it is labor intensive. Tucho et al. (2016) reported a similar constraint in developing countries with managing bio-slurry relating to mixing, storing, transporting and application. Health risks associated with storage and application of bio-slurry in Nepal were reported (Katuwal & Bohara, 2009). These technical constraints were found not only to affect the quality and quantity of the bio-slurry produce but also the attractiveness and effectiveness of the technology. An appreciable number of households value the bio-slurry more than the energy value. They witnessed that the use of the bio-slurry improves soil fertility and increases crop yields, despite reducing costs for purchasing chemical fertilizers.

Due to inadequate training, user households (approximately 67%) lacked sufficient technical skills in the preparation and utilization of bio-slurry. Informants (NBPE, SNV, and ISD) elaborated that training in how to manage and best use the bio-slurry is generally inadequate in Ethiopia. Households with better awareness appreciated the importance of bio-slurry in improving soil fertility and increasing yields, especially of vegetables of cabbage, tomato, onion, and potato and, perennial crops such as Ensete, banana, fruit trees and coffee (Plate 2 in appendix). For instance, such a benefit was observed in Wondo Genet, Aleta Wondo, Sodo Gurage, Meskan, Arba Minch districts, among others. Bio-slurry is mostly applied on farms around homestead because of the high labor demand for transportation. Furthermore, adopter households found bio-slurry as a favorable alternative to the use of chemical fertilizers and it decreased their expenditure on chemical fertilizers. Thus, there is a need for regular training to improve the technical skill of biogas technicians, extension workers, and user households. The other challenge was that the rate of a bio-slurry application per hectare for different crops has never been documented in Ethiopia, which could have increased its reputation and wider application in crop production. Moreover, there is a need to advocate the promotion of the multiple uses of biogas for purposes other than cooking and lighting such as an integrated farming approach of biogas and bio-slurry in SSA (J. Mwirigi et al., 2014). The MoWIE through its NBPE coordinating offices should encourage and financially support interested NGOs and research institutes such as the ISD, EDRI and others to continue working on promoting bio-slurry production and utilization. Such an attempt could enhance the awareness and skill of adopter households of bio-slurry preparation and utilization.

### 6.12. Toilet connection to bio-digesters and socio-cultural issues

Adopter households with toilets connected to bio-digesters witnessed that the technology has improved their environment, and hygiene and health conditions, especially of women and children (94%). One of the long-term objectives of biogas programs is to improve hygiene and health conditions of rural population (Ghimire, 2013). Nevertheless, several surveyed districts in the southern Ethiopia indicated that connecting a toilet to a bio-digester is a sensitive issue for a considerable number of households (18%). Such households were skeptical of the use of bio-slurry of this type of organic fertilization due to the bad smells and existing socio-cultural fabrics. Though most bio-digesters had second inlet pipes for future toilet connection (92%), an appreciable number of surveyed user households used only cow dung. However, households having such a connection witnessed that the use of toilets not only supplements shortage of cow dung, but also supplements shortage of water (through urine), especially during dry seasons. Households
frequently encountered limited available dung and water supply during droughts. Extended dry seasons were found to limit the amount of available cow dung through limiting available fodder and drinking water. Moreover, households with less number of livestock holding size can also be beneficiaries if toilets are connected to bio-digesters. Households in surveying districts mostly used free grazing for feeding their livestock. There was a poor trend of having a stall-fed livestock holding system and generally, livestock are not well fed. Socio-cultural convictions and religious issues such as stigmatization in the use of digested human excreta as fertilizer potentially affect the dissemination of biogas technology (Arthur et al., 2011; Mahat, 2004; Van Vliet et al., 2011). However, an increasing trend of connecting toilets to the bio-digesters increased bio-digester installation in Nepal (Katuwal & Bohara, 2009; Mahat, 2004) and improved the benefits of biogas energy in many sub-Sahara African and in Asian countries (Ghimire, 2013; Rupf et al., 2015).

Enhancing the awareness of adopter households on the advantage of connecting digesters to toilets could be done through household-to-household information exchange platform or through regional and national media. Such communication strategies could help the NBPE and its associates to increase the public awareness of the technology. Finally, to ensure the effectiveness and efficiency of biogas technology domestication as well as a sense of ownership of the technology by all stakeholders, it is important to create strong integration among government ministries (Ministry of Water, Irrigation and Electricity, Ministry of Agriculture and Natural Resources, Ministry of Environment, Forest and Climate Change), international and local NGOs, locally based Community Groups, Private companies and rural households. Furthermore, enforcing platform of cooperation at national and regional levels for information exchange and promotion of the technology is appealing.

7. Conclusion and policy implications
The domestication and functionality of biogas technology are constrained with ensuring adequacy in the: i) construction of standard bio-digesters, ii) amount of biogas energy generated for cooking, lighting, and baking Injera, iii) supply of appliances in household vicinity and at affordable prices, iv) supply of maintenance services with standby technicians and at affordable prices, v) arrangement of subsidy, credit or loan for the high initial investment cost, and vi) management of bio-slurry as organic fertilizer. Moreover, there are constraints with ensuring compatibility among digester size, available water supply, labor size and livestock holding size. For the same reason, for instance, about 64% of the visited bio-digesters were underfed and thus, malfunctioning. The two most important perspectives of biogas technology in Ethiopia, bio-slurry for fertilizer and a biogas stove for baking the staple traditional bread, Injera, are both underutilized. Moreover, NBPE’s planned number of bio-digester installations were not achieved. Exclusively, the NBPE and its regional coordinating units execute the implementation of the technology. The engagement of the private sectors, NGOs, and community-based organizations are underestimated, which is against NBPE’s official implementation document. The weak coordination capacity and the poor engagement of stakeholders have caused the prevailing technical, socioeconomic and institutional constraints. This, in turn, has hampered the domestication efficiency of the NBPE, the functionality of installed bio-digesters, the realization of the multiple benefits and the prospects of biogas technology in Ethiopia. There is an absolute seek for determining active engagement of all stakeholders to solve the prevailing constraints. Thus, for (1) improving the functionality of the already installed bio-digesters, (2) realizing the multiple benefits of biogas technology, and (3) successful implementation of the NBPE+ and up scaling of the technology to other potential regions in Ethiopia, the NBPE should focus on addressing the existing constraints and ensuring the existence of a platform for active key actors’ engagement. More emphasis should be given to promoting and exploring the potential benefits of bio-slurry as high quality organic fertilizers that can fully substitute chemical fertilizers. Attention should be given to improving the existing biogas stove that enables biogas energy baking Injera. Finally, these findings and recommendations indicate the essential areas of revisions and the policy implications for the sustainable use and the future adoption and functionality of bio-digesters.
The staple food in Ethiopia is Injera. A large (60 cm diameter) spongy pancake made of fermented Teff dough. A family would at least once, but often twice a day, eat Injera with vegetable or pulse sauce (Wat) Traditionally, Injera is baked in batches (20 to 40 at a time), mostly two times a week on a clay plate and open fire. By its nature, clay plate at >150°C, large diameter and open fire. These traditional "metads" have a high energy consumption (stove efficiency – 7%); an average family would burn 10 kg of fuelwood per session for baking Injera only (Eshete et al., 2005).

2. Kebele is the smallest unit in public administration in Ethiopia.

References

Abraham, E. R., Ramachandran, S., & Ramalingam, V. (2007). Biogas: Can it be an important source of energy? Environmental Science and Pollution Research International, 14(1), 67–71. https://doi.org/10.1007/espr2006.12.370

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

Amigun, B., & Von Blottnitz, H. (2010). Capacity-cost and location-cost analyses for biogas plants in Africa. Resources, Conservation and Recycling, 55(1), 63–73. https://doi.org/10.1016/j.resconrec.2010.07.004

Arthur, R., Baidoo, M. F., & Antwi, E. (2011). Biogas as a potential renewable energy source: A Ghanaian case study. Renewable Energy, 36(5), 1510–1518. https://doi.org/10.1016/j.renene.2010.11.012

Bensah, E. C., & Brew-Hammond, A. (2010). Biogas technology dissemination in Ghana: History, current status, future prospects, and policy significance. International Journal of Environment and Energy, 1(2), 277–294.

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

Bond, T., & Templeton, M. R. (2011). History and future of domestic biogas plants in the developing world. Energy for Sustainable Development, 15(4), 347–354. https://doi.org/10.1016/j.esd.2011.09.003

Buysman, E., & Mol, A. P. (2013). Market-based biogas sector development in least developed countries—The case of Cambodia. Energy Policy, 63, 44–51. https://doi.org/10.1016/j.enpol.2013.05.071

Chandrasekar, B., & Kondpal, T. C. (2007). An opinion survey based assessment of renewable energy technology development in India. Renewable and Sustainable Energy Reviews, 11(4), 688–701. https://doi.org/10.1016/j.rser.2005.04.001

Chen, Y., Yang, G., Sweeney, S., & Feng, Y. (2010). Household biogas use in rural China: A study of opportunities and constraints. Renewable and Sustainable Energy Reviews, 14(1), 545–549. https://doi.org/10.1016/j.rser.2009.07.019

Christiansen, L., & Helberg, R. (2012). Greening China’s rural energy: New insights on the potential of small-holder biogas. Development Research Group (DECRI); China & Mongolia Sustainable Dev (EASCS).

Clemen, H., Balis, R., Nyanbame, A., & Ndunguy, V. (2018). Africa biogas partnership program: A review of clean cooking implementation through market development in East Africa. Energy for Sustainable Development, 46, 23–31. https://doi.org/10.1016/j.esd.2018.05.012

Corbin, J., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. Qualitative Sociology, 13(1), 1. https://doi.org/10.1007/BF00988593

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. Theory Into Practice, 39(3), 124–130. https://doi.org/10.1207/s15431736tip3903_2

Dekelver, G., Ruzigana, S., & Larm, J. (2005). Report on the Feasibility study for a biogas support programme in the Republic of Rwanda, SNV, 2005.

EREDPC & SNV. (2008). Ethiopian Rural Energy Development and Promotion Center (EREDPC) and Netherlands Development Organization (SNV). National Biogas Pro-grame Ethiopia: Programme Implementation Document. EREDPC and SNV.

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

FAO. (2017). FAO in emergencies: Helping to build a world without hunger. Rome, Italy: FAO.

Gautam, R., Baral, S., & Herat, S. (2009). Biogas as a sustainable energy source in Nepal: Present status and future challenges. Renewable and Sustainable Energy Reviews, 13(1), 248–252. https://doi.org/10.1016/j.rser.2007.07.006

Gebregeziabher, Z., & van Kooten, G. C. (2013). Does community and household tree planting imply increased use of wood for fuel? Evidence from Ethiopia. Forest Policy and Economics, 34, 30–40. https://doi.org/10.1016/j.forpol.2013.03.003

Ghimire, P. C. (2013). SNV supported domestic biogas programmes in Asia and Africa. Renewable Energy, 49(Suppl. C), 90–94. https://doi.org/10.1016/j.renene.2012.01.058

Huba, E.-M., & Paul, E. (2007). National domestic biogas programme rwanda: Baseline study report. In Netherlands Development Organization (SNV) (pp. 61–94).The Hague: SNV - Netherlands Development Organisation.

Ilyas, S. Z. (2006). Biogas support program is a reason for its success in Pakistan. American-Eurasian Journal of Scientific Research, 1(1), 42–45. https://www.researchgate.net/publication/240632813

Jiang, X., Sommer, S. G., & Christensen, K. V. (2011). A review of the biogas industry in China. Energy Policy, 39(10), 6073–6081. https://doi.org/10.1016/j.enpol.2011.07.007
Kamp, L. M., & Bermúdez Forn, E. (2016). Ethiopia’s emerging domestic biogas sector: Current status, bottlenecks and drivers. Renewable and Sustainable Energy Reviews, 60, 475–488. https://doi.org/10.1016/j.rser.2016.01.068

Karekezi, S. (2002). Renewableisinafrica—meeting thee-negryneedsfortheeoor. Energy Policy, 30(11–12), 1059–1069. https://doi.org/10.1016/S0301-4215(02)00058-7

Katuwal, H., & Bohara, A. K. (2009). Biogas: A promising renewable technology and its impact on rural households in Nepal. Renewable and Sustainable Energy Reviews, 13(9), 2668–2674. https://doi.org/10.1016/j.rser.2009.05.002

Kaygusuz, K. (2012). Energy for sustainable development: A case of developing countries. Renewable and Sustainable Energy Reviews, 16(2), 1116–1126. https://doi.org/10.1016/j.rser.2011.11.013

Kelebe, H. E., Aymut, K. M., Berhe, G. H., & Hintsa, K. (2017). Determinants for adoption decision of small scale biogas technology by rural households in Tigray, Ethiopia. Energy Economics, 66(Suppl.C), 272–278. https://doi.org/10.1016/j.eneco.2017.06.022

Kemausuo, F., Adaramola, M., & Morken, J. (2018). A review of commercial biogas systems and lessons for Africa. Energies, 11(11), 2984. https://doi.org/10.3390/en11112984

Lewis, S. (2015). Qualitative inquiry and research design: Choosing among five approaches. Health Promotion Practice, 16(4), 473–475. https://doi.org/10.1177/1524839915580941

Lin, B., & Jiang, Z. (2011). Estimates of energy subsidies in China and impact of energy subsidy reform. Energy Economics, 33(2), 273–283. https://doi.org/10.1016/j.eneco.2010.07.005

Mabot, J. (2004). Implementation of alternative energy technologies in Nepal: Towards the achievement of sustainable livelihoods. Energy for Sustainable Development, 8(2), 9–16. https://doi.org/10.1016/S0973-0826(08)60455-X

Mang, H.-P., Li, Z., de Porres Lebofa, M. M., Huba, E.-M., Schwarz, D., Schnell, R., Luong, N. G., Kellner, C., & Selke, J. (2013). Biogas Production developing country: biogas production, Developing Countries biogas production developing countries. In Shikun Cheng (Ed.), Renewable Energy Systems (pp. 218–246). Springer.

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

Mengistu, M. G., Simane, B., Eshete, G., & Workneh, T. S. (2015). A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia. Renewable and Sustainable Energy Reviews, 48, 306–316. https://doi.org/10.1016/j.rser.2015.04.026

MoWIE. (2018). Ministry of Water, Irrigation and Electricity of Ethiopia (MoWIE) database. Ministry of Water, Irrigation and Electricity of Ethiopia.

Mulinda, C., Hu, Q., & Pan, K. (2013). Dissemination and problems of African biogas technology. Energy and Power Engineering, 5(8), 506. https://doi.org/10.4236/ep.2013.58055

Mwakaje, A. G. (2008). Dairy farming and biogas use in Rungwe district, South-west Tanzania: A study of opportunities and constraints. Renewable and Sustainable Energy Reviews, 12(8), 2240–2252. https://doi.org/10.1016/j.rser.2007.04.013

Mwirigi, J., Balana, B. B., Mugisha, J., Walekhwu, P., Melamu, R., Nakami, S., & Makenzi, P. (2014). Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. Biomass and Bioenergy, 70, 17–25. https://doi.org/10.1016/j.biombioe.2014.02.018

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

Okello, C., Pindozzi, S., Faugno, S., & Boccia, L. (2013). Development of bioenergy technologies in Uganda: A review of progress. Renewable and Sustainable Energy Reviews, 18, 55–63. https://doi.org/10.1016/j.rser.2012.10.004

Polinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoogwood, K. (2015). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. Administration and Policy in Mental Health and Mental Health Services Research, 42(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Parawira, W. (2009). Biogas technology in sub-Saharan Africa: Status, prospects and constraints. Reviews in Environmental Science and Bio/Technology, 8(2), 187–200. https://doi.org/10.1007/s11135-009-9146-0

Pattson, M. (2002). Qualitative Research and Evaluation Methods. Sage Publications.

Pokharel, S. (2003). Promotional issues on alternative energy technologies in Nepal. Energy Policy, 31(4), 307–318. https://doi.org/10.1016/S0301-4215(02)00063-5

Roooppnarin, A., & Adeleke, R. (2017). Current status, hurdles and future prospects of biogas digestion technology in Africa. Renewable and Sustainable Energy Reviews, 67, 1162–1179. https://doi.org/10.1016/j.rser.2016.09.087

Rupf, G. V., Bahri, P. A., de Boer, K., & McHenry, M. P. (2015). Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal. Renewable and Sustainable Energy Reviews, 52, 468–476. https://doi.org/10.1016/j.rser.2015.07.107

SNV. (2017). Biogas production and utilization in Ethiopia - challenges and opportunities: Netherland Development Organization (SNV).

Sutton, J., & Austin, Z. (2015). A Qualitative Research: Data Collection, Analysis, and Management. The Canadian Journal of Hospital Pharmacy, 68(3), 226–231. https://doi.org/10.4211/cjhp.v68i3.1456

Tuch, G. T., Moll, H. C., Uiterkamp, A. J., & Nonhebel, M. S. (2016). Problems with biogas implementation in developing countries from the perspective of labor requirements. Energies, 9(750), 1–16. https://doi.org/10.3390/en909750

van Vliet, B. J., Speargren, G., & Oosterveer, P. (2011). Sanitation under challenge: Contributions from the social sciences. Water Policy, 13(6), 797–809. https://doi.org/10.2166/wp.2011.089

Yousuf, A., Khan, M. R., Pirozzi, D., & Ab Wahid, Z. (2016). Financial sustainability of biogas technology: Barriers, opportunities, and solutions. Energy Sources, Part B: Economics, Planning, and Policy, 11(8), 841–848. https://doi.org/10.1080/15567249.2016.1148084
Appendix

Plate 1. Cow dung for feedstock preparation for feeding bio-digester (Left) and bio-digester with outflows of bio-slurry (Middle and Right).

Plate 2. Banana plantation before (Left) and after bio-slurry application (Right), in South Ethiopia.

Plate 3. Biogas energy for lighting with biogas lamp (Left) for cooking with biogas stove (Right), in south Ethiopia.
Plate 4. One of the key informant interviews and discussion, in south Ethiopia.

Plate 5. Cattle in shade in one of the study sites, in south Ethiopia.